Current Techniques In Small Animal Surgery

5th Edition

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TETON NEWMEDIA
INNOVATIVE PUBLISHING OF VETERINARY & HUMAN MEDICINE

Teton NewMedia
Teton NewMedia
90 East Simpson, Suite 110
Jackson, WY 83001

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Exclusive worldwide distribution by CRC Press an imprint of Taylor & Francis Group, an Informa business
Version Date: 20141020

International Standard Book Number-13: 978-1-4987-1656-7 (eBook - PDF)

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Preface

This book has been a long time coming and has taken many hours of sweat and tears to finish. It has been anticipated for several years and has been delayed because of the extensive amount of new and refurbished art work which was required. The book is designed to be a concise, comprehensive and highly graphic presentation of small animal surgery for the practicing veterinarian. It represents the viewpoints and surgical approaches of distinguished leaders in the various surgical fields and is therefore a valuable reference and review of the procedures that the veterinary practitioner is often called upon to perform. I have had innumerable veterinarians call me and say that they use this book daily and could not do the surgery they do without it. I instructed the authors to make each procedure accurate and current. Detailed but clear artwork accompanies each procedure and continues to be an important feature of this book for both students and practitioners. In this day and age the general small animal practitioner is asked to do more and more complicated procedures since many clients cannot afford a specialist. This book makes it possible for them to safely and accurately perform a broader range of procedures, and I have had many veterinarians tell me that they consider this the "bible" and that they could not practice without it. This new edition has been highly anticipated and is finally completed. I must thank each and every author for their hard work, dedication and patience throughout the revision process. My special thanks go to Drs. Waldron and Toombs, consulting soft tissue and orthopedic editors. Their untiring dedication made this book finally become a reality.

M. Joseph Bojrab DVM, MS, PhD.

Dedication

I am dedicating this book to my brother Dr. Donald Charles Bojrab, an outstanding veterinarian in St. Louis MO. Don's not only an excellent small animal practitioner, he is a wonderful human being. He is intelligent, compassionate, unselfish and loving. When our 98 year old mother developed Osteoporosis and was in severe pain for over a year, he flew to Fort Wayne, IN every other week to care for her. At the end he spent 3 months there caring for her before she died, leaving his St. Louis practice on auto pilot. I love him and my sister Darlene dearly.

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Part I

Soft Tissue

Section A

Surgical Principles

Chapter 1

Selection and use of currently available Suture Materials and Needles

Suture Materials and Needles

Daniel D. Smeak

Introduction

Surgeons rely on suture materials to provide critical support of healing tissues during wound repair. A wide variety of suture material types have been developed, each with their own advantages and limitations. The general performance of suture materials is based on their distinct physical properties, handling characteristics, and biological properties. An ideal suture should have acceptable handling characteristics, knot security, and tensile strength. Besides predictable performance, sutures should remain strong enough to prevent disruption of the wound until healing is complete and, ideally, the suture should undergo complete resorption over time. The suture should be sterile, nonallergenic, noncarcinogenic, stable in a contaminated environment, and it should elicit minimal reaction when buried in tissue. In most cases, there are many suture material choices that would be acceptable for wound repair because many have similar general characteristics but are developed by separate manufacturers. However, there is no ideal suture for every procedure, largely because each wound is different and must be considered individually. An otherwise identical wound created in a similar body region may require different suture considerations due to such factors as degree of bacterial contamination, whether there is a local or systemic factor which would delay healing, and even how active the patient may be after surgery. The most critical factors related to the choice of suture include how long the suture is needed to support the wound, and the mechanical and healing properties of the tissue undergoing repair. The surgeon must understand the nature of the suture material, the biological forces in the healing wound, and the interaction of suture and tissues when selecting suture material. This chapter reviews the characteristics of commonly used and newer suture materials, and needles in small animal surgery. Various wound related factors are discussed, which provide the rationale for choosing appropriate suture materials and needles.

Suture Classification and Definitions

Suture materials are classified as absorbable or nonabsorbable, natural or synthetic, monofilament or multifilament, according to their structure and composition (Table 1-1).

Absorbable suture materials undergo degradation and rapid loss of tensile strength within 60 days, whereas nonabsorbable suture materials retain significant strength past 60 days. This definition can be misleading with respect to silk, cotton, linen, and multifilament nylon sutures because these materials are considered nonabsorbable, yet they lose a portion of their tensile strength within 4 to 6 weeks after implantation. Natural materials (chromic gut, silk) are absorbed by enzymatic degradation and phagocytosis, while the newer synthetic sutures are more predictably absorbed through nonenzymatic hydrolysis. In addition, synthetic sutures generally cause less tissue reaction than natural ones. Monofilament sutures are made of a single strand so they resist harboring of bacteria. Multifilament or braided sutures are woven or twisted from many smaller strands. In general, multifilament suture materials are easier to handle than monofilaments. Multifilament sutures (particularly uncoated ones) often create more friction (chatter) as they are passed through tissues when compared to the smoother monofilaments. Excess friction can cause suture-tissue sawing and cutout, especially when suturing friable tissues with a continuous pattern. Multifilament sutures can be capillary, or act as a wick. This quality is undesirable since fluid and bacteria can travel along the suture and contaminate adjacent areas. The chemical composition and coating influence the capillary nature of a suture. For example, coated caprolactam transports nearly twice as much fluid as uncoated polyester of the same suture size. Waxed silk is not capillary, in contrast to the highly capillary nature of uncoated virgin silk. Capillary suture materials are not recommended when sutures could penetrate or become exposed to contaminated or infected areas.

Suture Selection and Use

When choosing a suture material, certain general principles based on the strength of the tissue being closed, the rate of gain in wound strength after closure, and various biological and mechanical suture characteristics should be considered. After considering these factors, the surgeon may have several choices of appropriate suture material that would be acceptable for use in the wound. Selection can then be made on the basis of familiarity with the material, its ease in handling, and other subjective preferences, such as color, or needle selection.

Strength of Tissue

A suture should be at least as strong as the tissue through which it passes. A tissue's ability to hold sutures without tearing depends on its collagen content and on the orientation of collagen fibrils. This explains why ligaments, tendons, fascia, and skin are strongest, muscle is relatively weak, and fat is weakest. Muscle has little suture-holding capability across its fibers and even less in the direction of the fibers. Visceral tissue, in general, ranks between fat and muscle in strength. Bladder and colon are the weakest hollow organs of the body, and stomach and small

intestine are among the strongest. Tissue strength varies within the same organ and with the age and size of the animal.

The choice of suture size is based on the tensile strength of the tissue as well as of the suture material. Catgut and synthetic suture materials are sized according to either United States Pharmacopeia (USP) or metric gauge (Table 1-2). A larger numeric USP value means a larger-diameter suture. Stated numerically, the more zeros (0s) in the number, the smaller the strand. (e.g., 2 polypropylene is larger than 0, and 2-0 is larger than 4-0). The metric gauge is the actual suture diameter expressed in millimeters multiplied by 10. Stainless steel suture can be sized by USP, metric gauge, or Brown and Sharpe wire gauge. Ranges of suture size recommendations for various tissues and surgical applications are provided in Table 1-3. These guidelines are general and are based on currently available literature and my experience. Larger sizes are used in heavier animals, in critical suture lines such as the abdominal fascia, or in tissues closed under excessive tension. The surgeon should strive to use the smallest suture size possible for wound closure since this will result in less tissue trauma, allow smaller knots to be tied, and encourage the surgeon to handle the sutures and tissue more carefully. Oversized sutures can actually weaken the wound through excessive tissue reaction and tissue strangulation. To maintain maximum suture strength once the suture is removed from the packet, certain suture handling rules are suggested (Table 1-4).

Loss of Suture Strength and Gain of Wound Strength

To use absorbable sutures safely, the loss of suture strength should be proportional to the anticipated gain in wound strength. The relative rates of suture strength loss and simultaneous wound strength gain are important to consider. Fascia, tendons, and ligaments heal slowly (50% strength gain in 40-50 days) and are under constant tensile force. For these tissues, nonabsorbable sutures or the prolonged-degrading, synthetic absorbable sutures are indicated. Maxon® and PDS II® sutures can be used whenever an absorbable suture is needed, but these should be considered especially in wounds that are expected to require suture support for more than 3 weeks (such as abdominal wall fascia). Because visceral wounds heal relatively fast, often achieving most of their strength in 21 days, rapid to intermediate-degrading absorbable sutures (Table 1-1) are good choices. Rapidly-degrading synthetic sutures (Caprosyn®, Monocryl®, Vicryl Rapide®) are indicated in rapidly healing tissues such as the mucosal lining of the mouth or urogenital tract where suture removal is not possible or undesirable. The more intermediate-degrading sutures such as (Vicryl®, Dexon®, and Biosyn®) are often chosen to close wounds that are expected to heal within 3 weeks, such as the subcutaneous tissue and muscle. Monofilament nonabsorbable sutures are suggested for skin closure because they induce little foreign body response and skin sutures should remain strong since they are subject to chewing and wear. These sutures also provide long-term stability in procedures involving fascia, tendons, and vascular prostheses. Systemic and local factors affecting wound healing must also be considered before an appropriate suture is selected. For example, catgut in the presence of infection or gastric secretions, or when placed in a catabolic patient can be degraded within days, rendering the wound closure susceptible to dehiscence. When healing is expected to be delayed, prolonged absorbable sutures or nonabsorbable sutures are better choices.

Healing Considerations

Surgeons must consider how the suture alters the biologic processes in a healing wound environment. Regardless of its composition, suture material is a foreign body to tissues in which it is implanted, and to a greater or lesser degree will elicit a foreign body reaction. The amount of reaction depends on the nature of the suture implanted (e.g., surgical gut versus inert, stainless steel), the amount of surface area and coating of the suture, the type and location of tissue closed (intestinal viscera and skin react strongly to silk, whereas fascia reacts minimally to silk), the length of implantation (polyglycolic acid, or Dexon II®, is moderately reactive early but within months is relatively inert), and the technique of suture placement (excessive suture tightening causes tissue strangulation). Excessive suture-induced tissue reaction increases the likelihood of suture-tissue cutout by softening surrounding tissues, increases the risk of infection, and delays the onset of fibroplasia. Sutures causing excessive tissue reaction are contraindicated in areas in which exuberant scar formation can cause a functional problem (e.g., for vascular repair or ureteral anastomosis) or a cosmetic problem (e.g., in skin). The surgeon should strive to inflict the least amount of trauma necessary for the operation, to reduce contamination, and to use sutures that cause the least tissue reaction to avoid excessive inflammation and delayed wound healing. Relatively speaking, it is not the suture material but the surgeon that causes inflammation within a wound, since most reaction is induced during tissue manipulation and the act of suturing.

All suture materials are capable of increasing wound susceptibility to infection. The suture's filamentous nature, capillarity, chemical structure, bioinertness, and ability to adhere to bacteria all play a role in suture related infection. In a classic experiment, a single silk suture reduced the total contaminating dose of Staphylococcus required to induce wound infection 10,000 fold. On the other hand, the byproducts of nylon and polyglycolic acid suture degradation in tissues may have beneficial bactericidal effects. A newer synthetic absorbable suture with an antibacterial coating has been developed specifically for use in contaminated wounds (see discussion under newly developed sutures). In general, sutures that induce the least foreign body reaction in tissues, such as monofilament synthetic absorbable and nonabsorbable sutures, produce the lowest incidence of infection in contaminated wounds. If possible, suture should not be implanted in highly contaminated wounds or wounds with a high risk of infection.

Multifilament nonabsorbable suture materials induce chronic sinus formation more often than absorbable or monofilament sutures. Multifilament nonabsorbable sutures harbor bacteria within the suture interstices, creating an effective barrier to phagocytosis. These sutures should never be used in contaminated wounds. Wound infection also increases the rate of loss of

Table 1-1. Common Sutures and their Salient Characteristics

Classification	Suture Trade Name	Origin	Filament Type	Absorption	Completion of Absorption
Absorbable Rapid					
	Surgical gut suture Chromic gut suture	collagen derived from beef and sheep	multi	(variable) 33% loss - 7 days 67% loss - 28 days	(variable) 60 - 90 days
	Vicryl Rapide (polyglactin 910)	copolymer of lactide and glycolide	multi	50% loss- 5 days 100% loss -14 days	42 days
	Caprosyn (polyglytone 6211)	glycolide, caprolactone, trimethylene carbonate, lactide	mono	50% loss - 7 days 100% loss - 21 days	56 days
	Monocryl (poliglecaprone 25)	copolymer glycolide and epsilon-capro-lactone	mono	40-50% loss - 7 days 100% loss - 21 days	91- 119 days
Absorbable Intermediate					
	Coated Vicryl and Vicryl PlusAntibac-terial (polyglactin 910, triclosan coating-Plus)	copolymer of lactide and glycolide	multi	25% loss -14 days 50% loss - 21 days	56 - 70 days
	Dexon S Dexon II (coated and uncoated polyglycolic acid)	homopolymer of glycolic acid II - polycaprolate coating	multi	35% loss -14 days 65% loss - 21 days	60 - 90 days
	Polysorb (lactomer)	glycolide/lactide copolymer	multi	20% loss -14 days 70% loss - 21 days	56-70 days
	Biosyn (glycomer 631)	glycolide dioxanone trimethylene carbonate	mono	25% loss -14 days 60% loss - 21 days	90-110 days
Absorbable Prolonged					
	PDS II (polydioxanone)	polydioxanene polymer	mono	30% loss -14 days 50% loss - 28 days	180 - 210 days
	Maxon (polyglyconate)	glycolic acid, polytrim-ethylene carbonate	mono	25% loss - 14 days 50% loss - 28 days	180 days

Foreign Body Response	Relative Knot Security	Relative Tensile Strength	Handling Ease	Comments
				Rapidly absorbing sutures should not be used where extended approximation of tissue under stress is required.
moderate	fair	poor	fair	Unpredictable absorption particularly in highly vascular or inflamed tissue, or in presence of gastric secretions.
mild	fair to good	fair	good	Provides about 70% of initial strength of coated Vicryl. Less reactive than gut; indicated for superficial closure of mucous membranes.
mild	good	good	good	Designed to be an attractive alternative to chromic gut. Similar suture characteristics and applications as Monocryl. Excellent choice for bladder closure.
mild	good	good to excellent	good	Minimal tissue drag; handling qualities are very good for monofilaments. Ideal for mucosal suturing and subcutaneous tissue closure.
				General soft tissue approximation; use in visceral tissue where healing is mostly complete in 21 days. Intermediate absorbing suture should not be used where extended approximation of tissue under stress is required.
mild	fair to good	good	good	Plus-Triclosan coating added to provide antibacterial effect. This suture is not to be used close to the eye.
mild	fair to good	good to excellent	good	Smooth coating allows easier knot formation without flaking.
mild	fair to good	good	good	Improvements in braid construction and coating provide better flow through tissue and more knot security.
mild	good	good to excellent	good	Nice handling monofilament absorbable, very strong suture.
				These sutures are indicated when suture strength is needed well beyond 3 weeks; ideal for fascial closure.
mild	fair to good	excellent	good	Excellent general use absorbable material.
mild	fair to good	excellent	good	Similar to PDS II; tends to have more memory and less knot security in larger sizes.

Table 1-1. Common Sutures and their Salient Characteristics (continued)

Classification	Suture Trade Name	Origin	Filament Type	Absorption	Completion of Absorption
Nonabsorbable Monofilament					
	Dermalon Monosof	extruded polyamide filament	mono	—	Slow chemical degradation over years
	Novafil Vascufil (polybutester)	copolymer butylene polytetramethylene	mono	—	—
	Prolene Surgipro II Fluorofil	polymerized polyolefin hydrocarbons	mono	—	—
	Pronova	polyvinylidine polymer	mono	—	—
	Surgical steel suture (steel)	chromium nickel molybdenum alloy	mono	—	—
Nonabsorbable Multifilament					
	Surgilon	polyamide filaments	multi	slow chemical degradation over years	—
	Vetafil Braunamide Supramid	coated polyamide filaments	multi	—	—
	Ticron Surgidac Ethibond excel	polyester fibers (+/- coating)	multi	—	—
	Sofsilk Permabond	silkworm cocoon fibers	multi	30% loss - 14 days 50% loss - 365 days	greater than 720 days

Foreign Body Response	Relative Knot Security	Relative Tensile Strength	Handling Ease	Comments
				Use when long term suture strength is needed. These sutures are more stable in contaminated environments than the multi-filament nonabsorbables; less reactive in tissue.
minimal	fair to poor	good	fair to good	Careful knot tying technique with appropriate number of throws during use is suggested.
minimal	fair to good	good	very good	Soft pliable monofilament suture; excellent for plastic surgery.
minimal	good	good	fair	Greater knot security than many monofila-ments; least thrombogenic. Fluorofil glows under blacklight for easy location.
minimal	good to very good	excellent	good	Good alternative to polypropylene. Better strength and handling; less fraying.
minimal to none	excellent	excellent	poor	Knot ends can cause severe irritation. Tends to fragment and cut into tissue; must secure knots.
				Do not use multifilament nonabsorbable suture in contaminated environments. Use when long term suture strength is needed. Overall better handling than the monofilaments.
minimal	fair	good	good	Should not be used when permanent retention of suture strength is required.
minimal to moderate (if coating breaks)	good	good to excellent	good	Inexpensive suture material often supplied in reels. For external use only.
moderate	fair to poor	excellent	good to excellent	Uncoated sutures have excessive tissue drag. Careful knot tying technique and additional throws may be needed with coated sutures.
moderate	fair to poor	fair	excellent	Best handling multifilament suture.

Table 1-2. Metric Measures, and U.S.P. Suture Diameter Equivalents

Suture Material Sizes			
Actual Size	**USP Size**		**Brown and Sharpe**
(mm)	**Catgut**	**Synthetic**	**Wire Gauge**
0.02		10-0	
0.03		9-0	
0.04		8-0	
0.05	8-0	7-0	41
0.07	7-0	6-0	38-40
0.1	6-0	5-0	35
0.15	5-0	4-0	32-34
0.2	4-0	3-0	30
0.3	3-0	2-0	28
0.35	2-0	0	26
0.4	0	1	25
0.5	I	2	24
0.6	2	3; 4	22
0.7	3	5	20
0.8	4	6	19
0.9		7	18

To obtain metric gauge, multiply actual size (mm) by 10; for example, USP 0 catgut 0.4 mm in diameter is metric size 4.

strength of suture material. If wound contamination is suspected, synthetic absorbable sutures should be chosen because these sutures are more stable and have predictable absorption rates in contaminated tissue, when compared to chromic catgut. If long-term wound support is required of the suture material, synthetic monofilament nonabsorbables or synthetic (prolonged-degrading) absorbable sutures such as PDS II® or Maxon® are indicated.

The presence of any suture material within the lumen of the biliary or urinary tract can act as a nidus and induce calculus formation or chronic infection. Thus, more rapidly absorbable sutures are recommended in these areas, since they will not persist indefinitely in tissue. Silk and nonabsorbable polyester material, because of their documented calculogenic effects, should never be placed in contact with urine or bile. General guidelines to avoid suture-related complications in surgery are listed in Table 1-5.

Mechanical Properties of Suture and Tissue

The mechanical properties or functions of the suture should be similar to those of the tissue being closed. For example, polybutester (Novafil®), is a suture material that is very pliable and elongates and is most suitable for skin closure because it remains flexible and stretches with movement. More inelastic suture materials, such as those composed of polyester or nylon fibers, are more applicable for anchoring prosthetic materials or

Table 1-3. General Suture Size and Usage Recommendations in Small Animal Surgery

Tissue	Suture Size (USP)	Suture Material: Classes
Skin	3-0 to 4-0	Monofilament nonabsorbable
Subcutaneous tissue	2-0 to 4-0	Absorbable
Fascia	1 to 3-0	Synthetic (prolonged degrading) absorbable, or synthetic nonabsorbable
Muscle	0 to 3-0	Skeletal: synthetic (prolonged degrading) absorbable
		Cardiac: synthetic nonabsorbable
Parenchymal organ	2-0 to 4-0	Intermediate degrading absorbable
Hollow viscus organ	3-0 to 5-0	Monofilament absorbable
Tendon, ligament	0 to 3-0	Monofilament nonabsorbable
Nerve	5-0 to 7-0	Monofilament nonabsorbable
Cornea	8-0 to 10-0	Synthetic absorbable. nonmetallic nonabsorbable
Vascular ligation	0 to 4-0	Small vessels-absorbable; larger vessels- prolonged absorbable or nonabsorbable
Vascular repair	5-0 to 7-0	Monofilament nonabsorbable

for joint imbrication. Similarly, inelastic suture material such as stainless steel should not be used in tissues that stretch or are under constant motion because premature suture-tissue cutout or suture breakage could occur.

Newly Developed Sutures

Newer synthetic sutures have been developed to improve suture strength profiles without negatively affecting suture handling or knot security. The newer synthetic monofilament absorbable sutures are more pliable and better handling. Multifilament sutures may convert a contaminated wound into an infected one, so antibacterial coatings have been developed to inhibit bacterial growth in and around multifilament suture.

Table 1-4. Suture Handling and Storage Rules

1. Protect all sutures from heat and moisture.
2. Never autoclave absorbable sutures.
3. Refrain from soaking absorbable sutures, particularly in hot water.
4. Use strands directly from the packet; avoid excessive handling of suture strands before use.
5. Avoid suture kinking, or crushing suture with instruments.
6. Suture strands with "memory" may be straightened with a gentle tug.
7. Periodically check suture strands for evidence of fraying or defects, particularly when using a continuous suture pattern.

Polyvinylidine *Pronova® (Ethicon)*

This unique synthetic nonabsorbable monofilament suture is made of two polyvinylidine polymers, with a special extrusion process. This produces an optimal balance between suture strength and handling characteristics throughout the range of suture sizes. Pronova® suture sizes, 10-0 through 4-0, are composed of an 80/20 polymer blend, that emphasizes tensile strength without compromising handing in smaller sizes. Pronova® suture sizes, 2-0 through #2, are composed of a 50/50 polymer blend that improves handling in these larger sizes, without compromising tensile strength. This suture will remain secure in critical surgical procedures where life-long strength is desired, particularly in delicate applications where fine sutures are used. Tensile and knot strengths of Pronova® suture meet or exceed those of polypropylene suture in all sizes. The suture has excellent resistance to breakage, fraying, and instrument damage, and has reduced package memory. It is an excellent alternate choice when polypropylene suture is indicated. The suture is best for general soft tissue approximation and ligation including cardiovascular, ophthalmic, and neurologic applications. [Ethicon, Product Information; http://jnjgateway.com/home]

Polyglactin 910 and Triclosan *Coated Vicryl Plus Antibacterial® (Ethicon)*

This synthetic multifilament absorbable suture has an antiseptic coating (Triclosan) that creates a zone of inhibition around the suture site that decreases bacterial colonization of the suture or tissue. The suture performs and handles similarly to Coated Vicryl® suture. Vicryl Plus® is available in suture sizes, 5-0 through 0. It elicits a similar tissue reaction as other synthetic absorbable sutures, and considerably less inflammation than chromic gut sutures, but it should not be used close to the eye (Triclosan may be irritating to the eye). The manufacturer suggests using the suture in procedures that have a higher risk of infection. Few clinical studies have been conducted to substantiate the beneficial effects of this suture.

Glycomer 631 *Biosyn® (Syneture)*

This absorbable monofilament suture is prepared from a synthetic polyester composed of glycolide, dioxanone, and trimethylene carbonate. The advanced extrusion process gives the suture excellent initial strength and knot security and minimal memory. This suture elicits minimal acute inflammatory reaction in tissues. Like other synthetic absorbable sutures, eventual absorption is predictable by means of hydrolysis. Biosyn® sutures are available in sizes #1 through 6-0. The suture maintains 75% strength at two weeks and approximately 40% at three weeks after implantation. Similar to Dexon® and Vicryl®, this suture should not be used where extended approximation of tissue is required.

Table 1-5. General Rules to Avoid Most Suture-Related Complications

1. Avoid multifilament nonabsorbable suture material use in contaminated or infected wounds. Multifilament suture harbors bacteria and may cause persistent sinus formation, or local infection.
2. Avoid nonabsorbable suture exposure within the lumen of hollow organs, such as the urinary bladder or gall bladder, in which calculus formation at a suture nidus is possible.
3. Avoid burying nonabsorbable suture that has been taken from a used open cassette. Consider all suture from an open cassette contaminated.
4. If continued suture strength is important, avoid chromic gut in inflamed or infected tissue, and in wounds with delayed healing (catabolic conditions, radiation wounds, etc). Gut in contact with proteolytic enzymes such as in the stomach lumen or pancreas loses most of its strength within days of implantation.
5. Avoid rapidly absorbable suture material use in critical areas such as tendons or ligaments that are known to heal slowly and are under continual tensile force, or in wounds with delayed healing.
6. Use suture materials that cause less inflammation in wounds that are predisposed to stricture (such as tracheostomies or urethrostomies) or excessive scar formation (such as skin)
7. Avoid capillary/multifilament suture material penetration through known contaminated areas such as the bowel lumen or skin. Bacteria are "wicked" or may be transported to adjacent sterile tissues to form microabscesses around sutures.

Polyglytone 6211 *Caprosyn® (Syneture)*

This absorbable monofilament suture is prepared from a synthetic polyester composed of glycolide, caprolactone, trimethylene carbonate, and lactide. It has very good handling and knot tying characteristics due to its excellent pliability, and has low tissue reactivity. Caprosyn®, similar to Monocryl®, is useful for general subcutaneous tissue closure, urogenital surgery particularly in the urinary bladder, and where the benefits and rapid absorption may play a role in postoperative success.

Suture Knots

A knot consists of a minimum of 2 throws (sometimes termed simple knots). As a knot is created, the material is deformed, and depending on the properties of the material, this deformation may weaken the suture by as much as 50% of its original strength. Therefore, the knot is the weakest part of a suture. The technical performance of the knot is critical to the security of the wound

closure as well as the strength of the stitch. A square knot is least likely to untie or loosen so it is the knot of choice for most suture lines. Depending on how the throws are placed, three different knots can be formed (square knot, granny knot, or a half hitch shown in Figure 1-1). The latter two knots tend to slip and are generally avoided. Square knots are produced by reversing direction on each successive throw while maintaining equal tension on both strands as they are held parallel to the plane of the tissue. Failure to reverse direction of successive throws will result in granny knots. If one strand is pulled under more tension away from the plane of the knot than the other strand, with successive throws, a half hitch (or slip knot) is formed. Sometimes surgeons using monofilament sutures intentionally apply half hitch knots (especially if the wound is under tension) and this allows precise control of intrinsic suture tension. All half hitch knots must be completed with several square knots to prevent loosening. A surgeon's knot is similar to the square knot except one strand is fed through the loop twice on the first throw. The additional pass of suture in the loop produces increased friction. This knot is especially useful when attempting to knot a stitch when tissues are under tension. Multifilament absorbable sutures such as polyglycolic acid or polyglactin 910 may require surgeon's knots when used to close abdominal fascia. This knot is avoided when using gut since the increased friction tends to fray the material and excessively weakens it. Caution should be exercised with using surgeon's knots during vessel ligation, since the bulk of the first throw may not allow complete occlusion of the vessel, and the knot is less reliable than the standard square knot. Surgeon's knots have increased bulk and are asymmetric, so this knot is used only when necessary.

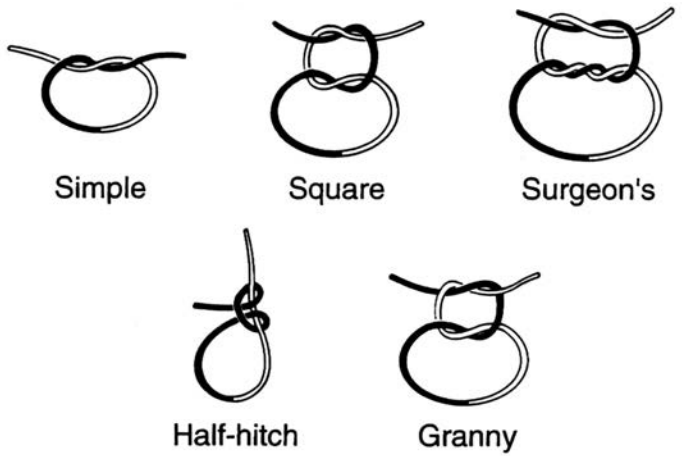


Figure 1-1. Surgical Knots.

Additional factors that influence knot security are the material coefficient, the length of the suture ends (ears), as well as the structural configuration of the knot, mentioned previously. Knots that swell (chromic catgut) or knots formed from stiff suture (ones with memory), require longer knot ears in general. Multifilament sutures possess a higher coefficient of friction, and have better knot-holding properties than the monofilaments in general; however, coating the strands to reduce friction or chatter in tissue also reduces knot security. Three single reversed throws are generally sufficient to secure knots in suture materials with high coefficients of friction and minimal tension. When using monofilament sutures (such as nylon or polydioxanone), or coated multifilament sutures, four or more throws should be applied. In a continuous suture line, the final knot (consisting of a loop and single strand) should have a minimum of 5 throws to be secure. General knot tying rules are included in Table 1-6.

Table 1-6. Knot Tying Principles

1. The primary objective in knot tying is to ensure knot security. The square knot is almost exclusively used since it is the simplest, most secure knot.
2. Use appropriate sized suture to keep the knot as small as possible. Knots in smaller sized material generally are more secure.
3. Avoid friction as the knot throws are tightened. Attempt to tighten throws by pulling in opposite directions, in a horizontal plane, with similar rate and tension.
4. Do not crush or kink suture with surgical instruments while knot tying. Grasp suture only on the end that will be discarded.
5. Avoid excessive intrinsic suture tension to reduce tissue cutting and strangulation.
6. Avoid cutting knot ends too short particularly when using suture with known knot security problems. If ends are left too long, however, irritation from the suture ends may create unwanted tissue inflammation.
7. With instrument ties, hold the needle holder parallel to the wound. Move the needle holder back and forth perpendicular to it.
8. Use a surgeon's knot only when suture tension is such that use of a standard square knot would result in poor tissue apposition. Surgeon's knots take longer to tie and place more suture in the wound than does the square knot. It may not permit proper tension on blood vessel ligations (resulting in partial occlusion) because of the bulk of suture material involved in the first throw.

Suture Needles

Surgical needles are manufactured in a variety of sizes, shapes, and types. Needles are selected to ensure that the tissues being sutured are altered as little as possible by the needle. The needle chosen should allow tissue passage without excessive force and without disruption of tissue architecture. The hole created by the needle should be just large enough to allow passage of the suture material. The needle should be rigid enough to prevent bending, yet flexible enough to bend before breaking.

Regardless of their intended use, all surgical needles have three basic components: the eye (or suture attachment), the body (or shaft), and the point. There are two types of needle eyes commonly used in practice, the economical closed eye (suture is fed through the eye) and swaged (eyeless). Needles permanently connected to suture (swaged needles) produce significantly less tissue trauma and are easier to handle compared to eyed needles; sutures supplied with needles, expectedly, are more expensive.

The bodies or shafts of needles vary in shape and size. The body should be as close as possible to the diameter of the suture material. The cross-sectional configuration of the body may be round, side-flattened rectangular, triangular, or trapezoidal. Some needle bodies are ribbed to prevent rotation and provide better stability of the needle in the jaws of needle holders. Easily accessible tissues such as the skin may be sutured by hand with straight needles but most surgeons prefer curved needles because they are easier to use with instruments. Curved needles are supplied in 1/4, 3/8, 1/2, and 5/8 circle configurations (Figure 1-2). Choice of length, width, and curvature of the needle is dependent on the size and depth of the area to be sutured. Quarter circle needles have limited use, primarily for eye surgery. Three-eighths circle needles are most commonly used in veterinary surgery and are suitable for most superficial wounds. Half circle needles are preferred for deeper wounds and in body cavities. Five-eighths circle needles are applicable for suturing wounds in confined areas such as the oral, nasal, and pelvic cavities.

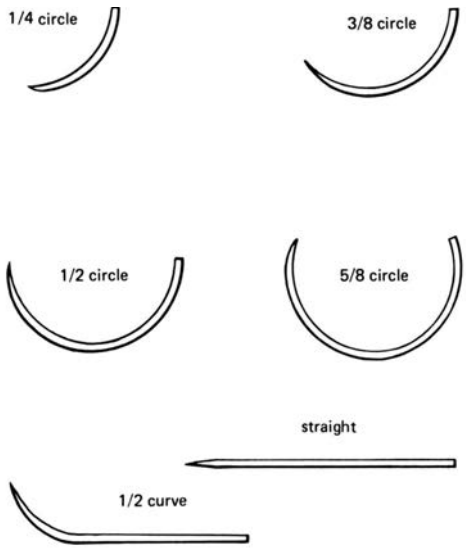


Figure 1-2. Suture Needle Configurations.

The needlepoint extends from the extreme tip of the needle to the maximum cross-section of the body. Three general types of needlepoints include: cutting, tapercut, and taper (or round point) (Figure 1-3). Cutting needles provide edges that will cut through dense connective tissue. They are most suitable for skin, tendon, and fascial closure. Like the conventional cutting needle, the reverse cutting needle has a triangular shaped cross-sectional area; however, rather than possessing a sharp edge on the inner curvature that is weaker and tends to cut tissue as the needle is passed, it has a flat inner curvature with an edge along the outer curvature of the needle point and shaft. Spatula point (side cutting) needles are flat on the top and bottom. They are used primarily in special ophthalmic operations. A tapercut needle combines a cutting point with a round shaft. The cutting point readily penetrates tough tissue but the shaft will not cut through or enlarge the needle hole when inserted. This needle is indicated when ease of penetration is important (vascular grafts, intestine) or when a delicate tissue is sutured to a more dense one (such as urethra to skin closure for a urethrostomy). Taper point or round needles have no edges to cut through tissue. The point pierces and spreads tissue without cutting. They are used for suturing easily penetrated soft tissues such as muscle, viscera, or subcutaneous tissue. Blunt pointed taper needles have a rounded point so they are most useful for suturing friable parenchymal organs such as the liver or kidney. General principles of needle use are list in Table 1-7.

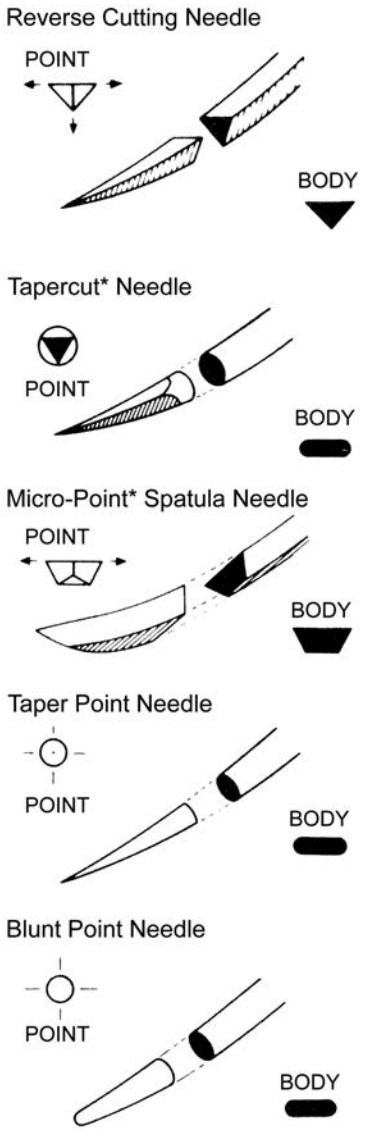


Figure 1-3. Types of Needle Points.

Table 1-7. Principles of Suture Needle Use

1. Swaged needles are less traumatic and always preferred.
2. Curved needles facilitate suturing of deep tissues, and straighter needles are useful in superficial tissues, particularly the skin.
3. For general use, needle holders are used to grasp the needle 1/3 to 1/2 the way down from the suture attachment to the point. Grasp the needle closer to the point if tissue is especially difficult to penetrate.
4. Hold needles in the narrow tips of the jaws of the needle holders.
5. Use taper needles wherever possible; they should not be used if it becomes difficult to pass through tissues.
6. With increasing tissue density, taper-cut or reverse cutting needles are required to penetrate tissue without excessive trauma.
7. Needles should be the smallest size to penetrate the tissue but long enough to penetrate both sides of the incision.
8. Do not grasp the needlepoint with the needle holders or gloved fingers.

Suggested Readings

Beardsley SL, Smeak DO, et al.: Histologic evaluation of tissue reactivity and absorption in response to a new synthetic fluorescent-pigmented polypropylene suture material in rats. Am J Vet Res 56:1246, 1995.

Bellenger CR: Sutures. Part 1. The purpose of sutures and available suture materials. Compend Contin Educ Pract Vet 4:507, 1982.

Bellenger CR: Sutures. Part 2. The use of sutures and alternative methods of closure. Compend Contin Educ Pract Vet 4:587, 1982.

Bezwada RS, Jamiolkowski DD, Lee IY, et al.: Monocryl a new ultrapliable absorbable monofilament suture. Biomaterials 16:1141, 1995.

Boothe HW: Suture materials and tissue adhesives. In: Slatter DH, ed. Textbook of Small Animal Surgery. Philadelphia: WB Saunders, 1985, p 334.

Bourne RB: In vivo comparison of four absorbable sutures: Vicryl, Dexon Plus, Maxon and PDS. Can J Surg 31:43, 1988.

Canarelli JP, Ricard J, Collet LM, et al.: Use of fast absorption material for skin closure in young children. Int Surg 73: 151, 1988.

Chu CC: Mechanical properties of suture materials: an important characterization. Ann Surg 193:365, 1981.

Crane SW: Characteristics and selection of currently available suture materials. In: Bojrab MJ, ed. Current Techniques in Small Animal Surgery. 2nd ed. Philadelphia: Lea & Febiger. 1983, p 3.

Edlich RF, Panek PH, Rodeheaver GT, et al.: Physical and chemical configuration of sutures in the development of surgical infection. Ann Surg 177:679, 1973.

Ford HR, Jones P, Gaines B, et al.: Intraoperative handling and wound healing: controlled clinical trial comparing coated VICRYL plus antibacterial suture (coated polyglactin 910 suture with triclosan) with coated VICRYL suture (coated polyglactin 910 suture). Surg Infect (Larchmt) 6:313, 2005.

Katz AR, Mukherjee DP, Kaganov AI, et al.: A new synthetic monofilament absorbable suture material from polytrimethylene carbonate. Surg Gynecol Obstet 161:213, 1985.

Peacock EE: Wound Repair. 3rd ed. Philadelphia: WB Saunders, 1984.

Ray JA. Doddi N, Regula O, et al.: Polydioxanone (PDS), a novel monofilament synthetic absorbable suture. Surg Gynecol Obstet 153:497, 1981.

Pineros-Fernandez A, Drake DB, Rodeheaver PA, et al.: CAPROSYN*, another major advance in synthetic monofilament absorbable suture. J Long Term Eff Med Implants 14:359, 2004.

Rosin E, Robinson GM: Knot security of suture materials. Vet Surg 18:269, 1989.

Schubert DC, Unger JB, Mukherjee D, et al.: Mechanical performance of knots using braided and monofilament absorbable sutures. Am J Obstet Gynecol 187:1438; discussion 1441, 2002.

Smeak DO, Wendelberg KL: Choosing suture materials for use in contaminated or infected wounds. Compend Contin Educ Pract Vet 11:467, 1989.

Stashak TS, Yturraspe OJ: Considerations for selection of suture materials. Vet Surg 7:48, 1978.

Taylor, TL: Suture material: a comprehensive review of the literature. J Am Podiatr Assoc 65:649, 1975.

Van Winkle W, Hastings JC: Considerations in the choice of suture material for various tissues. Surg Gynecol Obstet 135:113, 1972.

Chapter 2

Bandaging and Drainage Techniques

Bandaging Open Wounds

Mark W. Bohling and Steven F. Swaim

Wounds that are large, have extensive tissue damage, and are either contaminated or infected may be managed as open wounds until delayed primary or secondary closure can be performed, or alternatively, may be managed as open wounds throughout the entire healing process. The proper use of bandages and medications helps to provide an optimal environment for development of healthy tissue for wound closure. These techniques also help to provide an environment for rapid progression of contraction and epithelialization of wounds that will heal by second intention.

Bandage Components

A bandage consists of three layers, each of which has distinctive characteristics and functions (Figure 2-1).

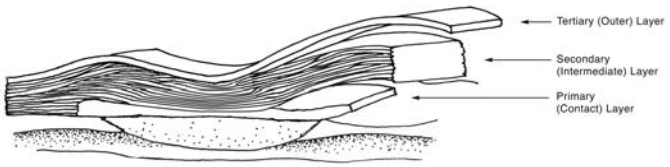


Figure 2-1. The component layers of a bandage. (From Swaim SF, Wilhalf D. The physics, physiology, and chemistry of bandaging open wounds. Compend Contin Educ 1985;7:146.)

Primary (Contact) Layer

The primary (contact) layer of a bandage should be sterile and should remain in close contact with the wound surface whether the animal is resting or moving. This layer should conform to all contours of the wound and, except for moisture retentive dressings (MRD), should allow fluid from draining wounds to pass through to the absorbent, secondary bandage layer. Depending on the wound type and stage of healing, the primary (contact) layer can function in tissue debridement, delivery of medication, removal of wound exudate, or in forming an occlusive seal over the wound. The primary layer is important in providing an environment that promotes healing as opposed to being a layer that just covers a wound. The properties of this layer vary, and it is important to select a dressing material that is appropriate for the current healing stage and to change the dressing type as healing progresses. There are materials that interact with wound tissues to enhance healing rather than to just conceal the wound.

Highly Absorptive Dressings

Gauze dressings are used as an initial dressing on heavily contaminated, infected, and debris-laden wounds. These wounds are in the inflammatory stage of healing. As healing progresses, the primary dressing is changed to one that will promote healing.

Gauze Dressings

Wet-to-dry and dry-to-dry gauze dressings are older techniques used to clean a wound. For wet-to-dry dressings, sterile saline, lactated Ringers solution, or 0.05% chlorhexidine diacetate solution is used to wet the gauze before placing it on a wound with viscous exudate or necrotic material. Exudates are diluted and absorbed into the secondary bandage layer. The fluid evaporates, the bandage dries and adheres to the wound. Bandage removal results in removal of adherent necrotic tissue and debris (Figure 2-2). Because this removal may be painful, moistening the gauze with warm 2% lidocaine may make removal more comfortable for the animal. On cats, warm saline is used to moisten the gauze.

Dry-to-dry gauze bandages are used to clean wounds that have a low viscosity exudate. The gauze is applied dry, and it absorbs the exudate, which evaporates. Removal of the adherent gauze is done as described above with similar results (Figure 2-2).

Gauze dressings have several disadvantages. 1.) Both viable and nonviable tissue are removed with dressing change. 2.) The function of cells and enzymes involved in healing are impaired. 3.) If a gauze is too wet, exogenous bacteria can wick toward the wound, and a wet bandage favors tissue maceration. 4.) Bacteria can be dispersed into the air by a dry gauze at bandage change. 5.) Adherent gauze fibers can remain in a wound to cause inflammation. 6.) Bandage removal can be painful. 7.) Cytokines and growth factors essential for optimal healing are removed with the gauze.

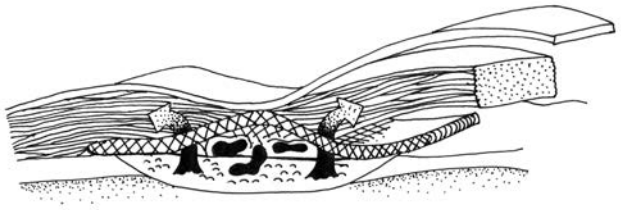


Figure 2-2. With both dry to dry and wet to dry bandages, wound exudate is absorbed into the intermediate bandage layers (arrows). As exudate is absorbed and the bandage dries, necrotic tissue and foreign material adhere to the contact layer. Exudate, necrotic tissue, and foreign material are removed with the bandage. (From Swaim SF, Wilhalf D. The physics, physiology,. and chemistry of bandaging open wounds. Compend Contin Educ Pract Vet 1985;7:146.)

Hypertonic Saline Dressings

These dressings are used in infected or highly necrotic, heavily exudative wounds. They have a 20% sodium chloride content which has the osmotic effect of drawing wound fluid from the tissue to reduce edema and increase circulation. The dressings are changed every one to two days until infection and necrosis are controlled. The dressing desicates both bacteria and tissue. Thus, debridement by these dressings is nonselective in that both healthy and necrotic tissue are removed. Once the wound has reached a moderately exudating granulation tissue stage, a calcium alginate, hydrogel, or foam dressing can be used.

Calcium Alginate Dressings
These are hydrophilic dressings that should be used in moderate to highly exudative wounds, such as would be the case in wounds in the inflammatory stage of healing. They should not be used over exposed bone, muscle, tendons or dry necrotic tissue. They are a felt-like material in a rope or pad form. The calcium alginate of the dressing interacts with wound fluid sodium to create a sodium aliginate gel that maintains a moist wound environment.

The hydrophilic/absorptive nature of the dressing can dehydrate a wound as healing progresses and exudate decreases. If it is left in a wound too long, it dehydrates, hardens, and forms a calcium aliginate eschar which is difficult to remove unless it is rehydrated with saline.

Calcium aliginate dressings are good for the transition from the inflammatory to the repair stage of healing. They enhance autolytic debridement and granulation tissue formation. Two other advantageous properties of the dressing are its hemostatic properties and its ability to entrap bacteria in the gel so they can be lavaged from the wound at dressing change.

Copolymer Starch Dressings
Another type of dressing that can be used in moderate to highly exudative, necrotic infected wounds is a highly absorptive copolymer starch dressing. A hydrocolloid dressing can be placed over the copolymer starch dressing as an occlusive dressing to hold it in place and retain moisture. At dressing change, lavage removes the copolymer from the wound.

The exudate amount in a wound should be observed while using this dressing. As healing progresses, fluid production decreases. If fluid levels get too low, the copolymer adheres to the wound and tissue damage can result when it is removed.

Moisture Retentive Dressings
Moisture retentive dressings (MRDs) provide a warm, moist wound environment that enhances cell proliferation and function during the inflammatory and repair healing stages. The fluid retained over the wound contains the cytokines, growth factors, proteases and protease inhibitors at the proper levels to support healing. In general, a highly absorptive dressing, such as those stated earlier, could be used initially in a wound with considerable necrosis, debris, infection and exudate. Once the wound is relatively clean, then an MRD could be considered.

There are several advantages to MRDs in promoting wound healing (Table 2-1). However, they also have the disadvantages that they can cause softening of periwound skin from retained moisture (maceration) and periwound tissue damage from retained proteolytic enzymes (excoriation).

Polyurethane Foam Dressings
Polyurethane foam dressings are soft, compressible, nonadherent, highly conforming dressings. They are highly absorptive and indicated for use on moderate to highly exudative wounds. The dressings maintain a moist wound environment which enhances autolytic debridement. They promote granulation tissue formation and epithelialization. Thus, the dressings can be used in both the inflammatory and repair stages of healing. An alternative use of the dressing is to saturate it with liquid medication for application on the wound.

Table 2-1. Advantages of Moisture-Retentive Dressings (MRDs)*

- Prevention of wound dessication and excessive whole-body evaporative fluid losses from the wound surface (full-thickness burns and large wounds)
- Maintenance of wound normothermia to improve cellular metabolism
- Provides barrier to urine and other liquids
- Provides barrier to bacteria
- Lower oxygen tension promotes lower pH and enhances collagen synthesis angiogenesis, and leukocyte chemotaxis, and inhibits bacterial growth
- Improved autolytic debridement due to improved leukocyte chemotaxis and retention, and maintenance of wound hydration and normothermia
- Higher concentration of systemically administered antibiotics via improved wound perfusion
- Comfortable for the patient when in place and less uncomfortable to remove compared to adhesive dressings
- Decreased frequency of bandage changes and reduced cost
- Reduced aerosolization of bacteria during bandage changes compared to wet-to-dry bandages
- Decreased scarring

Source: Campbell BG. Dressings, bandages, and splints for wound management in dogs and cats. In: Veterinary Clinics of North America: Small Animal Practice. 36(4): 759-91, 2006. Philadelphia: Saunders.

The stage of healing governs the frequency of changing foam dressings. It can vary between one and seven days, with the longer times time between changes being in the late stages of management when there is less fluid production.

Polyurethane Film Dressings
These film dressings are flexible, transparent, thin semiocclusive (permeable to gas but not water or bacteria) sheets. The transparency allows wound observation, and their adhesive perimeter provides for attachment to periwound skin. Because they are nonabsorptive, they are indicated for wounds with little or no exudate. Thus they are suited for dry necrotic eschars or shallow wounds, such as partial thickness wounds, e.g. abrasions. These dressings could also be used in the late repair stage of healing where there is a small amount of fluid production and a need to retain this to promote epithelialization. Another use is to place the dressings over other contact layers to cause moisture retention and supply a bacteria and waterproof cover.

These film dressings are contraindicated in wounds that are infected and have high exudate levels and wounds with fragile periwound skin. Neither should films be used on wounds with exposed tendon, muscle, bone, or deep burn wounds.

Adherence of the films is poor in areas of skin folds or unshaved hair, and hair growth on periwound skin can push the adhesive

attachment off. However, adherence to periwound skin can be improved with vapor-permeable film spray.

A cloudy white to yellow exudate under the film is just wound surface exudate and should not be confused with infection. The presence of heat, swelling, pain and hyperemia in surrounding tissues would indicate infection.

Hydrogel Dressings
Hydrogels are water-rich gel dressings in the form of a sheet or amorphorus gel. Some of these dressings contain other medications that are beneficial to wound healing, such as acemannan, metronidazole or silver sulfadiazin antimicrobials.

Because of their high water content, the dressings can be used to rehydrate tissues in wounds with an eschar or dry sloughing tissue. A nonadherent semiocclusive dressing or vapor-permeable polyurethane film can be placed over a hydrogel dressing to assure that its moisture is transferred to the tissue and not to the secondary bandage layer. Some hydrogels have an impermeable covering as part of the dressing to serve this purpose. Conversely to wound hydration, some hydrogels can absorb wound fluid and can be used in exudative wounds. These dressings can be used in necrotic wounds to provide a moist environment to enhance autolytic debridement and promote granulation tissue formation.

Hydrogel dressings are generally changed every three days in noninfected wounds, but if the dressing contains an antimicrobial or wound healing stimulant, daily bandage change may be necessary to maintain their activity in the wound. Hydrogel dressings can be changed every four to seven days when they are used to treat abrasions that have minimal exudates. Any hydrogel remaining on the wound at dressing change can be removed with gentle saline lavage.

Hydrocolloid Dressings
These are dressings made of a combination of elastomeric and absorbent components which form a gel when they interact with wound fluid. Some dressings have an outer occlusive polyurethane film. The hydrocolloid adheres to periwound skin while the dressing over the wound interacts with the wound fluid to produce an occlusive gel. This gel may have a yellow purulent appearance and have a mild odor; however, this should not be interpreted as infection it is surface bacterial growth. Infection would be manifested as hyperemia, pain, swelling and heat of the wound and periwound tissues. The gel is more tenacious than just exudate or the gel from hydrogel dressings.

The sheet form of the dressing is the one most frequently used. It provides a thermally insulated moist environment that is impermeable to gas, bacteria and fluid.

These dressings can be used on partial or full thickness wounds with clean or necrotic bases. Such wounds would include pressure wounds, minor burns, abrasions, or graft donor sites. Hydrocolloids can be used in the inflammatory and repair stages of healing. In the inflammatory stage they promote autolytic debridement, and in the repair stage they stimulate granulation tissue, collagen syntheses, and epithelialization. However, wound contraction may be slowed by the dressing adherence to periwound skin.

The dressings should not be used in infected wounds producing large amounts of exudate. The retained exudate can lead to maceration and excoriation of periwound skin.

To apply the dressing, the periwound skin is prepared aseptically. The sheet is cut to a size about two centimeters larger than the wound. The backing is removed from the sheet and it is placed over the wound. The dressing should be changed in about two or three days when it feels like a fluid filled blister over the wound. Change should take place before this fluid leaks from under the dressing edge. Lavage and gentle wiping are used to remove the gel from the wound and periwound skin.

Nonadherent Semiocclusive Dressings
These dressings are porous to allow fluid to move through them into the secondary bandage layer where it can evaporate. However, their absorptive capacity is low, and their porosity can allow exogenous bacteria to wick toward a wound. The dressings are generally used when a wound is in the repair stage of healing.

The dressing can be either an absorbent material encased in a perforated nonadherent covering or a wide mesh gauze impregnated with petrolatum. Although they are classified as nonadherent, these dressings can adhere to a wound. With the petrolatum impregnated gauze, granulation tissue and epithelium can grow into the interstices of the gauze to cause adherence. With the perforated nonadherent dressings exudate can dry in the perforations to adhere the pad to the wound.

Petrolatum impregnated gauze should be used early in the repair stage of healing and should be changed frequently enough to prevent granulation tissue from growing into the mesh openings. Because petrolatum may interfere with epithelialization, its early use may prevent this interference. However, once epithelialization starts, a perforated nonadherent material with absorbent filler should be used.

If the perforated nonadherent material with absorbent filler is used, its purpose is to retain some moisture over the wound to promote epithelialization while allowing excess fluid to be absorbed into the secondary bandage layer (Figure 2-3). This dressing is indicated for superficial wounds that have low to moderate exudate levels. They are often used in the latter part of the repair stage of healing when exudate levels are low. They are a good primary dressing for sutured wounds.

Antimicrobial Dressings
Antimicrobial dressings may contain such agents as iodine, silver, polyhexamethylene biguanide, activated charcoal and antibiotics. Such dressings are indicated to treat infected wounds or wounds at risk for infection. Because these dressings are not moisture retentive, covering them with a polyurethane film dressing may help keep them from drying out.

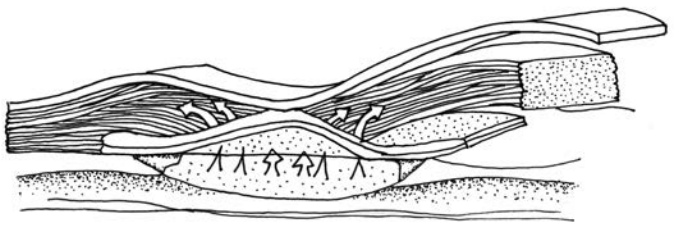


Figure 2-3. With a nonadherent semiocculsive bandage, the primary layer allows absorption of enough excess fluid to prevent tissue maceration (*longer arrows* penetrating the primary layer) but retains sufficient moisture to prevent dehydration and promote healing (*shorter arrows*). (From Swaim SF, Wilhalf D. The physics, physiology, and chemistry of bandaging open wounds. Compend Contin Educ Pract Vet 1985;7:146.)

Iodine dressings contain cadexomer iodine which is released into the wound without a negative effect on wound cells. The dressings are designed to maintain sufficient active iodine levels for about 48 hours.

Dressings with silver ions have a broad antimicrobial activity, which can be effective against otherwise antibiotic resistant organisms, and some mycotic organisms. Various silver-containing dressings are available to include gauze, gauze roll, low adherent, hydrocolloid, hydrogel and alignate dressings.

Polyhexamethylene biguanide (PHMB) is an antiseptic related to chlorhexidine. Gauze sponges and roll gauze have been impregnated with PHMB to provide an antimicrobial dressing (Kerlix® A.M.D., Covidien Co., Mansfield, MA). PHMB is a broad spectrum bactericide, and bacteria do not develop a resistance to it. PHMB-impregnated dressings have prolonged antibacterial activity and thus can prevent wound bacteria from contaminating the environment as well as resisting the penetration of exogenous bacteria into the bandage.

Activated charcoal dressings absorb bacteria and reduce wound odor. They also provide a moist wound environment.

Type I bovine collagen sponges impregnated with gentamicin provide high local levels of antibiotic, but serum levels remain below toxic levels. Such dressings have also been reported to have a hemostatic property.

Extracellular Matrix Bioscaffold Dressings

The extracellular matrix dressings (ECMs) are acellular biodegradable sheets with a three-dimensional ultrastructure. They are derived from porcine small intestinal submucosa (SIS) or porcine urinary bladder submucosa matrix (UBM). The ECMs contain structural proteins, growth factors, cytokines, and their inhibitors. Within two weeks of their presence in a wound there is degradation of the scaffold and the degradation products are chemotactic for repair cells. The repair cells enter the wound as stem cells and they deposit a site-specific matrix. For example, if the dressing is placed in a skin wound, the matrix will be skin/dermis-like. By 30 to 90 days, the bioscaffold is replaced by site-specific tissue.

The ECMs are utilized in a unique way. The wound must be thoroughly debrided, free of topical medications, cleaning agents and exudates. Infection should be eliminated or well-controlled. The ECM sheet is cut to a size slightly larger than the wound. It is rehydrated with saline, tucked under the skin wound edge, and sutured in place. It can be fenestrated if drainage is expected. A nonadhesive or moisture retentive dressing is placed over the ECM. In three to four days, at the first bandage change, all bandage parts are changed except the ECM. It will have a degenerated yellow or brown appearance. A second piece of ECM is placed over the degenerated first piece without removing it and the outer bandage is replaced. The next dressing change is in four to seven days. After two to three ECM applications, no new dressings are added. Usually a granulation tissue bed is present containing a site-specific matrix which will direct the wound healing with tissue like that of the surrounding area. Bandaging of the granulating wound is continued as healing progresses.

Secondary (Intermediate) Layer

Removal of bacteria, exudate, and debris from a wound by wound debridement, lavage, and chemotherapeutics greatly facilitates wound healing. Bandages can assist in this process by absorbing deleterious agents and removing them from a wound. Absorption of serum, blood, exudate, necrotic debris, and bacteria occurs within the secondary bandage layer. If a bandage allows evaporation of fluid (drying), then the exudate becomes concentrated, retarding bacterial growth.

The secondary bandage layer is usually started with a wide-mesh gauze product; (Sof Band® Bulky Bandage, Johnson & Johnson, New Brunswick, NJ; Kerlix® rolls, Covidien, Mansfield, MA) this layer should have a random pattern of fibers to provide maximum capillarity and absorption. It should be applied in a continuous wrapping layers from distal to proximal on the limbs. For the first layer over the primary (contact) layer and the skin of the leg, it is of particular importance to apply the gauze so as to have no wrinkles or folds contacting the skin. Such folds cause pressure spots and make the bandage uncomfortable to the patient, thereby inciting self trauma. This means that it is more important to follow the natural contours of the limb when applying the initial layer, rather than to adhere to a predetermined amount of overlapping of the gauze. Subsequent layers should be applied with approximately 50% overlap. The secondary layer should be applied thickly enough to collect absorbed fluid as well as to pad, protect, and immobilize the wound; besides using roll gauze exclusively, another way to build up the secondary layer is to apply roll cotton or cotton cast padding (Specialist® Cast Padding rolls, Johnson & Johnson, New Brunswick, NJ) over the initial gauze layer to provide additional absorption and padding. Besides its excellent conforming and cushioning properties, cotton cast padding has the further advantage of being relatively safe to apply, as it is difficult to apply it too tightly because it tears under low tension. Cotton cast padding or roll cotton should not be used directly over the primary (contact) layer, as these products could leave lint in the wound.

The frequency of bandage changes depends on the volume of wound discharge and the storage capacity of the absorptive layer. Thus, wounds in the early stages of healing usually produce a

greater volume of exudate and require more frequent bandage changes, though seldom more frequently than twice daily in the authors' experience. One consequence of waiting too long between bandage changes, particularly with contaminated, highly exudative wounds, is that the wet bandage material becomes a culture medium for bacterial growth and perpetuates infection rather than helping to remove it. In addition, if the outer bandage becomes wet ("strike-through"), contamination by exogenous bacteria can occur. Specialized gauze products that have been impregnated with polyhexamethylene biguanide as an antimicrobial (Kerlix® A.M.D., Kendall Co., Mansfield, MA) have been effective in the authors' experience in suppression of bacterial overgrowth in bandages. Even though these antimicrobial dressings have been found effective in preventing exogenous bacteria from contaminating wounds, it is still important to change the bandage before the intermediate layer becomes completely saturated. As healing progresses and wound fluid production decreases, or when an MRD is used, the secondary layer/bandage is changed less often.

Tertiary (Outer) Layer

The tertiary layer of a bandage serves primarily to hold other dressings in place and to immobilize the wounded area, especially when a splint is incorporated in the bandage. Surgical adhesive tape (porous, waterproof, or elastic) is commonly used for veterinary bandaging. Porous tape (Zonas® porous tape, Johnson & Johnson, New Brunswick, NJ; Curity® standard porous tape, Covidien, Mansfield, MA) allows fluid evaporation, thus promoting dryness, but, if the bandage becomes wet from exogenous fluid, surface bacteria can move inward by capillary action and contaminate the wound. Although the antimicrobial dressings help prevent this problem, it is desirable to maintain a dry bandage surface. Waterproof tape can protect a wound from exogenous fluid; however, if it is not properly applied, fluid can still enter the bandage and will be retained. Waterproof tape also tends to create an occlusive bandage that may lead to tissue maceration; therefore, it is primarily indicated for wounds that are not producing large amounts of fluid. Elastic coadhesive wrap (Vetrap® bandaging tape, 3M Co., St. Paul, MN; PetFlex®, Andover Products, Salisbury, MA) provides pressure, conformation, and immobilization. We use porous adhesive tape more often than either waterproof tape or elastic wrap.

If a wound has considerable drainage and absorption is the major function of the bandage, the tertiary layer of the bandage should be placed just tightly enough to hold all layers of the bandage in close contact with each other. An excessively loose bandage, with insufficient contact between the primary and secondary layers, allows fluid to accumulate over the wound, leading to tissue maceration. At the other extreme, if the tertiary layer is applied too tightly, it may compress the intermediate layer and reduce absorption, impede tissue blood supply, and impair wound contraction (Figure 2-4). In addition, overly tight application of bandages on the head and/or neck can lead to occlusion of the pharyngeal area and respiratory embarassment.

The tertiary bandage layer helps to ensure that a limb bandage remains in place. The final piece of adhesive tape is placed half on the bandage and half on the skin to prevent bandage slippage. To help adhere the tape to the skin, a hand is held over the tape for about a minute. The heat from the hand and from the animal's body softens the adhesive on the tape, making it more sticky so as to adhere better to the animal's skin. To help assure adhesion of the tape, a polymeric solution of hexamethyldisiloxane acrylate (Cavilon No Sting Barrier Film, 3M Health Care, St. Paul, MN) may be sprayed on the skin adjacent to the top of the bandage. In addition, when the tape is removed, this solution may be sprayed on the tape to help prevent epidermal stripping. When there are no open draining wounds on the paw, tape stirrups on the paw with incorporation in the bandage also help secure limb bandages.

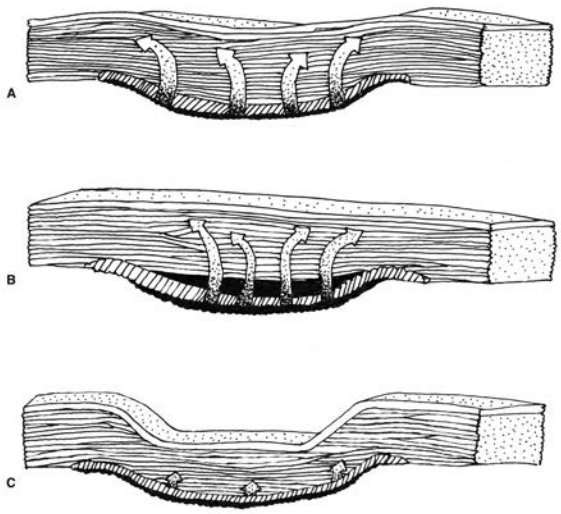


Figure 2-4. Pressure exerted by tertiary bandage layer. **A.** Ideal pressure. All bandage layers are in contact with each other, and the best absorption takes place. **B.** Too loose. All bandage layers are not in contact with each other and the wound; fluid may accumulate. **C.** Too tight. All bandage layers are compressed, resulting in decreased absorption and possibly reduction in tissue blood supply and wound contraction. (From Swaim SF, Wilhalf D. The physics, physiology, and chemistry of bandaging open wounds. Compend Contin Educ Pract Vet 1985;7:146.)

Pressure Bandages

A bandage may be placed to apply therapeutic pressure to an open wound or damaged limb. One indication for pressure bandages is control of minor hemorrhage; however, they must be used with caution and only for a short period of time. Pressure bandages can help to control peripheral edema, and they are more effective in controlling edema from venous or lymphatic stasis than inflammatory edema. Pressure bandages also help to prevent formation of exuberant granulation tissue, to obliterate dead space, and to immobilize fractures and other wounds.

Unless an elastic material is used to apply tension continuously, it is difficult to maintain pressure on a wound surface by using cotton or linen dressings. When cotton and similar materials are applied as a pressure bandage, they generally become compressed in a short time and thus no longer act as a pressure bandage. However, if cotton and linen do not compress sufficiently to relieve the constricting effect of tightly applied adhesive tape, the result may be circulatory embarrassment of the wound and bandaged structure.

A properly applied pressure bandage made with elastic material tends to keep some dynamic pressure on the wound as the patient moves. Even when an elastic material is used for a pressure bandage, excess pressure can impair arterial, venous, and lymphatic flow and can lead to tissue slough as well as nerve impingement. Therefore, the area of the limb distal to a pressure bandage should be carefully inspected for signs of swelling, hypothermia, cyanosis, moisture, loss of sensation, or odor; this duty should be performed at least twice daily by the veterinarian on hospitalized patients or by the client on outpatients. Many limb bandages are applied so as to include the entire foot; therefore the pad surfaces of the two middle digits should be left exposed so that they may be examined. An animal will usually not disturb a comfortable, properly applied bandage; if it licks or chews a pressure bandage, the bandage should be removed and the area should be examined.

Pressure caused by an elastic pressure bandage is governed by five factors: 1) the elasticity of the material used. Higher elasticity equates to more pressure, 2) tension applied at the time of application, 3) width of the tape, i.e., the narrower the tape, the greater the local pressure, and 4) the number and overlap of layers. The pressure produced by these factors is additive. Lastly, pressure is inversely proportional to the circumference of the bandaged body part, i.e., the smaller the circumference, the more pressure is applied, and the greater is the chance of circulatory compromise. Therefore, care should be taken when moving from an area of small circumference to one of larger circumference while bandaging.

For example, when bandaging a limb from distal to proximal, the distal portion of the bandage should be applied with less tension to prevent excessive constriction of this smaller circumference area.

Practice can help assure that elastic tape is applied with the proper tension. As the tape is applied off the roll, it is secured near the bandage with one hand while pulling tape off the roll. Thus, the danger of applying it too tightly is reduced. Another guideline for tape application is to apply it such that the textured pattern of the material is slightly distorted but sill visible. Wraps should overlap one-third to one-half the tape width.

Pressure Relieving Bandages

Bandages may also be configured to relieve pressure on an injured body part. The shape of the bandaged surface has an effect on the amount of pressure exerted on the tissue. The more convex the surface, the greater is the pressure exerted by the dressing on the tissue. Adding more gauze padding over a convex surface makes it even more convex, further increasing pressure. This can be detrimental when treating an open wound over a convex surface. Placing more padding over the wound in an attempt to protect it from pressure has the effect of increasing the pressure and impairing healing. Pressure relieving bandages are indicated for bandaging such areas.

Cast padding material (Specialist Cast Padding, Johnson & Johnson Orthopaedics, Raynham, MA) can be used to make a "donut"-type pad for placement over convex prominences. The principle is to place the hole of the donut over the prominence so the surrounding padding absorbs the pressure, and there is pressure relief over the prominence. Several layers of cast padding are folded on each other; thus, making a pad approximately 3 inches by 3 inches. The pad is folded over on itself and a slit is cut in its center with bandage scissors. After opening the pad, digital tension is used to enlarge the slit to a round opening ("donut" hole). The pad is then placed over the prominence with the hole over the prominence. Secondary and tertiary bandage wraps hold the pad in place (Figure 2-5A-D). These bandages are effective over prominences on the lower limbs, (e.g. lateral/medial malleolus, calcaneal tuberosity, carpal pad). A variant of the "donut" bandage principle has been employed to relieve pressure on the paw pads. This technique uses medium density open-cell foam of a special type used in aircraft seat padding (Confor™ Foam, HiTech Foams, Lincoln NE). Two configurations have proven effective to relieve pressure on a metacarpal or metatarsal pad: an oblong piece of foam is cut to cover the entire palmar or plantar paw surface and a hole is cut in it in the area over the metatarsal or metacarpal wound; the foam is then incorporated into the bandage. For pressure relief over digital pad wounds, a triangular piece of foam is placed directly over the metacarpal or metatarsal pad and incorporated into the bandage, thus helping to elevate the digits and relieve pressure. A metal paw pad cup (cup end of a mason metasplint) can be placed over the bandage with either of these configurations for further help with pressure relief. This type of pressure relieving bandage is indicated for moderate pad wounds on small to medium sized dogs.

Immobilization and extension are important to enhance wound healing over the olecranon. Immobilization allows tissues to heal together and extension prevents elbow flexion to prevent sternal recumbency and thus keeps pressure off of the wound. Several techniques have been used to bandage elbow wounds.

Pipe insulation bandages can be used for wounds over the olecranon. They are made by splitting two pieces of foam rubber pipe insulation lengthwise, cutting a hole large enough to go around the lesion in each piece, and then stacking and taping the pieces together. The cranial aspect of the humeroradial area is well padded with cast padding before taping the pipe insulation bandage in place with the hole over the olecranon. Such padding helps to keep the dog from flexing the joint to position itself in sternal recumbency to place pressure on the olecranon area. It may be difficult to secure the bandage to keep it from slipping distally on the limb, especially on an obese dog that has a short segment of limb proximal to the elbow to which the bandage can be affixed. Affixing the pipe insulation bandage to a body bandage may be necessary to hold the pipe insulation bandage in place: a body bandage is placed just caudal to the forelimbs. A strip of 2 inch adhesive tape is placed, adhesive side down, on this bandage from the dorsal area well down onto the forelimb. The roll of tape is left on the strip. The padding and pipe insulation bandage are placed and taped over the elbow area. The previously placed strip of adhesive tape is twisted 180° at the base of this bandage so the adhesive side faces outward. The tape is then placed adhesive side against the bandage and is taken back onto the body bandage over the animal's dorsum. This forms a "stirrup" to hold the pipe insulation bandage in place (Figure 2-6). No pressure is on the wound, and medications can be applied to

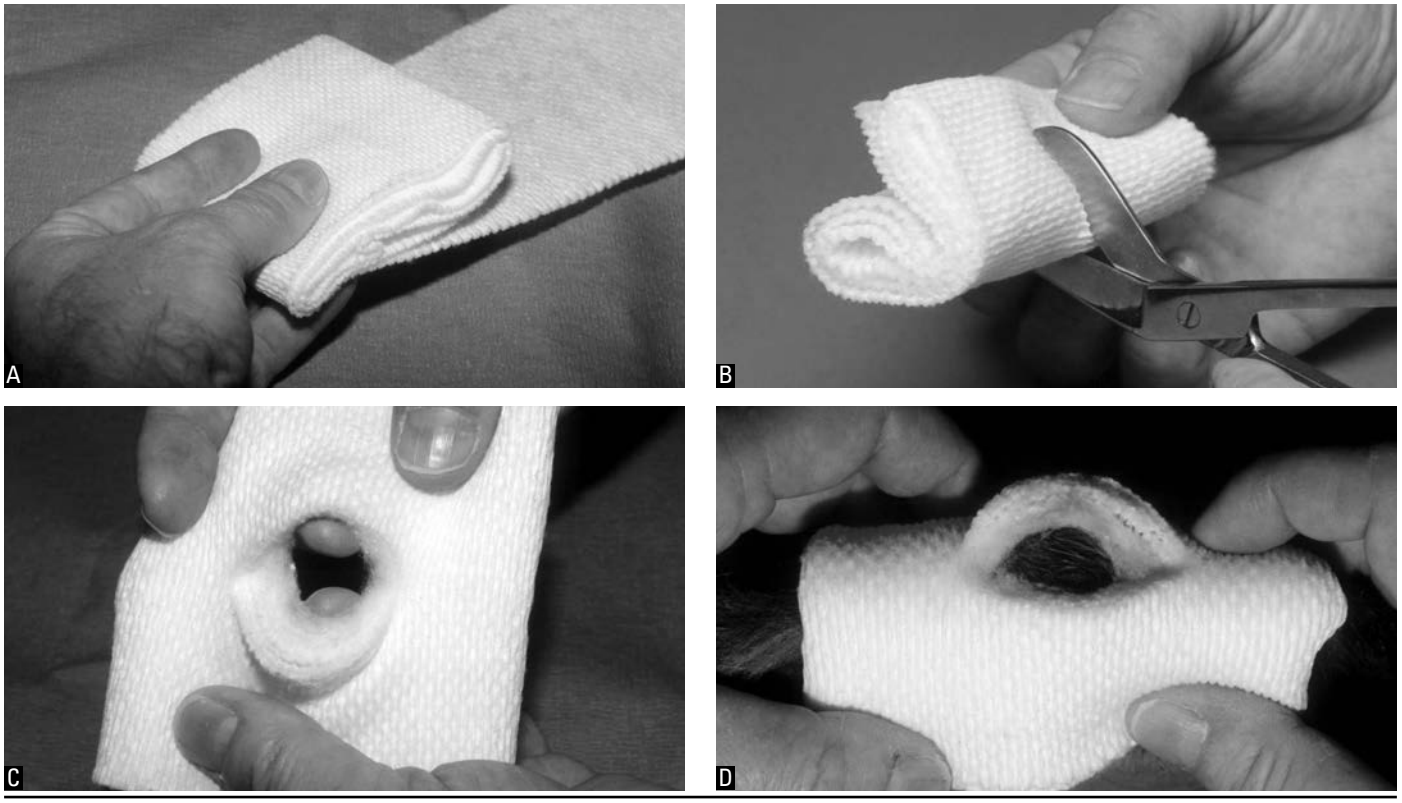


Figure 2-5. A.-D. Donut bandage. **A.** Folding several layers of cast padding to make a pad. **B.** Scissors cutting a slit in folded-over pad. **C.** Fingers enlarging the slit to a round hole. **D.** Pad placed over the calcaneal tuberosity to be held in place with secondary bandage wrap.

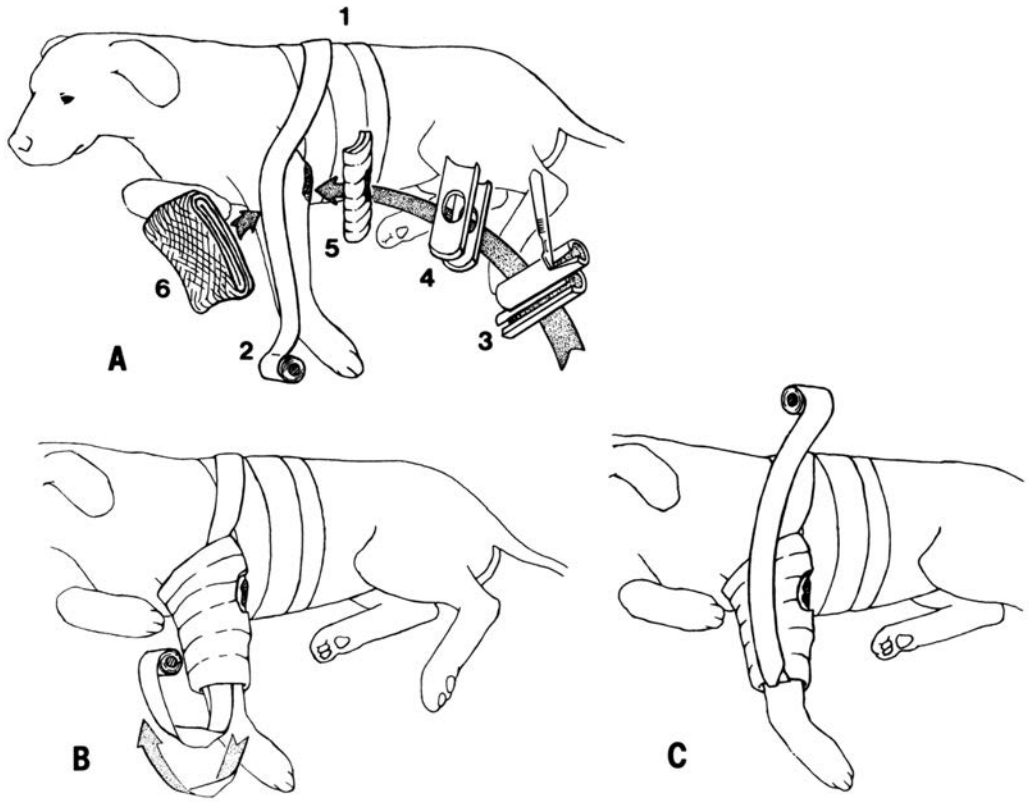


Figure 2-6. A. Steps for putting on a pipe insulation bandage: *1)* place a body bandage behind the front limbs; *2)* transfer tape from the body bandage onto the limb; *3)* split two pieces of pipe insulation; *4)* cut holes in the pipe insulation to go over the elbow ulcer and stack the pipe insulation; *5)* tape the pipe insulations together and place them over the olecranon wound; *6)* put cast padding in front of the elbow area. **B.** Tape the pipe insulation and padding in place. Twist the tape (180°) on the limb (arrow) so the adhesive side is back against the bandage. **C.** Complete the tape stirrup back onto the body bandage.

the wound through the holes in the pipe insulation. The bandage and padding remain in place for several days before adjustment or replacement are necessary. The only daily bandage change necessary is a small amount over the wound.

Splints may also be used on the cranial surface of the forelimb to immobilize the elbow joint in extension and to prevent pressure on wounds over the olecranon. A routine bandage wrap is placed around the elbow; then a section of aluminum splint rod is used to fashion a loop type splint, which is incorporated into the cranial part of the bandage (Figure. 2-7).

The authors have also been able to keep elbows extended and immobilized by placing a body bandage on the dog with extension of the bandage down the length of the leg, i.e., a forelimb spica-type bandage. The leg bandage has some bulk to it. After placing the bandage, fiberglass casting tape (Delta-Lite "S" Fiberglass Casting Tape, Johnson & Johnson, Raynham, MA) is used to create a lateral splint for the limb. The casting tape is layered along the lateral side of the bandage from the level of the paw to over the shoulders. Several layers of tape are used, especially on large dogs. The tape splint is molded by hand to the lateral surface of the bandage until it hardens. When taken away from the bandage, it has the shape of a shepherd's crook or a question mark. This is taped to the lateral side of the bandage, around the limb and over the shoulder area. A hole is cut in the bandage over the olecranon, through which the wound is treated. Usually, the bandage and splint remain in place 5 to 7 days before adjustment or replacement are needed, and the wound is treated daily via the hole with a small bandage covering, following treatment.

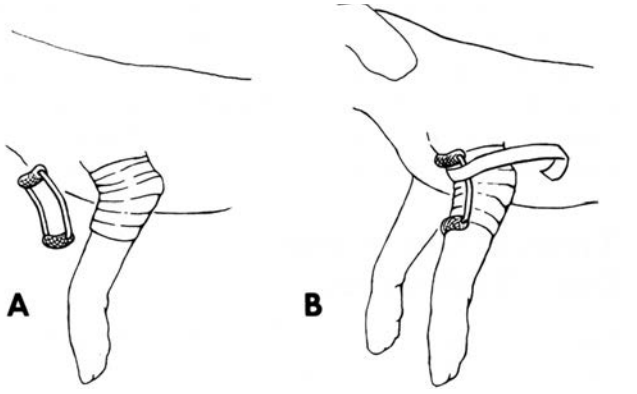


Figure 2-7. Applying an aluminum rod loop type splint in the front of an elbow bandage.

Another application of splints to a special wound healing situation is the use of "clamshell" technique to relieve pressure from the palmar or plantar surface of lacerated pads, pad flaps or pad grafts. This technique is even more effective at relieving pad pressure than the "donut" technique mentioned above and may be particularly indicated for protection of pad surgical sites. After bandaging the foot in a standard padded bandage, (a "donut" of the Confor™ Foam mentioned previously can also be applied over the affected pad or pads), two Mason metasplints are applied, one on the dorsal and the other on the palmar or plantar aspect of the limb with the paw cups facing each other and extending about 2.5 cm beyond the limb. Bandaging tape, applied in a dovetail fashion, secures the splints to the bandage. The metasplints should extend proximally almost to the elbow or to the tarsus. The functional effect is to convert the dog's ambulation to a "tiptoe" gait, like a ballet dancer, thereby relieving pressure from the pads. At the end of the splints, a final layer of duct tape or thick adhesive elastic bandaging material (Elastikon®, Johnson & Johnson, New Brunswick, NJ) helps protect the splints (and owners' flooring!) from abrasion (Figure 2-8).



Figure 2-8. Clamshell bandage splint. A Mason metasplint on the dorsal and plantar surface of a pelvic limb bandage. Paw cups extend beyond the bandage about 2.5 cm and face each other.

The pipe insulation bandage, splint rod loop bandage, and fiberglass splint bandages are also effective in keeping pressure off wounds on the sternum because they prevent elbow flexion and keep the animal out of sternal recumbency. A pressure relief bandage for wounds (i.e., decubital ulcers) over the ischiatic tuberosities is composed of a body bandage with padded aluminum splints taped to either side of the bandage. These splints extend behind the dog and prevent it from attaining a sitting posture to place pressure on the ischiatic area (Figure 2-9).

Mobilization Versus Immobilization

The decision whether a wound should be mobilized or immobilized during healing is often not clear, with advantages and disadvantages to both; wound location and type, and the stage of wound healing are important factors to consider in making the decision.

Maintaining mobility of wounds has been considered to minimize

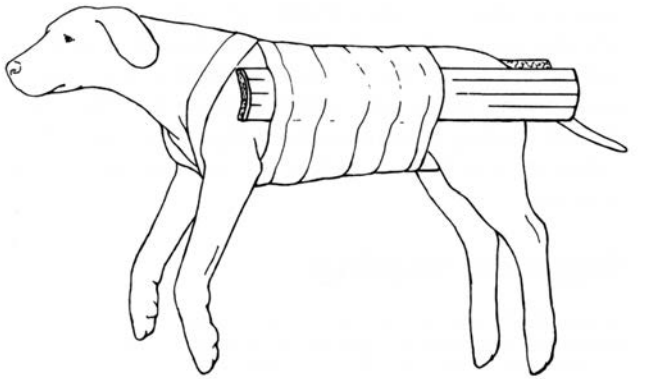


Figure 2-9. Body bandage with a lateral fiberglass splint to keep pressure off the ischiatic area.

negative nitrogen balance of the tissues, to stimulate circulation, to help combat infection, and to allow movement that loosens adhesions. Mobility can also provide massage for better wound drainage and can prevent joint stiffness and osteoporosis.

Other arguments favor wound immobilization to enhance healing. An immobilizing bandage is needed for wounds with underlying orthopedic damage. In addition to providing orthopedic support, wound immobilization may allow better healing over the olecranon, and the calcaneal tuber. Immobilization may also increase tissue resistance to bacterial growth and decrease the probability of infection and its spread by the lymphatics and tissue planes. Other factors favoring immobilization include patient comfort and support of the tissues during collagen synthesis. Wound immobilization also helps to prevent the dislodgment of fragile clots, rupture of new capillaries, and disruption of new fibrin. In addition, immobilization prevents tension on repaired structures (e.g., muscle, tendons, and ligaments).

Pressure bandages help to immobilize wounds; casts and splints also immobilize wounded limbs. Casts should be applied so that swelling can be accommodated as well as controlled. Applying a cast, then splitting the cast longitudinally on both sides, removing and reapplying it (bivalving a cast) allows for swelling and makes dressing changes possible. Application of a half of the cast to the side of the limb opposite the wound can be used for immobilization. Such a half cast can act as a point of counterpressure when a pressure bandage is required. It can be applied so the dressing can be changed without affecting immobilization. Incorporating a Mason metasplint into a bandage placed on a lower limb is an example of this type of immobilization.

Wounds over extensor and flexor surfaces of joints benefit from immobilization during healing. Because flexion of a joint tends to pull wound edges apart on the extensor surface of the joint, immobilization is indicated for such wounds. Large wounds over flexion surfaces of joints can benefit from early reconstructive surgery to help prevent wound contracture leading to deformity and loss of function of the joint. When large wounds over flexion surfaces are to be allowed to heal as open wounds, joint immobilization in extension is particularly important to help prevent contracture deformity. Another specific area where wound immobilization is indicated is the axillary region. As the forelimb moves, shearing and tension forces in this area interfere with wound healing. Reconstructive surgery and immobilization in a Velpeau bandage are needed for wound healing.

Prolonged joint immobilization may lead to cartilage degeneration, pressure wounds, joint stiffness and disuse atriphy. Thus, when bandages are changed, the wound should be cared for and joints should be evaluated for problems.

Suggested Readings

Anderson DM. Management of open wounds. In Williams J, Moores A, eds. BSAVA Manual of canine and feline wound management and reconstruction. 2nd ed. Quedgeley, Glouster, England: British Small Animal Veterinary Association, 2009: 37.

Anderson DM, White RAS. Ischemic bandage injuries: A case series and review of the literature. Vet Surg 2000;29:488.

Bojrab MJ. Wound management. Mod Vet Pract 1982;63:867.

Bojrab MJ. A handbook on veterinary wound management. Ashland, OH: KenVet Prof Vet Co, 1994.

Campbell BG. Dressings, bandages, and splints for wound management in dogs and cats. Vet Clin North Am 2006; 36: 759.

Hedlund CS. Surgery of the integumentary system. In: Fossum TW, ed. Small Animal Surgery. 3rd ed. Philadelphia: Saunders Elsevier, 2007: 159.

Lee AH, Swaim SF, McGuire JA. The effects of nonadherent bandage materials on the healing of open wounds in dogs. J Am Vet Med Assoc 1987;190:416.

Lee AH, Swaim SF, Yang ST. The effects of petrolatum, polyethylene glycol, nitrofurazone and a hydroactive dressing on open wound healing. J Am Anim Hosp Assoc 1986;22:443.

Lee WR, Tobias KM, Bemis DA, et. al. Invitro efficacy of a polyhexamethylene biguanide impregnated gauze dressing against bacterial found in veterinary patients. Vet Surg 2004;33:404.

Mentz P, Cazzangia A, Serralta V, et. al. The effect of an antimicrobial gauze dressing impregnated with 0.2% polyhexamethylene biguanide as a barrier to prevent Pseudomonas aeruginosa wound invasion. Mansfield, MA: Kendall, Wound Care Research and Development, 2001.

Miller CW. Bandages and drains. In: Slatter DH, ed. Textbook of small animal surgery. 3rd ed. Philadelphia: Saunders Elsevier, 2003: 244.

Morgan PW, Binnington AG, Miller CW, et al. The effect of occlusive and semiocclusive dressings on the healing of full thickness skin wounds on the forelimbs of dogs. Vet Surg 1995;23:494.

Pavletic MM. Atlas of small animal reconstructive surgery. 3rd ed. Philadelphia: Saunders Elsevier, 2010.

Ramsey DT, Pope ER, Wagner Mann C, et al. Effects of three occlusive dressing materials on healing of full thickness skin wounds in dogs. Am J Vet Res 1995;56:7.

Swaim SF. The effects of dressings and bandages on wound healing. Semin Vet Med Surg Sm Anim 1989;4:274.

Swaim SF. Bandages and topical agents. Vet Clin North Am 1990;20:47.

Swaim SF. Bandaging techniques. In: Bistner SI, Ford RB, eds. Handbook of veterinary procedures and emergency treatment. 7th ed. Philadelphia: WB Saunders, 2000.

Swaim SF, Bohling MW. Bandaging and splinting canine elbow wounds. NAVC Clinician's Brief, 3(11):73-76, 2005

Swaim SF, Henderson RA. Small animal wound management. 2nd ed. Baltimore: Williams & Wilkins, 1997.

Swaim SF, Marghitu DB, Rumph PF, et. al. Effects of bandage configuration on paw pad pressure in dogs: A preliminary study. J Am Anim Hosp Assoc, 2003;39:209-216.

Swaim SF, Renberg WC, Shike KM. Small animal bandaging, casting, and splinting techniques. Ames, IA: Wiley-Blackwell, (in press).

Wound Drainage Techniques

Mark W. Bohling and Steven F. Swaim

Indications

Although wounds drain best when left open, often they must be closed before they have drained completely. In general, wounds must be drained 1) when an abscess cavity exists, 2) when foreign material or tissue of questionable viability that cannot be excised is present, 3) when massive contamination is inevitable (e.g., wounds in the anal area), and 4) when it is necessary to obliterate dead space to prevent the accumulation of air, blood, serum or exudate, or to permit the egress of air or fluid accumulations from an existing cavity or wound. Specifically, wound drainage in veterinary surgery is used in the management of dog bite wounds with separation of the dermis from underlying tissue, abcessed cat bite wounds, lacerations with loose skin, radical mastectomy and other large excisional wounds, seromas, auricular hematomas, elbow and ischial hygromas, and certain instances of orthopedic trauma such as high energy fractures with extensive soft tissue trauma and swelling.

Types of Drains and Drain Techniques

Materials used for wound drains should be relatively soft, nonreactive, and radiopaque. Flat drains such as Penrose drains are made of soft, thin latex rubber material shaped cylindrically. Tube drains are composed of rubber or plastic tubes or catheters with thicker walls that are not as easily collapsed as flat drains. Multilumen drains are a combination of drain tubes that allow fluid to drain from a wound through one lumen while allowing air or lavage fluids to enter the wound by another lumen.

Drains are classifled as passive or active. Passive drains can be single lumen flat drains, tubular drains, or multilumen drains. These drains function by pressure differentials, overflow, and gravity. Active wound drainage occurs when an external vacuum is applied to the end of a drain tube. Active drains may or may not be open to the atmosphere.

Passive Drains

Flat Drains (Penrose Drains)

Penrose drains are thin walled rubber tubes available from 1/4 to 2 inches in diameter and from 12 to 36 inches in length. The mechanical action of these drains depends on capillary action and gravity because they provide a path of least resistance to the outside. Fenestrating a drain is not advised because drainage is related to surface area and fenestrating the drain reduces the surface area. Penrose drains allow egress of foreign material from the wound. Dead space is obliterated as fluid is drained and normal healing tissue fills the potential space.

Penrose drains are easily sterilized, are readily available, and cause little foreign body reaction. However, the latex causes the earlier formation of a fibrous tract in the tissue, a property that makes it good for draining abscesses because this tract between the abscess cavity and the skin is desirable for better drainage. Because they are soft and flexible, these drains do not exert undue pressure on adjacent blood vessels or other structures.

Single-Exit Drains

Penrose drains can be placed with one end of the drain emerging at the distal aspect of the wound. In preparation for placing such a drain, the hair around the area where the drain will exit should be clipped liberally. The length of drain placed in a wound should be recorded for comparison with the length that is removed. The dorsal end of the drain should be positioned before wound closure, slightly dorsal and lateral to the most dorsal aspect of the wound. The preferred technique for fixing the drain in the dorsal aspect of the wound is to pass a nonabsorbable suture through the skin and the drain and to tie it outside the skin. Only a very small bite is taken in the end of the drain; in the event that the patient removes the drain prematurely, a small suture bite in the drain minimizes the chance that a piece of the proximal portion of the drain will be torn off and remain in the wound. This suture is removed before the drain is removed (Figure 2-10).

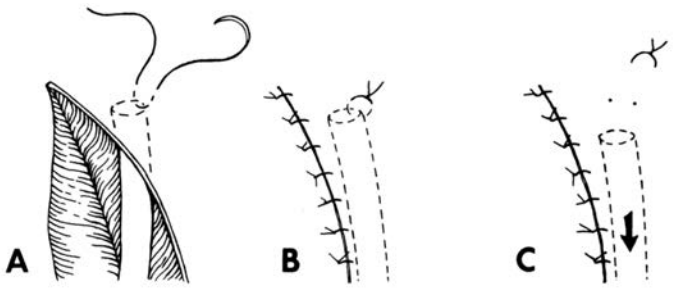


Figure 2-10. Tacking a drain in the proximal aspect of a wound. **A.** The drain is placed off to one side of the wound, and a simple interrupted anchor suture is placed through skin, drain, and skin again. **B.** The wound is closed and the anchor suture is tied. **C.** When the drain is removed, the anchor suture is cut and the drain is pulled out.

When the drain is placed in the wound, it should run as vertically as possible, and placement next to large vessels should be avoided. A drain should never emerge through the end of the suture line; instead, an incision is made in the skin ventral and lateral to the ventral aspect of the wound. A pair of hemostatic forceps can be used to make a tunnel just under the skin for the drain to exit at this incision (Figure 2-11). The exit incision should be large enough to allow drainage around the drain, usually one and one half to two times the width of the drain. A tacking suture placed through the drain and skin where the drain emerges further secures the drain and prevents it from retracting into the wound (Figure 2-12). As the wound is closed, contact between the drain and the skin suture line should be strictly avoided; this can be accomplished by suturing subcutaneous tissue over the drain and by directing the drain so it does not lie under the suture line. Failure to follow this principle invites suture line dehiscence and/or inadvertent incorporation of the drain into the closure. Care should be taken to avoid incorporating the drain into any sutures as they are placed. If the drain is incorporated into a skin suture, it cannot be removed until the skin sutures are removed. If a drain is incorporated into a subcutaneous suture, its removal usually requires at least a partial re-opening of the wound.

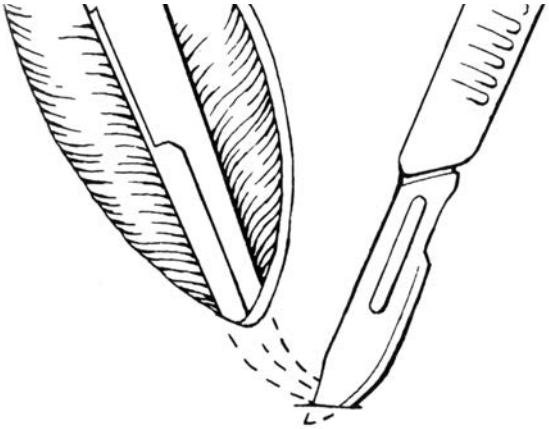


Figure 2-11. Making a subcutaneous tunnel at the distal end of the wound with the tips of forceps. A scapel blade is used to incise the skin over the forceps tips to create a drain emergence site.

To prevent drain incorporation in the suture line, the drain is placed in the wound via the ventral drain hole. The dorsal end of the drain is placed at the appropriate location in the wound. The point at which the drain exits through the ventral drain hole is marked on the drain. The drain is then pulled from the dorsal end of the wound. This pulls the mark on the ventral part of the drain into the wound. The subcutaneous tissue is now apposed over the drain. Every 2 or 3 suture bites, both ends of the drain are grasped, and the drain is pulled back and forth to be sure no suture bite has incorporated the drain. Lack of free drain movement indicates drain incorporation in a suture, and 2 to 3 sutures can be removed and replaced. After all subcutaneous sutures are placed and the drain moves freely, the ventral end is pulled so that the dorsal end is now within the wound, and a deep simple interrupted suture through the skin, drain, and skin again is used to anchor the dorsal end of the drain. The previously placed mark on the drain is again at the level of the ventral drain hole. The skin can now be closed without concern for incorporating the drain because it is protected beneath the subcutaneous tissue. The ventral drain anchor suture is then placed.

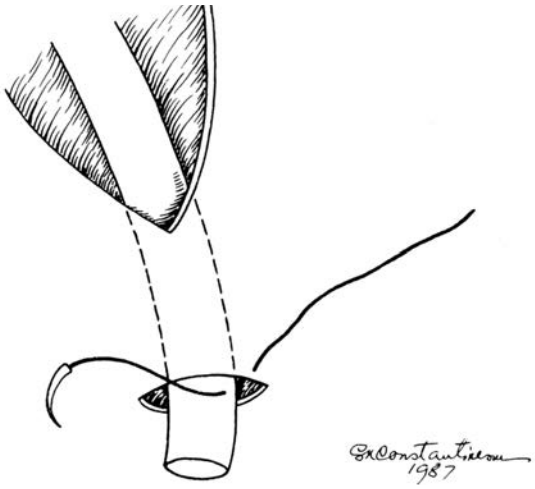


Figure 2-12. Placing and anchoring a drain distally. The drain exits through a hole distal to the wound. The exit hole is large enough to allow drainage around the drain. A simple interrupted nonabsorbable suture is placed through the skin and drain at the drain's exit hole.

When a closed wound (e.g., an unruptured abscess) requires drainage, an instrument with long jaws, such as a Doyen intestinal forceps, can be used to place one end of the drain in the depths of the wound through a stab incision near the dependent aspect of the wound. The tip of the forceps is used as a palpable landmark to pass a simple interrupted suture through the skin, into the drain, and back out through the skin. The suture is tied to anchor the drain in the dorsal aspect of the wound.

Penrose drains can also be used to drain deep wounds; however, care should be taken that an adequate pathway is created from the deep pocket to the skin surface to provide drainage. An open approach is usually made to the deep wound to allow debridement, lavage, culture, and biopsy. Apposition of the tissues overlying the deep pocket is usually sufficient to hold the drain in place. The usual principles of exiting the drain in a position that is dependent to the wound, and not within the primary closure, are followed.

Drains should be covered with sterile absorbent dressings to absorb wound fluid and prevent external contamination. Bandages also help to prevent molestation of the wound by the patient. The bandage should be changed frequently to remove fluid from the wound area. The area around the exit drain should be cleaned at bandage change; antiseptic ointments or creams are sometimes applied to the skin at the drain exit site to protect the skin from irritation from the draining exudate. In these cases, the ointment or cream should not be applied too thickly around the drain exit, or drainage may be obstructed. Inspection of the bandage reveals the nature and amount of drainage, to determine how long a drain should remain in place.

Double-Exit Drains

Penrose drains can also be placed with one end emerging above the dorsal aspect of the wound and the other end emerging below the ventral end of the wound. Simple interrupted sutures are placed through the skin and drain at both points of emergence to prevent the drains from retracting into the wound (Figure 2-13). The use of double exit drains remains somewhat controversial; many surgeons avoid the use of vertically oriented double exit drains, asserting that the double exit holes increase the risk of ascending bacterial infection. However, there is no support for this hypothesis in the scientific data, whether based on experimentation or patient statistics. Double exit drains can be advantageous if the wound is to be flushed with an antibiotic or antiseptic. They are usually used in heavily contaminated or infected wounds. Lavaging the wound from the proximal tube emergence site exposes the wound tract to the solution, although the lavage solution may merely follow the path of least resistance, the drain tract, and not reach the crevices of the wound. Moreover, if pressure is applied to the lavage solution or if the distal drain opening is occluded, the lavage solution can spread wound debris and bacteria into surrounding tissue by hydrostatic pressure.

Another use for double exit drains is when considerable subcutaneous dead space extends up the lateral trunk, across the dorsum, and down the opposite lateral trunk. A drain can be placed from the most dependent area of dead space on one side,

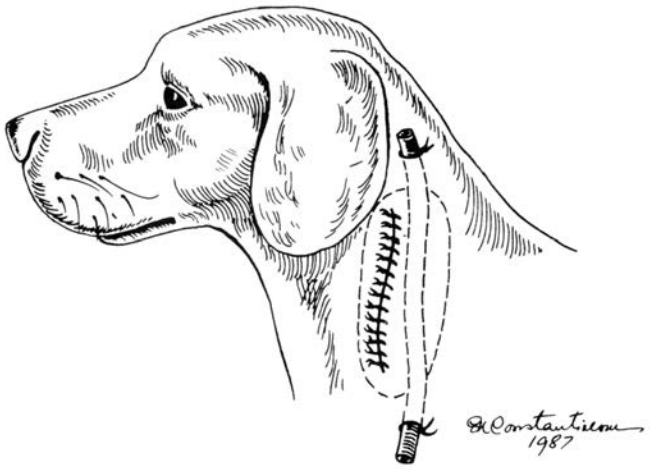


Figure 2-13. A drain can exit at both proximal and distal aspects of a wound. The drain is anchored to the skin at both exit holes. (From Swaim SF. Surgery of traumatized skin: management and reconstruction in the dog and cat. Philadelphia: WB Saunders, 1980:159.)

across the dorsum of the animal to a like area on the opposite side. Thus, the drain passes subcutaneously across the animal's back with an exit on each side to provide drainage.

Tube Drains

Rubber or plastic tubes and catheters of various diameters and designs can be used as tube drains. These cylindrical tubes have a thicker wall than flat drains. They have a single lumen with or without small or large side holes. Additional side holes, if desired, should be cut in an oval and should be no more than one third the diameter of the drain, to prevent kinking and possible tearing of the drain. The basic mechanism of action and the principles of application of tube drains are the same as for flat drains.

Fenestrated tube drains can drain from both inside and outside the lumen, and they can be connected to a suction apparatus for use with a closed collection system. These tubes also allow irrigation through the drain. They are not expensive and they are readily available. Silicone plastic (silastic) tube drains may cause less tissue reaction than rubber tube drains. One disadvantage of tube drains is that their stiffness can cause patient discomfort. These drains may become obstructed by clots and debris, necessitating flushing to clear them.

Active Drains

Open Suction Drains

When a vacuum is applied to one lumen of a multilumen drain, fluid is removed from the wound as air enters the wound through another drain lumen as a sump drain. Although the procedure reduces the drainage time, we do not use it because the increased volume of environmental air drawn into the wound increases the chance of bacterial infection and can be traumatic to the tissues. Bacterial filters can be fitted to the air intake to help decrease contamination.

Closed Suction Drains

Closed suction drainage occurs when suction is applied to a drain tube that has been placed into a wound with no external air venting. This implies not only a single, airtight exit site for the drain, but in addition, an airtight wound (either a natural blind pocket or surgical airtight closure) allowing the creation of a vacuum within the wound. This drainage system facilitates continuous flow and reduces the chance of drainage tube occlusion and the need for wound irrigation. Closed suction drains do not depend on capillary action or gravity. Closed suction drains have the same indications as passive drains; however, they work best when no foreign material or necrotic tissue is present, because these could plug the drain holes.

Numerous commercial portable closed suction drainage systems are available. When incorporated into a bandage, these drains provide portable, continuous, even pressure, and aseptic closed suction drainage. In some of these systems, unless a one way valve device is included, fluid may reflux back into the wound if the animal lies on or puts pressure on the evacuator. The location of the wound, the size of the animal, and the size of the commercial apparatus should be considered when choosing a commercial closed suction system; one model in common use (Jackson-Pratt®, Allegiance, a Cardinal Health company, McGaw Park, IL) employs a clear silastic 100 ml bulb-type reservoir with one-way valve. This is attached to a 25 cm length of 3 x 10 mm, multi-fenestrated drain by a 30" silastic tube. The drain and tube can be trimmed to the desired length, and the suction reservoir can be conveniently stored in a pocket that is constructed in the animal's bandage.

An inexpensive and simple closed suction drainage system can be made using a butterfly scalp needle with its extension tube as the drainage tube, and a 5 or 10 mL evacuated blood collection tube to provide suction. The Luer syringe adapter of the butterfly scalp needle is cut off the tubing and discarded, leaving the needle and attached tubing intact. A scissor is used to cut small (1-2 mm) oval holes into the tubing, extending for a length a little shorter than the length of the wound (Figure 2-14). The fenestrated portion of the tube is inserted through a small puncture wound near the site to be drained. The puncture wound should be the same diameter as the tube. The tubing is secured to the skin with a nonabsorbable pursestring suture. After the wound is closed, the needle on the free end of the tube is inserted into a standard 5 or 10 mL evacuated blood collection tube (Figure 2-15). A light bandage into which the collection tube is incorporated is usually all that is necessary. For large wounds, two drain sets may be necessary.

If the drain is placed under a (non-fenestrated) skin graft, the end of the drain should be placed under the skin at the edge of the graft. A simple interrupted tacking suture is placed through the skin, through the tube, and back out through the skin to anchor the end of the drain. This suture, along with the pursestring suture at the drain exit hole, secures the drain under the graft so it does not move to interfere with graft revascularization (Figure 2-16).

A modification of this closed suction apparatus involves the use of plastic syringes. To prepare the drain tube, the butterfly needle

is removed from the scalp set, leaving the Luer adapter attached to the tubing, and the tubing is fenestrated. (Figure 2-17A). After the tubing has been placed in the wound and the wound has been closed, a plastic syringe is attached to the Luer adapter. The plunger is withdrawn enough to create the desired negative pressure without collapsing the drain tubing, and a 16 or 18 gauge needle is driven crosswise through the syringe plunger just above the syringe barrel to hold the plunger at the desired level within the barrel (Figure 2-17B). Fixation at different levels creates different negative pressures. The size of syringe that is used corresponds to the expected volume of fluid to be drained; a 6 ml syringe can be used when little drainage is anticipated, while a 30 mL syringe can be used when large amounts of fluid are to be removed.

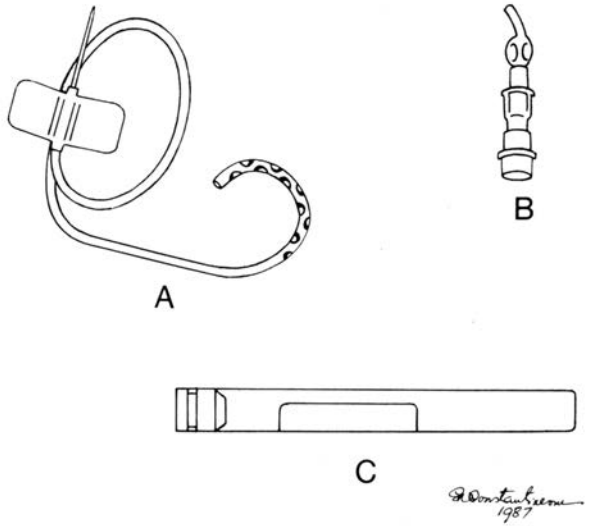


Figure 2-14. Components of a simple closed suction drain. **A.** A 19 gauge butterfly catheter after multiple fenestrations have been made in the tubing. **B.** Luer adapter that was removed from the catheter. **C.** A 10 mL evacuated glass tube.

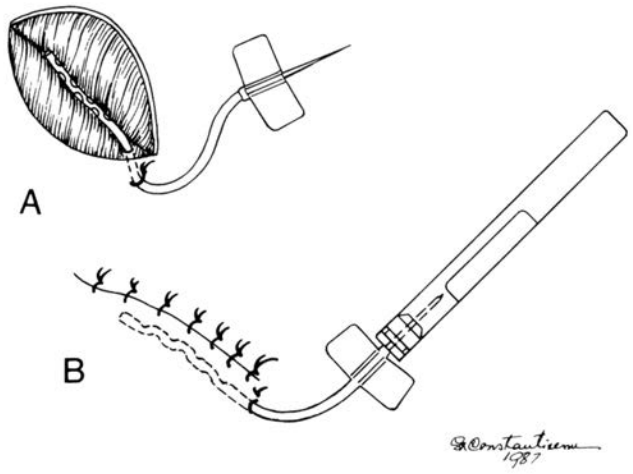


Figure 2-15. Placement of a closed suction drain in a wound. A. The fenestrated portion of the drain is inserted into the wound through a small opening near the distal end of the wound. The tube is secured to the skin with a simple interrupted nonabsorbable suture. B. The wound is closed. The needle on the tube is inserted into a 5 or 10 mL evacuated blood collection tube.

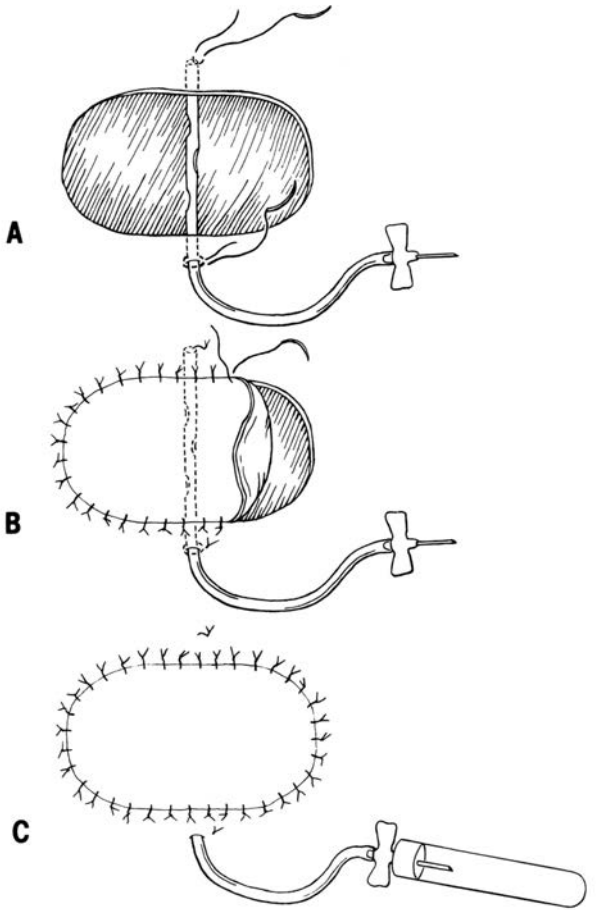


Figure 2-16. Placement of a closed suction drain under a skin graft. **A.** A butterfly catheter with the Luer adapter removed and the tubing fenestrated is placed across the wound bed before the graft is placed. The proximal end is secured with a simple interrupted suture placed through skin, catheter, and skin again. A pursestring suture is used to secure the distal end of the tubing to the skin. **B.** The graft is sutured into place over the drain. **C.** The needle on the catheter is inserted into a 5 or 10 mL evacuated blood collection tube. (From Swaim SF. Skin grafts. Vet Clin North Am Small Anim Pract 1990;20:147.)

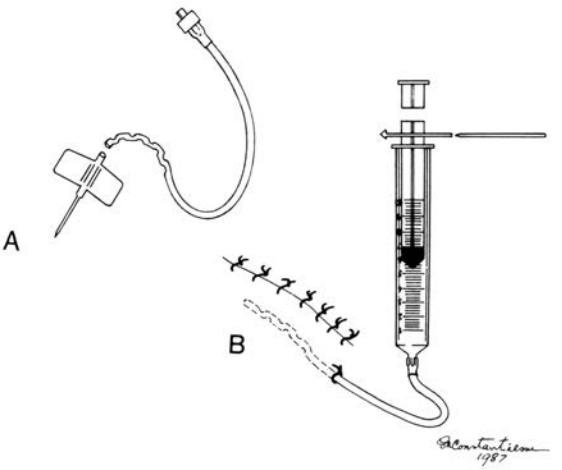


Figure 2-17. Modified closed suction drain. **A.** The butterfly needle is removed from the catheter and the catheter tubing is fenestrated. The Luer adapter is left on the catheter. **B.** A plastic syringe is attached to the Luer adapter of the catheter. A metal pin or hypodermic needle is driven through the plunger just above the barrel after the plunger is withdrawn the desired distance. The end of the plunger can be cut off.

Closed suction drains allow wounds and dressings to be kept dry: they help to prevent bacterial migration through or around the drain; they provide continuous drainage to decrease drainage time; they reduce the need for irrigation; and they have few complications. When used under skin grafts, these drains help to hold the graft in contact with the wound bed, enhancing revascularization and early engraftment. Evacuated blood collection tubes can be changed as often as necessary, and wound fluid can be accurately measured and cytologically examined to assess wound infection.

One disadvantage of closed suction drainage is that high negative pressure can injure the tissue. In addition, although the 10 mL evacuated blood tubes are effective and not cumbersome to incorporate into a bandage, they may need to be changed several times each day in highly productive wounds.

Duration of Drainage

The times for drain removal vary depending on the type of wound drained. A drain should be removed as soon as the need for it no longer exists. The amount and character of drainage fluid are the most important factors in determining when a drain should be removed. In general, it is time to remove the drain when the amount of drainage is significantly decreased (usually by half or more) and is remaining relatively constant from day to day, and the character of drainage fluid becomes less turbid, becoming serous or serosanguinous. Closed suction drains incorporate fluid storage within the system, simplifying evaluation of volume and character. When a passive drain is employed, absorbent bandage material should be placed over the drain to protect the wound and the drain, and to capture the drainage for evaluation of volume and character. To give some specific examples of approximate duration of drainage, a drain placed in a wound to prevent hematoma formation from capillary oozing can be removed within 24 hours. A drain used for an infection, such as an abscess, should be removed in 3 to 5 days or when the infection is controlled. For hygromas and large seromas, the drain may need to remain in place for as long as 10 to 14 days, for severe bite wounds, 4 to 6 days; and for major tumor resection with creation of extensive dead space, 4 days.

Complications and Failures of Drains

Failure to secure a drain to the skin or to protect it from molestation can result in removal of a drain before it has accomplished its purpose, slippage back into the wound, or breaking off in the wound. If strong adhesions form around a drain or if a suture has inadvertently been passed through the drain, the drain may break when being removed, leaving a portion in the wound. Use of drains can cause wound infection because of decreased local tissue resistance and infection ascending around the drain with bacterial proliferation in the area. Proper aseptic technique should always be followed whenever drain management is performed (e.g. emptying the reservoir of a closed suction drain) to minimize the risk of this complication. Drains placed in some areas (e.g., axillary or inguinal areas) may allow air to be sucked into the wound as tissues move. This can result in subcutaneous emphysema. Surgeons should not rely on drains rather than good surgical technique to manage wounds, nor should they give in to the temptation to close and drain areas that would be better left open.

Suggested Readings

Fox JW, Golden GT. The use of drains in subcutaneous surgical procedures. Am J Surg 1976;132:673.

Hak DJ: Retained broken wound drains: A preventable complication. J Orthop Trauma 2000;14:212.

Hampel NL. Surgical drains. In: Harari J, ed. Surgical complications and wound healing in the small animal practice. Philadelphia: WB Saunders, 1993.

Hampel NL, Johnson RG. Principles of surgical drains and drainage. J Am Anim Hosp Assoc 1985;21:21.

Ladlow J. Surgical drains in wound management and reconstructive surgery. In: Williams J and Moores A, eds. BSAVA Manual of Canine and Feline Wound Management and Reconstruction, 2nd ed. Quedgeley, Gloucester, UK, BSAVA, 2009.

Lee AH, Swaim SF, Henderson RA. Surgical drainage. Compend Contin Educ Pract Vet 1986;8:94.

Moss JP. Historical and current perspectives on surgical drainage. Surg Gynecol Obstet 1981;152:517

Pope ER, Swaim SF. Wound drainage from under full thickness skin grafts in dogs. Part 1. Quantitative evaluation of four techniques. Vet Surg 1986;15:65.

Roush JK. Use and misuse of drains in surgical practice. Probl Vet Med 1990;2:482.

Swaim SF. Surgery of traumatized skin: management and reconstruction in the dog and cat. Philadelphia: VVB Saunders, 1980:157 160.

Swaim SF, Henderson RA. Small animal wound management. 2nd ed. Baltimore: Williams & Wilkins, 1997.

Chapter 3

Electrosurgery and Laser Surgery

Electrosurgical Techniques

Robert B. Parker

Electrosurgical units are probably among the most frequently used and least understood surgical instruments. Little information is available in the veterinary literature concerning basic electronics, proper surgical techniques, and potential hazards. Judicious use of electrosurgery can be of great benefit to the veterinarian in maintaining a bloodless surgical field, but indiscriminate use can create serious complications. The following discussion describes available electrosurgical methods and apparatus and provides a guideline for their proper use.

Electrolysis

Electrolysis implies a unidirectional, direct current flow that produces strong polarity in the anode and cathode (Figure 3-1). The system is of low voltage and amperage. When the electrodes are inserted into the body, hydroxides are produced at the treatment cathode by the following formula:

$$2\,NaCl + 4\,H_2O \longrightarrow \begin{cases} 2\,NAOH + 2\,H_2 \text{ (cathode)} \\ 2\,HCl + O_2 \text{ (anode)} \end{cases}$$

The hydroxides liquefy tissue, yet produce minimal discomfort.

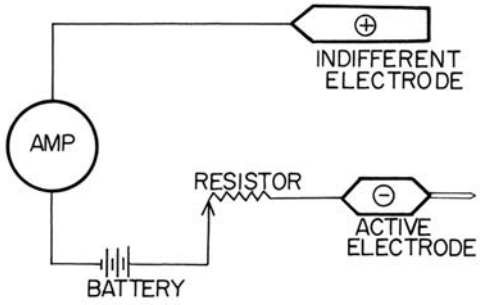


Figure 3-1. Basic circuit diagram for an electrolysis unit.

Electroepilation has been used in ophthalmic surgery for treatment of ectopic cilia or distichiasis. The fine cathode electrode is passed to the base of the cilia, where the current and hydroxides liquefy and destroy the ciliary root.

Electrocautery

The use of cautery to control hemorrhage dates back to ancient times, when a hot iron was used to cauterize wounds. More sophisticated microcautery is now available, but the technique of direct heat application is the same.

Low voltage current is used to heat the treatment electrode, and therefore, electrical energy does not pass through the body (Figure 3-2). The destructive effect is heat coagulation, and the temperature is proportional to the intensity of the current flowing through the resistance of the tip.

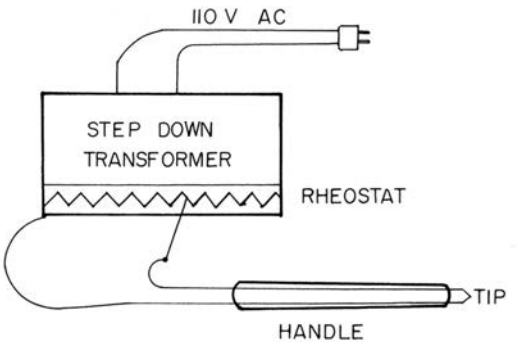


Figure 3-2. Basic circuit diagram for a thermal electrocautery unit.

Advantages of this technique are that 1) the degree of tissue damage is apparent, 2) it coagulates well in a bloody field, and 3) it is inexpensive and simple. The disadvantages are that 1) tissue destruction can be extensive and 2) large lesions are slowly destroyed.

Electrocautery units are generally reserved for minor surgical procedures, such as dewclaw or tail removal in puppies. Disposable electrocautery units, frequently used in ophthalmic surgery, provide fine hemostasis by pinpoint heat application (Figure 3-3).

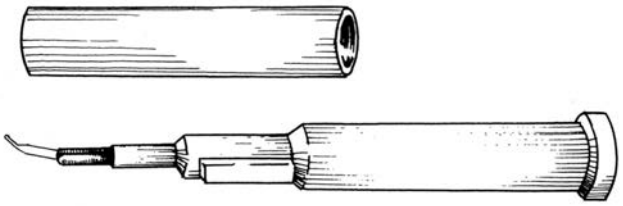


Figure 3-3. Disposable electrocautery unit.

High Frequency Electrosurgery

Most electrosurgical units available today fall into this category. The unit is essentially a radio transmitter that produces an oscillating high frequency electrical field of 500,000 to 100,000,000 hertz (cycles per second). Above 10,000 hertz, current can be passed through the body without pain or muscle contraction. In contrast to electrocautery, the treatment electrode is not hot, but serves to deliver electrical energy at a concentrated area. The electrosurgical effect is determined by 1) the tissue resistance, 2) the mode of application, and 3) the amount and type of current. These factors can be modified to produce the desired surgical response.

Body tissue and fluids have a definite electrical impedance or resistance. Heat is produced by the resistance to current flow as electrical energy is absorbed and converted to thermal energy. Because resistance is inversely proportional to surface area, resistance decreases as the current spreads over the body.

The mode of application can be either uniterminal or biterminal. Biterminal application, used most frequently with cutting or coagulation, implies the use of an indifferent electrode or "ground plate" (Figure 3-4). The indifferent electrode collects

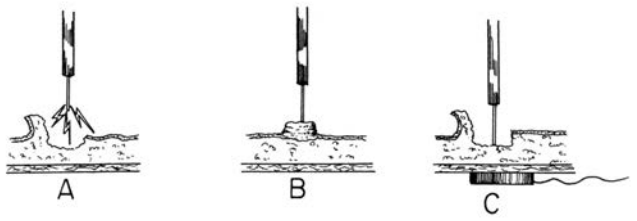


Figure 3-4. Uniterminal techniques, electrofulguration **A.** and electrodesiccation **B.** Biterminal techniques, electrotomy and electrocoagulation **C**.

the current when it has passed through the body and dissipates it over a large surface area to produce a low current density. Because heat production is inversely proportional to the contact area, the large size of the indifferent electrode evenly distributes the heat to prevent burning. The active electrode concentrates the same energy at a small point and produces the surgical effect (Figure 3-5).

With the uniterminal technique, the patient is not incorporated into the electrical circuit. An indifferent electrode is not used and the electrical energy is absorbed by the patient and is radiated into the air. Thus, sparking is produced at the tip and is directly applied to the lesion to cause either fulguration or desiccation (See Figure 3-4).

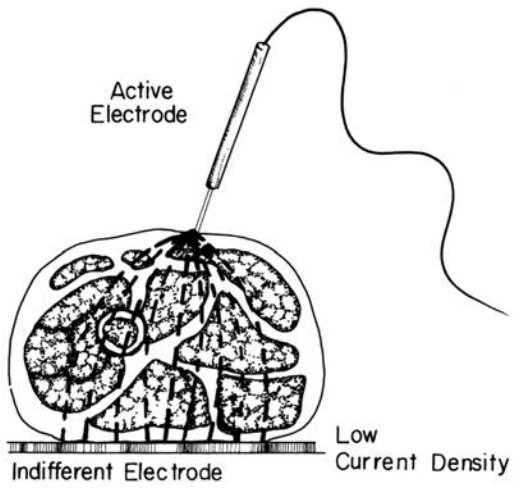


Figure 3-5. High current density at the active electrode and low current density with a properly placed indifferent electrode.

Most modern electrosurgical units provide different waveforms to bring about either cutting or coagulation. An undamped, continuous sine wave makes the most effective cutting current (Figure 3-6). Little hemostasis is achieved with a pure sine wave. In older units, a triode vacuum tube was used to produce the sine wave, but newer solid state units use electronic circuitry to yield a more refined current. A series of damped or interrupted waves achieve coagulation with limited cutting capability (Figure 3-7). Blended currents are possible and produce a combined cutting and coagulation mode (Figure 3-8). The more expensive units are capable of varying the "on-to-off" time to accomplish degrees of cutting versus coagulation.

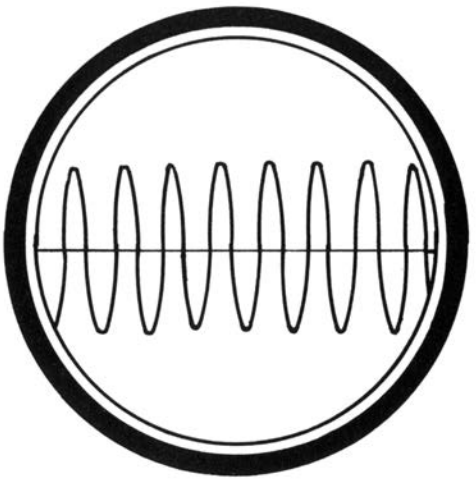


Figure 3-6. Undamped, continuous sine (cutting) waves.

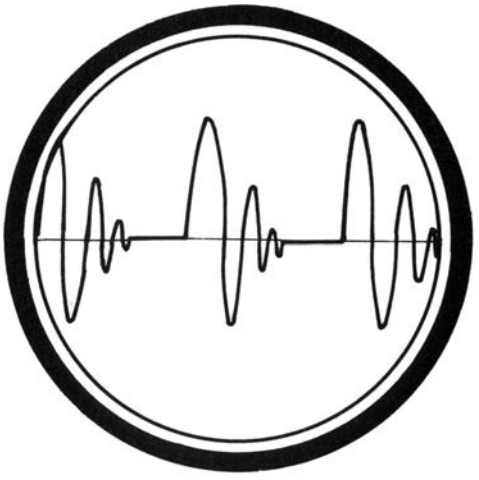


Figure 3-7. Damped (coagulation) waves.

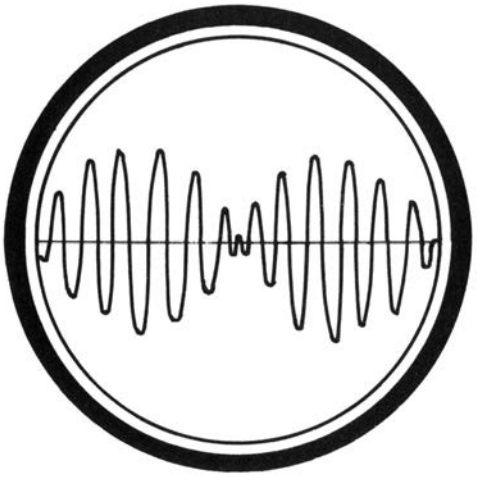


Figure 3-8. Blended (combined cutting and coagulation) waves.

Surgical Techniques

These techniques include electrotomy, electrocoagulation, and electrofulguration and electrodesiccation.

Electrotomy

Electroincision of any tissue causes greater tissue damage than sharp incision; therefore, the veterinarian must weigh the advantages of reduced blood loss and operating time against the disadvantages of increased tissue destruction and healing time. Electroincision of the skin heals primarily, but a definite lag is seen in the ultimate healing of the wound. Healing does occur, however, and maximal breaking strength is achieved.

The primary indications for electroincision of the skin are in patients with clotting disorders or when anticoagulant treatment is anticipated, such as with cardiopulmonary bypass procedures. Because of the initial delay in wound healing, it is recommended that skin sutures remain approximately 2 to 3 days longer with a skin incision made with an electrosurgical unit. The amount of coagulation and necrosis is proportional to the amount of heat produced and its duration of contact. Therefore, it is best to use a smooth, swift stroke when using an electrosurgical scalpel.

The high frequency electrosurgery units such as the Ellman Surgitron (Ellman International, Hewlett, NY) cause no more tissue destruction than traditional cold scalpel surgery if used in the pure cutting mode.

An electrosurgical scalpel has been used to cut virtually every type of tissue; its use in division of muscle or other highly vascular tissue is generally accepted procedure. By using blended currents, muscular tissue can be divided with less blood loss and in less operating time. The small blood vessels traversing muscular tissue can be effectively coagulated without the necessity of using ligatures that are difficult to place unless one includes significant amounts of normal tissue. With electrotomy of muscular tissues, particular attention should be made to large vessels; they can be incompletely coagulated, may retract, and may form a hematoma. If muscle twitching is a problem, one should tense the muscle between one's fingers to facilitate transection.

Although I do not routinely use them, electrosurgical scalpels and loops have been advocated for performing tonsillectomies, uvulectomies, ventriculocordectomies, anal sacculectomies, and skin tumor resections.

Electrocoagulation

The electrosurgical apparatus is extremely useful for coagulation of small bleeding vessels. A damped wave pattern provides the ultimate current for coagulation. Proper technique is required, and the technique of "frying tissue until it pops" is to be avoided. This practice is comparable to mass ligation of a bleeding point, and both lead to unnecessary tissue necrosis.

Vessels less than 1.5 mm in diameter can be sealed by pinpoint electrocoagulation. If larger vessels are coagulated by this method, delayed breakdown and hemorrhage may occur. Because fluids are current conductors, the field must be dry in the area surrounding the bleeding vessel. There are two ways to coagulate a bleeding vessel properly. The first is to apply the activated tip directly onto the vessel. The end point of coagulation is determined by tissue contraction and color change. A more precise method is to occlude the vessel initially with a hemostat or plain tissue thumb forceps. The active electrode is applied directly to the surgical instrument, which carries the current directly to the vessel. Care should be taken to prevent unwanted coagulation by not allowing the instrument to rest on normal tissue when the current is applied.

Electrofulguration and Electrodesiccation

These electrosurgical techniques cause dehydration and superficial destruction by a high-voltage, high-frequency current. These techniques are uniterminal; an indifferent electrode is not used. Electrofulguration damages tissue by electrical energy transmitted through an electrical arc or spark. Electrodesiccation is similar, although the electrode directly touches the lesion (See Figure 3-4). Tissue damage is deeper than with fulguration and may be difficult to control. Electrofulguration of perianal fistulas after a sharp "deroofing" procedure has produced encouraging results. Electrodesiccation has been used for removal of superficial skin lesions.

Precautions

Accidental burns are probably the most frequently observed complication of electrosurgery. It is imperative that an adequate indifferent electrode ("ground plate") be incorporated in the system. Because of its large surface area, the indifferent electrode normally provides a low current density to complete the electrosurgical circuit. If contact between patient and plate is inadequate, however, high density electrical current can easily cause a burn (Figure 3-9). Although the indifferent electrode is designed to be the preferential pathway for the current, a faulty connection between the plate and the unit can result in a burn where the patient touches the metal operating table or the attachment sites of electrical monitoring equipment.

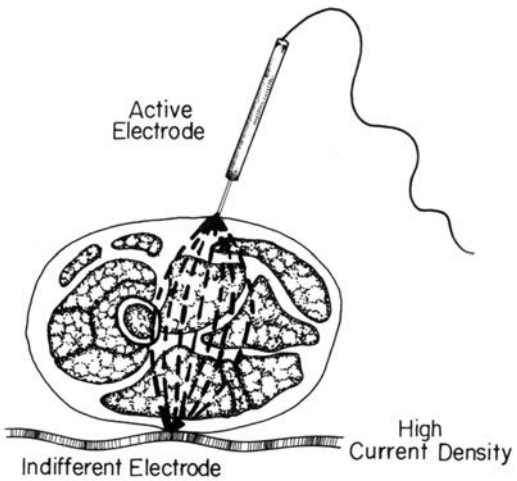


Figure 3-9. High current density produced at the indifferent electrode with improper technique.

More expensive units have a 60 cycle monitoring current flowing through the "ground plate" system. A break in the ground wire or in its ground plate connection interrupts the monitoring current and sounds an alarm. Electrolyte jellies and a large area of contact with the patient are recommended to lower skin resistance and to provide more intimate contact between the skin and the indifferent electrode.

Explosions and fire are potential hazards when inflammable anesthetics, such as ether, chloroform, and cyclopropane, and inflammable skin preparations, such as alcohol, are used.

Electrical channeling occurs when the treatment electrode is used on tissue that has a thin connection to the body. An example is the testicle mobilized out of the scrotum. If electrocoagulation is used, electric energy will be channeled or funneled along the spermatic cord and will cause heat damage.

Cardiac pacemakers are implanted with increasing frequency in veterinary medicine, and the veterinary surgeon should be aware that high frequency electric energy may cause a cardiac arrest by interfering with the operation of the pacemaker.

Suggested Readings

Battig CG. Electrosurgical burn injuries and their prevention. JAMA 1968;204:91.

Fucci V, Elkins AD. Electrosurgery: principles and guidelines in veterinary medicine. Comp Contin Educ Pract Vet 1991;13:407.

Giddard DW, Jones WR, Wescott JW. Electrosurgical units: particular attention to tube, spark gap and solid state generated currents–their differences and similarities. J Urol 1972;107: 1051.

Glover JL, Bendick PJ, Link WJ. The use of thermal knives in surgery: electrosurgery, lasers, plasma scalpel. Curr Probl Surg 1978; 15:7.

Greene JA, Knecht CD. Electrosurgery: a review. Vet Surg 1980;9:27.

Greene JA, Knecht CD. Healing of sharp incisions and electroincisions in dogs: a comparative study. Vet Surg 1980;9:42.

Ormrod AN. Electrosurgery: its usefulness and limitations for the small animal surgeon. Vet Rec 1963;75:1095.

Swerdlow DB, et al. Electrosurgery: principles and use. Dis Colon Rectum 1974;17:482.

Wald AS, Mazzia VDB, Spencer FC. Accidental burns associated with electrocautery. JAMA 1971;217:916.

Electrosurgery–Radiosurgery

A. D. Elkins

Introduction

Electrosurgical units are used to some degree in many veterinary practices. These units are often incorrectly used and in most hospitals under-utilized due to a lack of understanding of proper technique. The use of radiosurgery reduces operative time when used correctly with no delay in healing. The following discussion describes the difference in low frequency, electrosurgery and high frequency (3.8 to 4.0) radiosurgery units and provides a guideline for their proper use.

Radiosurgery is defined as the use of energy created by high frequency alternating current to perform surgical procedures. This is in contrast to electrosurgery in which low frequency (.5 mhz to 3.7 mhz) alternating current is used. The resistance of the tissue to the passage of this current creates heat internally in the tissue resulting in either cutting or coagulation.[1] In radiosurgery, two electrodes (an active electrode and a patient return plate) of greatly different sizes resulting in increased current density at the point of the smaller active electrode are utilized. (Figure 3-10). While the electrode itself remains cold, the highly concentrated high frequency energy creates molecular heat inside each cell. The intercellular water boils and creates a microexplosion, thus incising tissue. The key to successful use of radiosurgery is control of the heat adjacent to the primary incision. By the choice of electrodes and selection and adjustment of the current, the surgeon controls the effect of this energy on the tissues to achieve the desired results. The ideal frequency for radiosugery is 3.8 to 4.0 MHz.[2] This frequency allows for consistent primary healing of skin incisions. When low frequency energy is used to perform a skin incision, the risk of having delayed tissue healing increases due to the build up of lateral heat in the tissue.

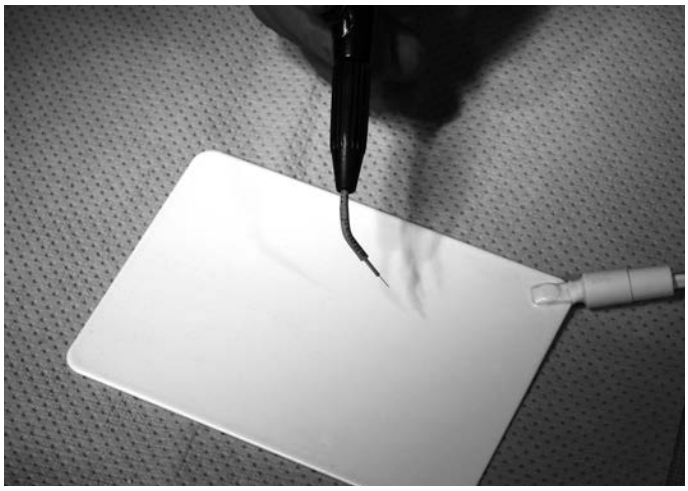


Figure 3-10. Active electrode (wire) and indifferent plate.

A 4.0 mhz radiosurgery incision, unlike a scalpel blade incision, requires no pressure. The results are technique related (these techniques will be discussed later). Most of the factors related to a successful outcome are controlled by the surgeon. The buildup of lateral heat adjacent to an incision should be avoided. The following formula expresses the factors involved in the development of lateral heat.

$$\text{Lateral heat} = \frac{\text{Electrode size x electrode contact time with tissue X intensity of power x waveform}}{\text{Frequency}}$$

The only factor not in the surgeon's control is the output frequency of the equipment used. As can be seen from the above formula, the lower the frequency, the more lateral heat produced.[3]

Radiosurgery can be used for making an incision, excising a mass, obtaining a biopsy or controlling hemorrhage. The majority

of veterinarians who use electrosurgical units use them primarily for hemorrhage control.

Electrocautery

The term electrocautery denotes the use of a hot iron to stop bleeding. The use of cautery to control hemorrhage dates back to the ancient Egyptains.[1] Low voltage current is used to heat an electrode. When this heated electrode is applied to tissue a thermal burn occurs. The destructive effect on tissue is heat coagulation and hemorrhage control. Using electrocautery causes collateral damage to the tissue, resulting in delayed healing, therefore, electrocautery is not the ideal method of hemorrhage control. When describing the use of a radiosurgery unit to stop hemorrhage, the correct term is electrocoagulation. Since there is no heat build-up at the electrode tip this is not cautery. The terms electrocautery and electrocoagulation have been incorrectly used synonymously in the literature.

Electrocoagulation

Electrocoagulation is the use of electrosurgical current to control hemorrhage. Vessels up to 2 mms in diameter can be coagulated with electrosurgery units. Vessels larger than 2 mms should be ligated. Utilizing proper technique by touching an electrode to a vessel in a relatively dry field or to a hemostat which has been applied to the vessel will form a coagulum at the end of a vessel. Excessive heating of the tissue until it snaps or pops should be avoided as this causes increased tissue necrosis. The use of electrocoagulation to control hemorrhage results in better visibility thus allowing the surgeon to be more efficient and reduce operative time. It also reduces the amount of foreign material left in a wound from ligatures. The majority of surgical procedures can benefit from the use of radiosurgical electrocoagulation. It has been said that a poor surgeon is not made better by the use of radiosurgery, only more efficient.

The application of an electrode to an actively bleeding vessel is only successful in controlling hemorrhage if the bleeding is temporarily arrested. This can be accomplished by either direct pressure to the vessel then applying the electrode or clamping a hemostat to the vessel then touching the electrode to the hemostat (Figure 3-11).

When touching the electrode directly to the vessel, a larger electrode, like a ball or blade, is more effective (Figure 3-12). Either of these techniques is effective if the field is relatively dry. This is known as monopolar electrocoagulation. An alternative is the use of biopolar forceps. (Figure 3-13). In using bipolar forceps, one tip acts as the active electrode and the other the indifferent plate. This gives precise pinpoint control of the electrocoagulation effect. It can be used anywhere in the body, but is very useful near delicate and sensitive tissue such as the spinal cord, eye, nerves, or large vessels. Bipolar forceps are very useful for surgery in avian and small exotic species.

Electroincision

An incision with high frequency radiosurgery may replace a scalpel incision in any tissue. This being said, it is imperative to

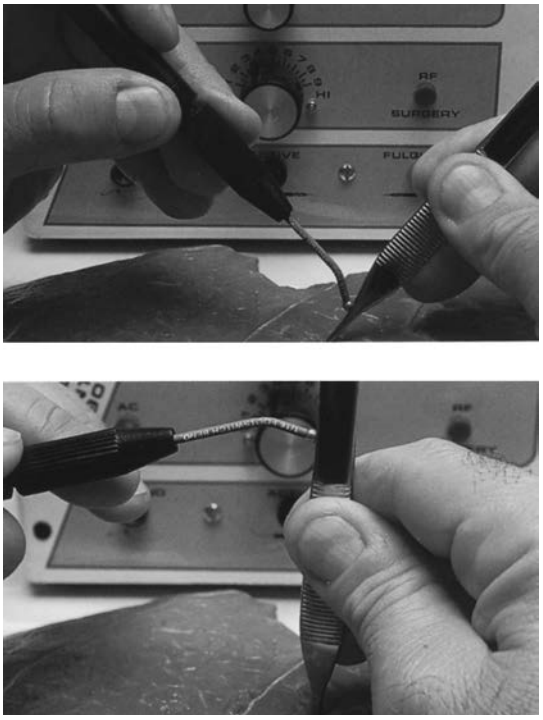


Figure 3-11. Thumb forceps on vessel with electrode applied to thumb forceps.

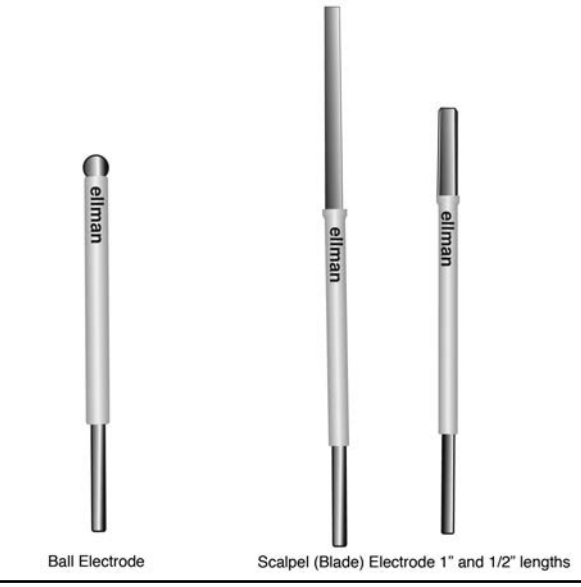


Figure 3-12. Ball electrode and blade electrode used for electrocogulation.

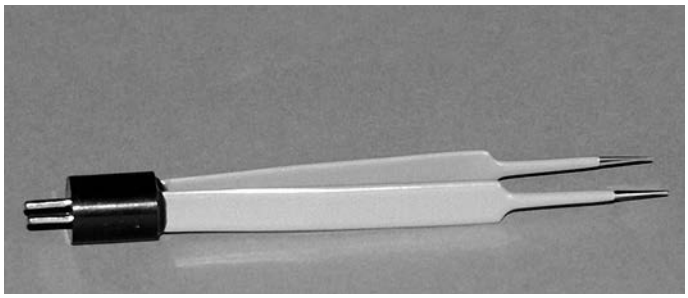


Figure 3-13. Bipolar forces.

use proper technique and a frequency of 3.8 to 4.0 MHz when making skin incisions. A frequency lower than 3.8 to 4.0 MHz risks the buildup of lateral heat in the tissue. This may result in delayed healing and/or dehiscence of the incision.[4]

Four wave forms or current types may be selected when using a high frequency radiosurgery unit. These wave forms are:

A. Fully filtered or continuous wave form is a continuous high frequency waveform that produces a smooth cut (Figure 3-14). It gives a 90% cut and a 10% coagulation effect. It generates the least amount of lateral heat. When this waveform is delivered by a fine wire electrode, it is comparable to a scalpel blade with excellent healing properties[4] (Figure 3-15). A biopsy obtained with this waveform creates a micro-smooth cut with no heat artifact at the edges. This allows an accurate reading by the pathologist on the biopsy specimen. The fully filtered/ continuous waveform should always be used when making skin incisions.

B. Fully rectified waveform is not as smooth as the continuous wave form; thus reducing the efficiency of the cut (Figure 3-16). It does, however, achieve a significant amount of hemostasis. When using a unit with 3.8 to 4.0 output frequency, minimal thermal damage can be expected. This setting produces a 50% cut and 50% coagulation effect. It is ideal for sub-cutaneous tissue incision, dissection or when working in vascular tissue such as the oral cavity.

C. Partially rectified waveform is an intermittent transmission of high frequency waves that increases lateral heat production (Figure 3-17). This is ideal for electrocagulation of small vessels up to 2 mms. It gives 90% coagulation with a 10% cut effect.

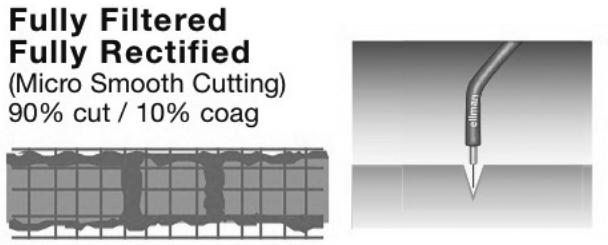


Figure 3-14. Oscilloscope showing fully filtered, 90% cut waveform. Notice the smooth, continuous nature of the waveform



Figure 3-15. Fine Wire electrode.

D. Fulguration is a spark-gap wave form (Figure 3-18). Fulguration rapidly dehydrates or desiccates tissue. This is ideal for areas where the surgeon wants intentional tissue destruction (such as perianal fistula, abscess or draining tracts). This may also be used with a ball electrode to control diffuse, weeping type bleeding. The tissue destruction is self-limiting by the insulating effect of tissue carbonization, therefore only a superficial layer of tissue is damaged.

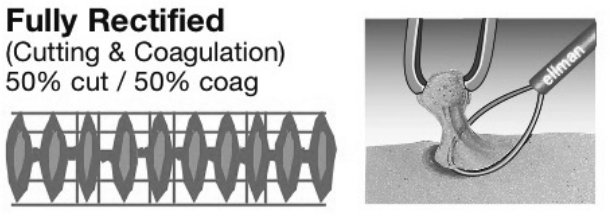


Figure 3-16. Fully recitifed, 50% cut, 50% coagulation waveform on oscilloscope.

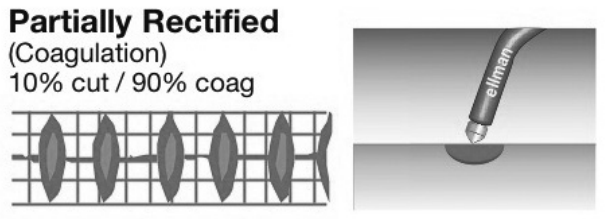


Figure 3-17. Partially recitifed, 90% coagulation/10% cut waveform on oscilloscope.



Figure 3-18. Fulguration waveform on oscilloscope.

Factors to Consider in Selecting Electrosurgery

Tissue selectability is determined by the degree fibers are cut compared with how much they shift as energy is applied.[4] This is important in making incisions around the eye or other mobile skin areas. When incising skin in these areas with a scalpel blade, significant pressure is required and the final incision may not have the desired appearance. This is avoided with radiosurgery in that it is a pressureless cut. Pre-planning the incision by drawing its margins with a skin marker may be helpful.

Multiple studies have been performed comparing high frequency radiosurgery, scalpel and carbon dioxide laser.[5] In one study in human oviduct excision, it was found that radiosurgery produced less lateral heat damage to the surrounding tissue than laser.[5] Although the learning curve with radiosurgery is not steep, poor technique using this method of tissue incision may result in delayed wound healing.

The following points should be considered when utilizing radiosurgery:

A. Use a high frequency (3.8 to 4.0 MHz) unit when making skin incisions. This helps prevent lateral heat damage.
B. Chose the smallest wire electrode available to reduce tissue resistance and heat build-up.
C. Use the full filtered or continuous wave form when making skin incisions.
D. Use the lowest power setting possible without producing drag of the electrode through the tissue. The electrode should pass through tissue effortlessly with minimal sparking or plume production. There should be minimal to no charring of the tissue.
E. Electrode contact time with the tissue is directly proportional to the lateral heat transferred to the tissue. The electrode should be moved rapidly through the tissue. If you have to return to the same area, allow an eight second lag period to occur. This allows heat build-up in the tissue to dissipate.
F. Avoid contact of the electrode with cartilage, bone or enamel. The most sensitive tissue is cartilage due to its high water content. Therefore, when performing a procedure like a feline onychectomy the distal portion of P2 should be avoided.

Precautions

Accidental burns to the patient are the most serious observed complication to electrosurgery.[4] Many electrosurgery units utilize a metal ground plate. If good contact between the ground plate and patient is not present, a burn can be created. The ground plate is designed to be the deferential preferred pathway for current. If a faulty connection exits then a burn can occur.[1] Electrolyte jelly and a large area of contact with the patient are recommended to lower skin resistance and to provide more intimate contact between the skin and the ground plate.[4]

A safer system is the use of an indifferent plate or an antenna plate found with the the Ellman Surgitron or Dual Frequency unit[a] (Figure 3-19). This is a plastic coated plate that requires no conductive gel and does not have to be in contact with the patient. This indifferent plate can be placed under the surgical drape but it should be in close vicinity to the surgical site. This makes the unit more efficient and allows the surgeon to use a lower power setting.

Explosions or fire are potential hazards if using flammable liquids like alcohol. If alcohol is used in the skin preparation for surgery, allow an adequate time for the alcohol to dry.

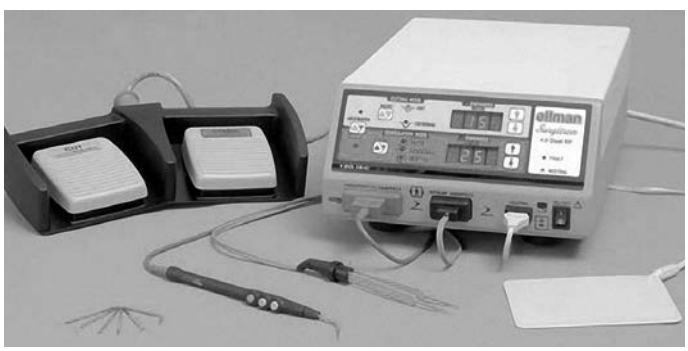


Figure 3-19. 4.0 MzH Dual Frequency radiosurgery unit with indifferent plate.

[a] Ellman International 3333 Royal Avenue, Oceanside, N.Y. 1 1572

In summary, this author has been performing radiosurgery with either an Ellman Surgitron (3.8 mhz) or the newer Dual Frequency (4.0 mhz) Unit for over 30 years. Excellent clinical results can be achieved when high frequency, low temperature radiofrequency devices are used and good radiosurgery principles are followed. The modern radiowave units are affordable, durable and become work horses in surgical practice. Some form of radiosurgery, either for making an incision, excision, dissection or hemostasis is used on each surgery performed.

References

1. Parker RB: Electrosurgery and Laser Surgery in Bojrab MJ, ed; Current Techniques in Small Animal Surgery. Philadelphia: Lea & Febiger, P. 41.

2. Fucci V, Elkins AD: Electrosurgery: Principles and Guidelines in Veterinary Medicine. Comp Contin Educ Pract Vet 1991; 13; 407.

3. Miller WM: Using High-Frequency Radiowave Technology in Veterinary Surgery. Vet Med Sept 2004; 796-802.

4. Olivar AC et al: Transmission Electron Microscopy: Evaluation of Damage in Human Oviducts Caused by Different Surgical Instrumetns, Ann Clin Lab Sci. 1999 29 (4): 281-285.

Lasers in Veterinary Medicine–An Introduction to Surgical Lasers

Kenneth E. Bartels

Introduction

The principles necessary for the concept of laser development were reported as early as the 19th century with Bohr's theory of optical resonance. In 1917, Einstein proposed the concept of stimulated light emission. Finally, in 1960, Theodore Maiman developed the first laser which was a pulsed ruby laser.[1] Since medical use began in the early 1960's, the laser has been considered by many to be "a tool in search of an application." Many of the earlier medical lasers were extremely cumbersome, expensive, and difficult to maintain. However, as biomedical laser technology merged with military and industrial efforts, innovations and improvements in devices and development of new concepts occurred and continue today. Developmental requirements to implement these new technologies include improvements in light delivery systems (robust articulated arms, small diameter wave-guides, and small-diameter optical fibers), compatible laser wavelengths, endoscopic visualization, and more portable, economical, user-friendly biomedical lasers.

Unique Properties of a Laser

Light bulbs and lasers both generate *light,* which is the common name for electromagnetic energy that we can see. The electromagnetic spectrum extends from the very short wavelengths (gamma radiation at 10^{-11} m) to radio waves (10^{-1}). Laser wavelengths fall between the infrared and ultraviolet wavelengths of electromagnetic radiation, which include the

invisible and visible light spectrum. The word **"LASER"** is an acronym that stands for **L**ight **A**mplification by the **S**timulated **E**mission of **R**adiation. An extensive discussion in laser physics is not consistent with this general overview. In simpler terms, as a bow stores energy and releases it to propel an arrow, a laser stores energy in atoms, concentrates it, and then releases it in powerful waves of light energy. This process is called **stimulated emission**. The resulting emission of photons resonates between mirrored ends of a laser resonating cavity. These bouncing photons further excite other atoms in a laser medium. Momentum builds until a highly concentrated beam of light passes through a partially transmissive mirror at one end of the laser resonating cavity.[2]

Like sound through air or water on a lake, light travels in waves. Moreover, the color of light is governed by its frequency and wavelength (distance of one peak to the next). Normal white light is incoherent and includes many wavelengths radiating in all directions. The peaks and valleys of the waves do not coincide. A prism illustrates this as it sorts a white light into individual colors of the rainbow. Laser light does differ from ordinary light much as music does from plain noise. Laser light, in comparison to ordinary light, is **coherent**. Each peak and valley of individual light waves align exactly. If laser light waves could be heard, their sound would resonate with the clarity of a single musical tone. In addition, laser light is of one wavelength (one color), or is **monochromatic**. Finally, laser light is **collimated**, or non-divergent, and directional. Parallel light waves move in unison, reinforcing each other as they travel through space forming a virtual tidal wave of laser energy.

Today's technology allows the manufacture of lasers that produce wavelengths of light extending from ultraviolet to far-infrared wavelengths. Devices range in size from miniaturized diode lasers capable of being passed through the eye of a needle to a free electron laser which covers the entire length of a large building. However, each laser is composed of the same basic components and functions according to the lasing medium stimulated to produce energy emission and light. Please refer to Figure 3-20: Laser Components.

Laser wavelength refers to the physical distance between crests of successive waves in the laser beam, indicated in units of length expressed as nanometers or microns. By definition, 1 nanometer (nm) = 10^{-9} meter, or one-billionth of a meter. One micron (μm) is equal to 10^{-6} meter or 1000 nm. More common medical lasers include ultraviolet (193 nm and 308 nm), visible (532 nm and 630 nm), near-infrared (805 nm, 980 nm, and 1064 nm), mid-infrared (2100 nm), and far-infrared (10,600 nm) wavelength systems. This means that many of the common laser wavelengths used for medical applications (diode/805-980 nm; carbon dioxide/10,600 nm) cannot be seen by the human eye and can be extremely dangerous as far as ocular hazards due to this fact.[2]

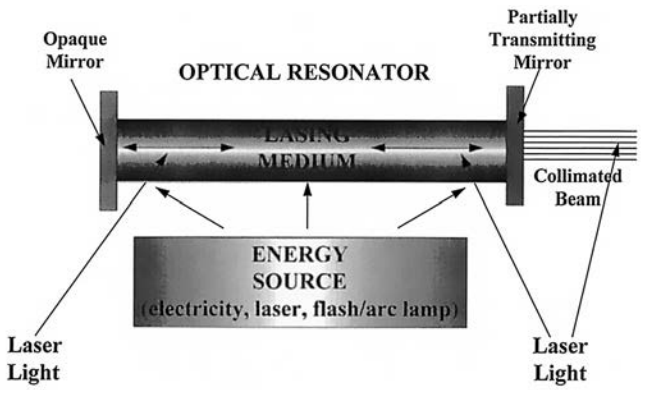


Figure 3-20. Components of a laser.

Types of Laser–Tissue Interaction and Laser Operational Modes

Laser radiation must be converted into another form of energy to produce a therapeutic effect. Laser-tissue interactions are categorized according to whether laser energy is converted into heat (photothermal), chemical energy (photochemical), or acoustic (photomechanical/photodisruptive) energy. Photothermal interactions occur when laser light is absorbed by tissue and converted into thermal energy, which results in a rise in tissue temperature. When far-infrared laser wavelengths (10,600 nm) are used, the water component of tissue plays a predominant role in the absorption of laser energy. Water is heated directly with laser energy, and other molecules may then be indirectly heated via heat conduction. Other tissue components (hemoglobin, melanin, proteins) may also absorb energy at specific mid-infrared wavelengths (805, 980, 1064 nm) and play an important role in the tissue heating process. The absorption of laser energy in any tissue is the sum of the absorptions of each of the tissue components coupled with the absorption coefficient of water. For example, the effective absorption depth or extinction coefficient of CO_2 carbon dioxide laser energy (10,600 nm), which is heavily absorbed by water, is approximately 0.030 mm, but is about 1 to 3 mm for the diode (805/980 nm) or neodymium yttrium aluminum garnet Nd:YAG (1064 nm) lasers, which are less heavily absorbed by water.[3]

Visible laser wavelengths (400 to 700 nm) are poorly absorbed by water and usually rely on blood or other endogenous tissue pigments or exogenous photoactive compounds to absorb laser light and convert them to heat or active photochemical components. Naturally occurring molecules that absorb visible wavelengths include hemoglobin and melanin. Protein molecules, DNA, and RNA absorb ultraviolet wavelengths strongly and usually play a dominant role in converting UV light energy into heat. Figure 3-21 illustrates the water absorption curve, which is an essential component in understanding the concept of laser-tissue interaction.[3]

Pulsed laser energy generated by the dye, holmium, or erbium lasers can be converted into acoustic (photomechanical) energy in the form of a shock wave or a high-pressure wave, which can physically disrupt the targeted structure when combined with a photothermal interaction (laser lithotripsy). Laser light can also be absorbed and converted into chemical energy (photochemical) that can break chemical bonds directly or excite molecules into a biochemically reactive state. Laser wavelength is the critical factor in this process. Short ultraviolet wavelengths (*e.g.,* 193 nm) are needed to maximize chemical bond-breaking processes while minimizing the photothermal process as observed with

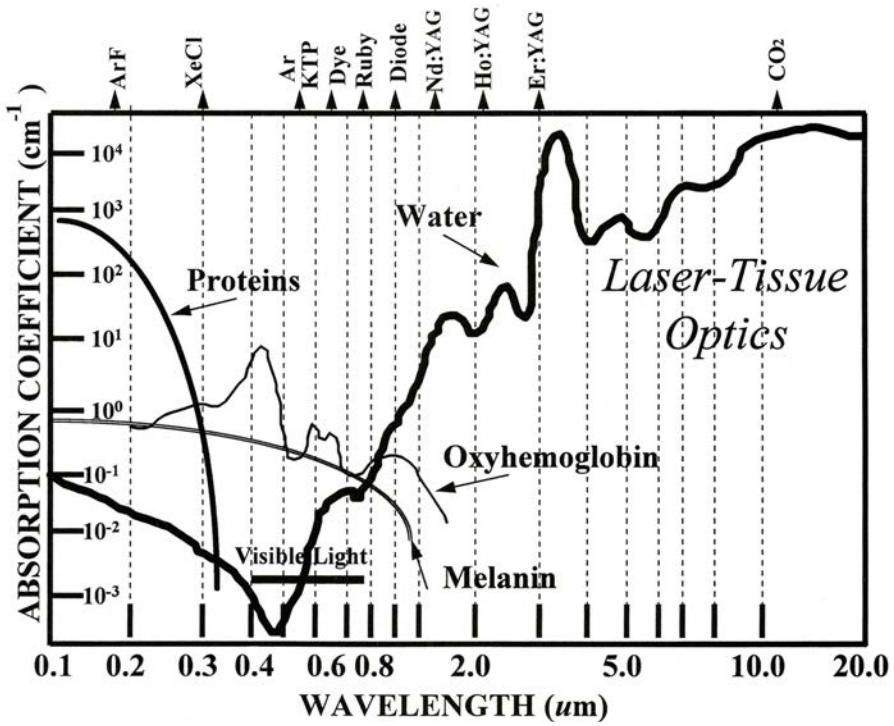


Figure 3-21. Laser tissue optics: water absorption curve. This graph illustrates the varying degrees of absorption of a specific wavelength (color) of light by water compared to absorption in oxyhemoglobin, melanin, and tissue proteins including amino acids, DNA, and RNA. Ar, argon; KTP, potassium titanyl phosphate; XeCl, xenon chloride; YAG, yttrium aluminum garnet.

excimer laser energy commonly used in human ophthalmologic procedures (LASIK).[2,3]

Specific visible wavelengths (630 to 730 nm) can also induce photobiochemical reactions. This type of reaction can be related to photodynamic laser interaction. In general, photodynamic interactions employ light-absorbing molecules (photosensitizers such as hematoporphyrin derivatives) to produce a biochemically reactive form of oxygen (singlet oxygen) in tissue when activated by light of a specific wavelength. Photodynamic interactions are considered to be a special type of photochemical interaction. The therapeutic process is called photodynamic therapy (PDT).[2,4,5]

Biostimulation is a process induced by lower power lasers (5 mW to 12 W/635 to 1064 nm) that may provide pain relief, stimulate wound healing, or alter other biological processes. The entire concept is considered controversial due partly to the fact that all of the physical, biochemical, and physiologic mechanisms are not well understood. Many of the reported results are mostly subjective in nature and are difficult to quantify. However, this therapeutic modality may gain favor as more objective studies are reported.[5,6]

Laser light focused on tissue may be reflected, absorbed, scattered throughout, or transmitted through the tissue. The application of laser energy is very dependent on wavelength, as mentioned previously. It is also essential to say the effect of a laser on tissue is dependent on power. Power is usually expressed in watts. When time is figured into the equation of energy delivery, the term "joule" is used, which is defined as a watt/second. Focal spot size (size of the incident beam of the laser light) results in the concentration of energy within an area, known as "power density" and expressed as watts/cm^2. The advantage of a small spot size is that laser energy is more concentrated and causes less collateral damage, where fewer cells will be affected and destroyed at the margins of an incision. When a rapid, deep incision is required, a small spot size is advantageous in that it will concentrate a high amount of energy into the tissue leading to rapid vaporization. A larger spot size will be less precise and enhance tissue coagulation rather than vaporization. The important term "fluency" takes into account the "time domain" or laser "on time" and is used to describe the total energy delivered to the target tissue in joules/cm^2. Total energy delivered to the tissue target is extremely important when considering a laser beam that is set for a pulsed mode delivery.[2,7]

Biomedical lasers can operate in continuous wave (CW) or pulse mode (single pulse, chopped or repeat, and super-pulse). Laser output in CW mode remains constant, whereas lasers operating in pulse mode deliver short bursts of energy. Manipulating pulse duration and pulse frequency allows the surgeon to adapt laser output to suit a particular clinical application, as well as ensure exquisite control. A laser operating in single pulse mode emits a single, user-defined pulse of energy lasting from a few milliseconds to several seconds. When operating in chopped or gated mode, a laser emits energy at selected pulse duration and frequency. The primary difference between chopped and CW emission is that chopped mode has periodic gaps of zero power in an otherwise CW emission.[2,7]

Superpulse is another temporal mode of CO_2 laser energy delivery that incorporates high peak power in short, high frequency pulses. Lasers operating in a super-pulse mode deliver extremely

high peak power, often 7-10 times higher than the CW maximum power, short pulse duration, and shorter off time than chopped mode. The maximum peak power in super-pulse mode is higher than the maximum CW power by a factor that depends on type of laser and its specific design. The main advantage of using a carbon dioxide laser in superpulse mode is the reduction of carbon formation or a decrease in char.[2,7]

In very simple terms, a volume of tissue cools between rapid pulses of targeted energy, a phenomenon known as thermal relaxation. When laser exposure (pulse duration) is less than thermal relaxation time for the targeted structures, maximal thermal confinement occurs and vaporization (ablation) occurs without damage to non-targeted collateral structures. This concept along with minimal carbon formation on the target tissue surface provides the laser surgeon with exquisite control and precise vaporization not seen with other means of tissue dissection. For surface ablation, use of computerized microprocessors, accessories for some high power carbon dioxide lasers, utilize superpulse laser energy delivery coupled with optomechanical hand-pieces to decrease the "dwell time" a laser beam interacts with the tissue surface. These scanning devices decrease surface carbonization and permit rapid and precise laser vaporization.[3,7,8]

Pulsed laser energy can be converted into photomechanical (photo acoustic) or photothermal energy, depending upon pulse duration, peak power density, and pulse frequency. Photomechanical effects occur when very short (nanosecond – 10^{-9} sec.), high-power laser energy pulses are directed at tissue through a small-diameter optical fiber. The energy plasma-induced shock waves generated at the tip of the optical fiber mechanically disrupts the targeted tissue or calculi. Photomechanical interactions are important in many specialized laser applications, including lithotripsy and ophthalmologic surgery.[9,10]

Photodisruption is a relatively new term used to designate tissue interaction related to effects of ultrafast (femtosecond – 10^{-15} sec.) laser pulses. Laser light is tightly focused to tremendous power density levels (10^{12} W/cm^2) but pulse energies of only 1 uJ. The photomechanical and photothermal side effects are negligible. Tissue is ionized and optically broken down by a process called multiphoton absorption and offers the possibilities to perform very precise surgical operations at the cellular and sub-cellular levels.[9]

The tissue response to the application of photothermal laser energy is a very dynamic process. Changes in the local microcirculation influence the tissue reaction to additional laser energy. When the beam interacts with tissue, the photothermal effect produces a characteristic lesion in living tissue. Initially, hyperthermia and desiccation of tissue and cells occurs and then are followed by coagulation and vaporization. At the impact site, a crater may be formed when tissue has been vaporized from the region. Immediately surrounding the cavity is an area of hyperthermia, cellular coagulation, and eventually, necrosis. This zone is created by the diffusion of laser energy from the point of laser impact. Immediately adjacent to this zone is an area of cellular edema without evidence of alteration in the collagen stroma. The milder thermal injury to the tissue in this region may resolve within 48-72 hours. These phenomena are illustrated in figure 3-22. The generation of smoke, hemorrhage, and char can interfere with the incident laser beam by resulting in scatter, reflection, and absorption of the laser energy and may result in uncontrolled effects on the target tissue or adjacent structures.[3,7,10]

Precise control of hemorrhage and inflammation by photothermal sealing of blood vessels, lymphatic vessels, and incised nerve endings is perceived by most to be distinct advantages of laser surgery. These benefits relate directly to laser tissue interaction depending on wavelength, power, and fluency. However, by inhibiting the early stages of the inflammatory process (lag phase) due to cellular constituents and platelets not being immediately available at the wound site, the healing of laser incisions is minimally delayed. Laser incisions, discounting collateral photothermal effects due to poor surgical technique, gain strength as quickly as incisions made by a steel scalpel and incisional tensile strengths are comparable within 10 to 14 days.[11,12]

Laser vaporization is the process of removing solid tissue by converting it into a gaseous vapor or plume. This is usually in the form of steam or smoke, but laser plume may also contain noxious substances. Therefore, the use of smoke evacuation during laser surgery is deemed essential. Safety issues will be discussed more specifically in a following section. The term "vaporization" is used as a synonym for tissue ablation.

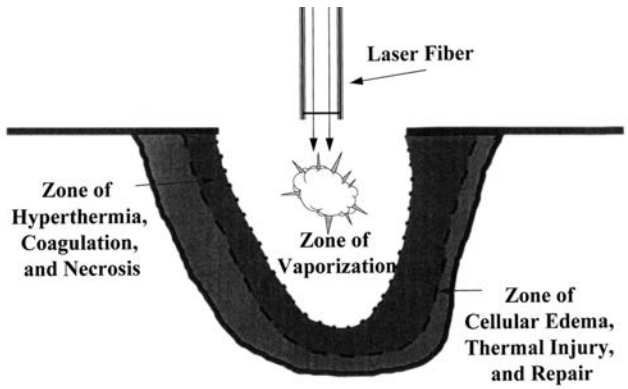


Figure 3-22. Laser tissue interaction. The generalized tissue response to the application of laser energy results in zones of vaporization, necrosis, and reversible thermal injury.

Types of Commonly used Medical Lasers

The development and use of biomedical lasers is considered to be a significant step ahead of mechanical instruments, but falls short of what is needed to be considered as the optimal "light knife" for every surgical situation. Considering differences in laser-tissue interaction, it's still very uncertain whether an "ideal" laser wavelength will ever exist. Discounting future use of free-electron lasers with multi-wavelength variability, acceptance of biomedical use of lasers with a fixed-wavelength has depended more on cost, capability for fiberoptic delivery, portability, flexibility, ease of use, and dependability.[2,4,13]

In medicine today, many different types of biomedical lasers are in use. Each instrument is usually acquired for a specific purpose

in mind, such as dermatologic or endoscopic applications. Overall, the use of laser energy can be an extremely precise and controlled method for tissue removal or cellular destruction. Medical lasers are expensive and require a dedication to proper use and objective evaluation. Lasers in common use today are the carbon dioxide (CO_2), neodymium yttrium aluminum garnet (Nd: YAG), diode, holmium: YAG (Ho: YAG), and dye lasers. The following general descriptions are meant to be used as an overall guide to medical lasers. In no way should it be considered complete. Changes in laser types, wavelength preference, and delivery devices are made on a frequent basis, since they are closely aligned with changes in today's technologic advancements in computer hardware and software.

Carbon Dioxide Laser (CO_2-10,600 nm)

The carbon dioxide laser was one of the first medical lasers used for tissue ablation. At 10,600 nm, the wavelength is ideal for cutting and vaporization because it is highly absorbed by water. It can cut tissue cleanly when the beam is focused onto tissue and can debulk tissue by photovaporization when defocused. Because of the high absorption the 10,600 nm wavelength in water, CO_2 laser energy transmission requires energy delivery through a series of mirrors in an articulated arm or through a semi-rigid waveguide, which makes it awkward for use in an open abdomen or in other localized and confined areas. However, thermal injury from a given amount of energy is relatively superficial (50 to 100 μm in depth).[2] The net surgical result is expressed as "What you see is what you get!" when using the carbon dioxide laser. The learning curve for using a carbon dioxide laser seems to be shorter than with other surgical laser wavelengths (805, 980, 1064 nm) which are optically scattered more in tissue. However, since CO_2 laser delivery systems (articulated arms, hollow waveguides) must be used in a non-contact mode, the tactile appreciation for tissue is lost. This is a disadvantage which can be overcome quite easily with practice. Pertinent engineering specifications for carbon dioxide lasers include the "excitation" mechanism. That is, how the CO_2 gas mixture in the resonating cavity is stimulated to produce 10,600 nm light. Direct current (DC) devices are usually larger machines capable of emitting higher power (> 20 W). Most of these devices use a water cooling mechanism that is either closed or can be connected to a circulating cooling water system. Radiofrequency (RF) excited CO_2 lasers are usually smaller, more robust devices that are either cooled by convection or by an integral cooling fan. RF excited devices usually emit lower power laser energy ($\leq$ 20 W).[10,14]

Nd: YAG Laser (Neodymium Yttrium Aluminum Garnet-1064 nm)

The Nd: YAG or "YAG" laser differs from the CO_2 laser because the wavelength allows transmittance though tissue in addition to surface absorption. High powers up to 100 watts can be delivered through small-core optical fibers that can easily be inserted through the accessory channels of standard GI endoscopes. Since the Nd:YAG laser has less specific absorption by water and hemoglobin than the carbon dioxide laser, the depth of thermal injury can exceed 3 mm in most tissues, which can be useful for coagulation of large volumes of tissue. Fairly rapid tissue vaporization in non-contact mode is possible with a bare non-contact fiber, but collateral thermal injury may be substantial. Power levels approaching at least 50 watts are usually needed for these soft tissue applications.[2]

Continuous wave (CW) Nd: YAG and diode lasers can be used with "hot-tip" delivery systems to perform vaporization and cutting of soft tissue in a contact mode with surgical precision, little collateral thermal injury, and good hemostasis. Hot-tip fibers include sculpted quartz fibers, contact-tipped sapphire fibers, metal-capped fibers, temperature controlled bare fibers, and dual effect fibers. In principle, contact use of fibers for mechanical coaptation of tissue while it is being heated can be advantageous for hemostasis and controlled excision. Use of contact tips for endoscopic application is widely accepted, but some tips are too large to insert through flexible endoscopes.[15,16,17]

Diode Laser (635, 805, 980 nm)

Advancement of semiconductor diode laser development has progressed tremendously in concert with other aspects of medicine described previously. Engineering and commercial specifications have allowed development of devices with wavelengths varying from approximately 635 to 980 nm. Newer technologies may actually allow evolution of diode lasers capable of emitting wavelengths in the mid-infrared range (1.9 to 2.1 μm).[2]

Therapeutic products that employ semiconductor diode lasers were first approved for surgical use in this country in 1989. Diode lasers (1 to 4 watts) are also used for photocoagulation of retinal and other ocular tissues, and have been employed for ophthalmologic applications since approximately 1984.[18] The compact size and high efficiency offer significant ergonomic and economic advantages. High power semiconductor diode lasers appropriate for other surgical applications have been recently introduced for a variety of uses. These lasers currently provide up to 25 to 100 watts at 805 nm or 980 nm, wavelengths that can penetrate deeply into most types of soft tissue, and produce tissue interactions comparable to the Nd: YAG laser (1064 nm).[15] The theoretical difference between use of a diode laser at 805 nm and one emitting a 980 nm wavelength is that a 980 nm device is absorbed to a greater extent by water than is the 805 nm laser, but in actual clinical practice this difference is negligible. Diode lasers can be used with bare-fiber delivery accessories in non-contact mode for deep coagulation, or with hot-tip fibers for precise cutting or vaporization in contact mode. As mentioned, diode lasers can be used for many of the same applications as 1064 nm continuous wave Nd: YAG lasers. However, surgical diode lasers offer considerable advantages compared to Nd: YAG lasers. They are smaller, lighter, require less maintenance, are extremely user-friendly, and can be more economical. Some medical device manufacturers predict prices for diode lasers will eventually drop to the point where they may be competitive with high-end electrosurgical equipment.

Additional applications for diode laser energy have been for chromophore enhanced tissue ablation or coagulation, tissue fusion or laser welding, and photodynamic therapy. The use of sutureless tissue repair employing laser energy has emerged

over the last decade. Tissue welding or fusion has the potential to be one of the most important technical developments in surgery. Used in conjunction with laparoscopic as well as open procedures, laser energy used with biological glue or "solder" reinforcement can provide a higher leakage pressure for vascular and alimentary tract structures than sutures alone. Preliminary investigations involving selective fusion of nerves, urethral tissue, skin, tracheal mucosa, and even bone fragments have also shown promise. Despite a decade of laboratory success in which the superiority of laser tissue welding has been demonstrated, there is still not much clinical use of this technology.[13]

Diode laser (805 nm) induced photothermolysis of tissue selectively stained with indocyanine green (ICG) has shown promise for selective coagulation/vaporization of tumors and contaminated wounds.[4] Diode laser wavelengths of 805 nm have also been reported as being used for tissue welding investigations because applications have been centered around the peak absorption spectrum of indocyanine green (780-820 nm), the selective chromophore used in fibrinogen solder. Laser energy required for tissue fusion is significantly lower (300 mW to 9.6 W/ cm^2) than for incisional/ablative procedures, since minimal thermal changes are required to produce noncovalent bonding between denatured collagen strands and produce the weld.[9] The small, convenient size coupled with reliability and user friendliness has also focused extensive diode laser development for applications in photodynamic therapy, primarily at 635 nm wavelength.[19]

Ho: YAG Laser (Holmium Yttrium Aluminum Garnet-2100 nm)

Clinical holmium lasers have appeared in recent years for arthroscopic surgery, general surgery, laser angioplasty, and thermal sclerostomy. Additional applications have been implemented for laser diskectomy, removal of sessile polyps in the gastrointestinal tract, and otorhinolaryngeal procedures. The main attraction of the holmium laser is its ability to cut and vaporize soft tissue like a carbon dioxide laser, with the added advantage that holmium energy can be delivered through flexible, low OH, quartz optical fibers. Good surgical precision and control can be obtained with a bare optical fiber. Unlike visible wavelength lasers, and again similar to the carbon dioxide laser, photothermal interactions with the holmium laser do not rely on hemoglobin or other pigments for efficient heating of tissue. The water component of tissue is responsible for absorbing holmium laser energy (2100 nm) and converting it to heat. The depth of absorption is quite shallow at approximately 0.3 mm. When cutting or vaporizing tissue, actual zones of thermal injury vary from 0.1 to 1 mm, depending on exposure parameters and the type of tissue. These small thermal necrosis zones provide better surgical precision and adequate hemostasis.[2] Current holmium instruments are flashlamp-pumped systems. The active laser medium consists of a chromium-sensitized yttrium aluminum garnet host crystal doped with holmium and thulium ions. This active medium is referred to as Thulium (Tm), Holmium (Ho), Chromium (Cr): YAG or THC: YAG, and is common to all holmium laser medical devices. Unlike the carbon dioxide laser, higher power holmium lasers cannot operate in a continuous wave mode at room temperature. The relatively low pulse rates (10 to 20 Hz) available from most holmium lasers may be considered as a disadvantage since cutting may be slow or result in jagged tissue edges during incisional applications. In addition, at higher pulse energies ($\geq$ 1 Joule), considerable amounts of acoustical or mechanical energy are generated in tissue. An audible acoustical "pop" may be generated and actually heard during laser application. However, acoustical energy may be considered an advantage when using holmium energy for photodisruptive procedures such as lithotripsy of gallstones or urologic calculi.[20,21,22]

Dye Laser (635 to 700 nm)

Pulsed and continuous wave dye lasers employ an active laser medium that consists of an organic dye dissolved in an appropriate solvent. For the dye laser to work, the dye solution must be re-circulated at high velocity through the laser resonator. Dye lasers are useful for medical applications because they can generate high output powers and pulse energy at wavelengths throughout the visible wavelength spectrum (400 to 700 nm). They are usually pumped by argon lasers, flashlamps, or a frequency-doubled YAG laser. Dye lasers have been used for lithotripsy of biliary and urologic calculi (504 nm-pulsed), activating photosensitizers for photodynamic therapy (635 to 720 nm CW), ophthalmologic operations (805 nm pulsed or CW), and dermatologic applications (577 to 585 nm pulsed) including treatment of birthmarks and removal of tattoos.[2,5,13,20,23]

Laser Delivery Systems

A delivery system refers to the optical hardware needed to transfer energy from the laser to the treatment site. Devices for guiding laser beams to the patient include articulated arms with internal mirrors, hollow waveguides, and optical fibers. Articulated arms and hollow waveguides are used with laser wavelengths (2800 nm to 10,600 nm) that cannot be transmitted through conventional fiber optics due to their light absorption characteristics. Laser energy delivery through an articulated arm has inherent disadvantages due to the size of the arm, durability, and its inability to be used for minimally invasive (endoscopic) procedures. Using carbon dioxide lasers with an articulated arm allows delivery of a precise collimated (Gaussian) focused beam to the incision site. Using a semi-rigid hollow wave-guide provides a non-collimated beam that is multi-model (top-hat) in nature, but still very precise since the laser energy is concentrated and directed through small, aperture delivery tips (0.2 to 1.4 mm diameter) that can be used for precise incisional and ablative applications. Hollow waveguides are advantageous in permitting greater flexibility for performing laser procedures but are not as useful as conventional fiber optic delivery through quartz fibers. Future advances in laser and optical waveguide technologies will include smaller diameter waveguides that can deliver collimated laser energy and be used through endoscopic portals for minimally invasive procedures.[2,16]

The availability of functional and inexpensive optical fibers for laser delivery has played a crucial part in the acceptance of lasers for medical applications. The fibers used in laser medical delivery are made of quartz glass and have diameters ranging from 0.1 to 1 mm. Laser energy is transmitted and reflected along the bends and curves of the fiber until it reaches the tip where it exits.

The ability to transmit visible and near-infrared laser energy, small diameter and flexibility, lower cost, and ruggedness makes quartz optical fibers essential for endoscopic and other minimally invasive applications. Configurations of fiber tips (e.g., flat or cleaved, sculpted orb, chisel) and their ability to transmit energy is a physical science in its own right, but delivery parameters are primarily based on two factors, contact mode of delivery or non-contact mode of delivery. In non-contact mode, a free beam of focused laser energy is delivered to the tissue target surface. The power density and fluency of the laser beam determine the degree of photothermal interaction. Non-contact mode usually increases the surface area covered by laser energy which can decrease the power density and consequently decreases vaporization efficiency unless laser power output is increased. In contact mode, a laser optical fiber tip is brought into direct contact with the tissue target and the resulting photothermal interaction causes carbonization of the tip, which then becomes a focused "hot knife." The chemical structure of certain optical fibers permits transmission of mid-infrared laser energy (Ho: YAG at 2100 nm through a low-OH polyamide fiber) and allows minimally invasive laser surgery through small diameter endoscopes and myelographic needles.[16,24,25]

Laser Safety

Even though sci-fi movies and television portray lasers as "death rays" and "phaser disintegrators," the instrument is probably safer to use than a scalpel or scissors in the hands of a trained operator. However, lasers use by untrained individuals can be dangerous for both the operating team and the patient. Safety standards for medical laser applications have been issued that consider potential hazards and their control measures. The current consensus standard in the United States is through the American National Standards Institute's (ANSI Z136.3) document entitled *Safe Use of Lasers in Health Care* (Available from Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826). Application of surgical lasers in veterinary medicine should adhere to these regulations and guidelines to ensure operator and patient safety. Laser hazards depend on the laser wavelength and power, the environment, and the personnel involved with the laser operation. The laser hazard is defined by a hazard classification (1 to 4). Surgical lasers are almost all classified as Class 4 laser products because they may represent a significant fire or skin hazard and also produce hazardous diffuse reflections. Hazardous diffuse reflections are of concern because the probability of damaging retinal exposure is extreme without proper eye protection.[26,27]

With the biomedical application of lasers, the following safety concerns must be considered:

1. Inhalation of Smoke or Laser Plume

Laser surgery usually creates more smoke than electrosurgical procedures. Reports have mentioned that smoke products from lasers are really no different than those created by electrosurgery, although the quantity is greater. Some studies have actually isolated viable tumors cells from smoke evacuation tubes, so the concept of uncontrolled viral or bacterial vaporization must also be taken into account. Since even sterile smoke can be an irritant, all products of combustion as a result of laser vaporization must be evacuated with a dedicated smoke evacuator. The filters and tubes on these devices require maintenance and periodic replacement, increasing the cost of laser surgical procedures.

2. Laser Induced Combustion

Laser beams can cause fires. The obvious way to prevent laser induced combustion is to make certain the beam is always directed towards the surgery site. In addition, the use of moistened sponges surrounding the surgical site decreases the chance for accidental ignition of drapes, etc., especially when using wavelengths highly absorbed by water, such as the carbon dioxide laser. Polyvinyl chloride endotracheal tubes are especially prone to ignition. An endotracheal tube which is carrying oxygen will literally become an airway blowtorch instantaneously after impact of the laser beam. In airway and oral surgery, the endotracheal tube should be of a type that includes specific laser-safe tubes and less desirably, endotracheal tubes made of red-rubber protected by an application of reflective metal tape.

3. Eye and Skin Burns

Laser energy burns to the eyes or skin on the patient, operator, and assistants are of extreme importance for consideration. Safety glasses or goggles, **specified for each laser wavelength,** must be worn for every laser procedure. Saline moistened surgical sponges or even laser safety eyewear should be considered for protecting patient's eyes. In addition, window barriers, laser safety warning lights, ebonized or a dulled, satin-type finish on surgical instruments to reduce reflection, and laser warning signs on doors are important safety aspects that should not be ignored. The potential for accidental burns and fires usually is related to accidental depression of the footswitch for the laser. All machines are equipped with a standby mode of operation in which the machine is running but laser energy cannot be activated. A major responsibility of the laser nurse or technician is to evaluate the progress of the laser operation and have the machine switched to standby when laser energy is not required. The phrase, "laser on," spoken by the operating laser surgeon and required before the laser is activated, becomes as important as safety glasses, smoke evacuators, or the engineering of the machine itself in fostering safety. A team approach with the surgical laser technician, who basically is in charge of the laser, and the surgeon is essential.

Ignition of methane from the rectum or rumen can also be an exciting occurrence; the gas should first be removed by suction or blocked by tamponade. Vaporization of iodine skin preparations into irritating fumes, ignition of alcohol, or ignition of any pure oxygen environment mentioned previously are also important concerns.

4. Miscellaneous Problems

Other hazards include electrical injury from the high voltage power supply. Laser operation with newer devices is easy since they are extremely user-friendly and reliable, BUT machine maintenance including the purchase of maintenance contracts

may be required to maximize use and minimize safety concerns for mechanical, electrical, and optical failures. This aspect of medical laser usage must be recognized because maintenance contracts and laser repair can both be quite costly.

The use of Biomedical Lasers in Veterinary Medicine

Early reports concerning the use of lasers for medical applications involved animals, either as experimental models or as clinical veterinary patients. In 1968, the removal of a vocal-cord nodule in a dog demonstrated one of the first practical clinical applications of the carbon dioxide laser as a precision surgical instrument.[28] Since that time, use of biomedical lasers has expanded tremendously in both small and large animal surgery. However, to some veterinarians, the laser is still a tool in search of an application. The rising popularity of the surgical laser has been influenced most often by their use in private practice and stems from a blend of its demonstrated precision and control, improved hemostasis, fewer signs of postoperative pain, increased client satisfaction, and affordability. An objective and practical approach to laser surgical procedures in veterinary medicine is essential if the total beneficial potential is to be realized. "Zap and vaporize" techniques coupled with a "burn and learn" philosophy can do potential harm to patient and operator and outweigh any beneficial effect. These concepts have no place in the objective use of lasers in medicine. A concerned effort must be made to evaluate the use of a laser for its potential patient benefit, rather than portraying it as a miracle device of the 21st century that is advertised on an illuminated bill board in front of a hospital. Although the use of biomedical lasers has created an entirely new definition for performing surgery, a surgeon's knowledge of pathophysiology and technical expertise must be the primary factors to determine whether a laser should be used for a particular surgical procedure in lieu of more conventional approaches.[4]

Veterinary Clinical Applications– Small Animal

Many of the early reports involving the use of biomedical lasers concerned endoscopic use of fiber-delivered devices (Nd: YAG laser at 1064 nm) for treatment of laryngeal conditions and pathology of the upper respiratory system in the horse.[17,29,30] Since that time, however, a number of investigators and many practitioners have used carbon dioxide, diode, and Nd: YAG lasers in the treatment of various surgical conditions in small animals.[4,5,18,31-46] Most recently, use of the carbon dioxide laser for both excisional and ablative procedures has become common in many small animal practices. Well informed clients have often requested "laser surgery" due to extensive efforts towards marketing the technology by both veterinarians and laser manufacturers. Often, the procedure of choice for laser surgery has been a feline laser onychectomy.[32] Results that include minimal intra-operative hemorrhage and decreased perception of post-operative pain have been the primary advantages. In addition, elective procedures including laser ovariohysterectomy and orchidectomy have also been promoted for similar reasons. Other applications in general surgery have included conventional soft tissue procedures where precise dissection and control of hemorrhage is important. These procedures have included liver biopsy, resection of hepatic lobes, splenic biopsy, prostatic dissection and ablation, partial nephrectomies and nephrotomies, and excision/resection of a variety of intra abdominal, intrathoracic, cutaneous, and mammary neoplasms.[31] Reports have reviewed clinical uses of laser energy for ablation/palliation of a brain tumor (Nd:YAG), ablation of neoplasms (CO_2, Nd:YAG), and treatment of eosinophilic granulomas (CO_2, Nd:YAG), perianal fistulas (Nd:YAG, CO_2), or acral lick dermatitis (Nd:YAG, CO_2).[33,36,38,42,43,46] Upper airway surgery, especially excision of an elongated soft palate in the dog, is most easily performed using laser energy with minimal post-operative complications.[41]

With advantages of lower morbidity time for some conditions, less perceived signs of pain, and potential treatment regimes for conditions not amenable to conventional surgical/medical procedures, employment of biomedical lasers has not only found use in the clinical small animal setting, but also in the realm of exotic animal and avian practice, where even minimal blood loss can be significant in smaller patients. In addition, clinical use of the holmium:YAG laser for percutaneous prophylactic ablation of intervertebral discs and lithotripsy of urologic calculi in dogs have been reported and show tremendous potential.[24,25,47-49] The use of biomedical lasers for veterinary ophthalmologic applications has been firmly established, although use has not become as common as it is in human medicine. The Q-switched or continuous wave ophthalmic Nd:YAG, argon, and diode lasers have been used as funduscopic photocoagulators in retinopathies, for treatment of lens-induced pupillary opacification, and for transcleral laser cyclodestruction of the ciliary body for glaucoma therapy in dogs. The carbon dioxide laser has also been used for soft tissue periocular and scleral surgical procedures. As experience and interest increases, and lasers become more available to veterinary ophthalmologists, clinical applications will increase as treatment protocols are initiated and proven useful.[18,50]

Photodynamic therapy (PDT) has been used for clinical applications in veterinary medicine by several investigators. A number of initiatives have been reported using PDT for treatment of spontaneously occurring neoplasms in dogs and cats. This exciting treatment modality for selective destruction of neoplasms, employing interaction of a photosensitizer with light in the presence of oxygen, will continue to play a more dominant role in clinical veterinary medicine as protocols are established and new photosensitizing drugs are manufactured and approved for use.[19,51]

Use of biomedical lasers in veterinary orthopedics has been more limited due to a lack of laser devices with appropriate wavelengths for incisional and ablative procedures in bone.[52-54] The horse has been used as a model for biostimulation of articular cartilage and other research applications using the Ho: YAG laser.[21] Practical use of lasers for ablation of bone has not been effective, although laser ablation (CO_2) of methylmethacrylate during removal/revision of total hip prosthesis is possible.[45]

General Surgical Technique in Laser Surgery

The use of surgical lasers can be broadly classified as incisional or ablative surgery. For incisional surgery, a small spot size (0.2

to 0.4 mm) which delivers a high power density is ideal. The main reason surgical lasers are used for incisional surgery is because of the excellent degree of hemostasis obtained. At the tissue interface, blood vessels less than 0.5 mm in diameter can be coagulated and sealed so that use of the surgical laser as a light scalpel is relatively hemostatic in most capillary beds and in the transection of small venules and veins. Lymphatics are also sealed so postoperative edema may be minimized. Subjectively, there seems to be less pain associated with a laser incision and dissection. This observation could be due to the fact that smaller nerves are sealed or even spared at some laser wavelengths.[55] Microorganisms are also destroyed in the process of photothermal ablation, so tissues may be "disinfected" (bacterial numbers reduced by reduction of numbers due to direct vaporization) during laser tissue-interaction.[57,58]

The depth of the incision made by a surgical laser is both a function of the irradiance (power density) and the speed with which the incision is made. With practice, the surgeon can use the laser beam as precisely as the scalpel, with the added advantage of less hemorrhage, and less pain, although objective, published results in veterinary medicine are few.[59,60] Laser incisions tend to be made more slowly than those made with a scalpel, at least initially. The improved hemostasis and incisional control generally makes up for this delay, and in some cases involving highly vascular tissue, a laser incision may actually make it possible to perform laser surgery faster than conventional surgery. Care must be taken not to create excessive collateral photothermal injury (char formation) during the process. Providing tissue counter tension during the incisional procedure aids not only tissue separation, as it does with a scalpel, but also decreases the amount of char formation. A defocused laser beam (holding the handpiece or cleaved optical fiber an appropriate distance from the tissue surface) can be used in some cases to stop bleeding from larger blood vessels that were not sealed by the focused or contact-mode incisional laser beam. Tissue excised with a surgical laser can still be histopathologically evaluated for tumor margins without much difficulty, if proper technique is used that minimizes collateral photothermal damage and the pathologist is informed that a laser was used for the biopsy.[40] As mentioned earlier, healing of laser incisions is minimally delayed due to photothermal collateral tissue interaction.[11,12,61]

Tissue ablation or vaporization is most easily accomplished using a defocused or non-contact, free-beam mode of energy delivery. Defocused beam delivery through an articulated arm or a hollow waveguide can be utilized to ablate tissue efficiently, if carbonization (char formation) is minimized. To accomplish this, optical and mechanical scanners (described previously) are ideal accessories for the carbon dioxide laser. In addition, as char formation occurs, the surgeon should be diligent to remove any buildup of carbonized tissue by using saline moistened gauze sponges to mechanically debride the ablated tissue surface.

Tissue ablation can also be performed using fiberoptic delivery systems in non-contact mode with compatible laser wavelengths (diode – 808/980 nm; Nd:YAG to 1064 nm; Ho:YAG – 2100 nm). Laser power and energy delivery levels must be substantially higher (> 20 W < 100 W) for non-contact, free-beam tissue ablation using fiber optic delivery. It must also be understood that a laser fiber used for contact mode delivery for incisional purposes cannot usually be immediately changed from contact mode to non-contact mode free-beam energy delivery. Since contact mode incisional surgery requires the fiberoptic tip to be carbonized so it can absorb adequate energy to incise tissue, higher energy levels required for non-contact ablation will usually melt the fiberoptic tip. Using a freshly cleaved, a surgeon can go from non-contact, free-beam energy delivery to contact delivery, but cannot go from contact laser surgery to non-contact delivery without re-cleaving the fiber. In the case of sculptured fiber tips (tapered, orb) meant to be used only in contact mode, high power free-beam delivery should be avoided to prevent premature fiber degradation. However, once a sculpted fiber tip is degraded, the fiber can be cleaved and reused in that configuration for both free-beam and contact delivery.

Future Innovations

The use of lasers in medicine is an exciting treatment modality that will continue to produce innovative and new methods for managing diseased tissue. Research focused on basic laser-tissue interaction and selective tissue destruction will become increasingly important. The use of photodynamic therapy (PDT) for treatment of malignant tumors will become an effective part of the veterinary oncologist's armamentarium as more efficacious photosensitizers become available and expanded use of lower cost lasers or even non-laser light sources occurs. Photothermolysis using appropriate chromophores for selective tissue destruction and sterilization/disinfection is currently proving to be efficacious in both the clinical and laboratory settings. Minimally invasive urologic techniques for ablation of bladder, urethral, and prostatic pathologic conditions in small animals will become more common as technologically enhanced and smaller endoscopes are developed, as delivery systems are improved, and as new laser wavelengths are investigated. Laser lithotripsy is now possible using both visible and infrared wavelengths. This technology is currently being used in academic and specialty hospital settings permitting minimally invasive lithotripsy of urinary tract calculi. Tissue fusion/welding of blood vessels, alimentary tract, ureter or urethra, skin, and even bone will become clinically available in the near future. Application of lasers for micromanipulation of gametes and laser energy for improving fertilization and hatching rates during *in vitro* fertilization in domestic animals are close to becoming clinical realities. The use of lasers for soft tissue dental procedures is already feasible and, as investigations continue, use of laser energy for hard tissue dental procedures will be possible.

Low level laser therapy (LLLT), or biostimulation, is now being used commonly in a variety of therapeutic settings in veterinary medicine. The efficacious use of this modality to decrease inflammation and pain, as well as enhance wound healing will continue to be investigated. Well controlled studies are underway using reliable LLLT devices. Positive objective results will provide additional therapeutic option for the practitioner and rehabilitation specialists.[63]

Development of user-friendly, durable, portable, less expensive

laser systems is definitely on the near horizon. Semiconductor laser development from ultraviolet to far infrared wavelengths is feasible. At this point in biomedical laser technology, diode laser development and similar technologies seem to hold the greatest promise. Use of lasers as diagnostic tools and sensors is one of the fastest growing branches of biomedical laser development. Clinical applications involving noninvasive recognition of malignant cells, abnormal tissue, or abnormal metabolites have tremendous potential. Use of available and future laser diagnostic technology could have a significant impact on the veterinary profession if a reasonable cost for equipment can be realized.

Future use of lasers in medicine depends on the active participation of veterinarians in the inception and development of new devices that meet the needs of the entire medical profession. The sensible clinical approach that must be taken every day in the practice of veterinary medicine equips the veterinarian with a unique ability to understand the practical and economic values of biomedical lasers. Veterinary medicine can and should be in the forefront during these exciting times, adding an essential dimension to development of this 21st century technology.

References

1. Swaim, CP, Mills, TN. A history of lasers. In: Krasner N, ed. Lasers in gastroenterology. New York: Wiley-Liss, 1991: 3.

2. Katzir, A: Medical Lasers. In: Lasers and Optical Fiber in Medicine, Academic Press, Inc., San Diego, CA, 1993:15.

3. Anderson, RR. Laser-tissue interactions in dermatology. In: Arndt, RA, ed. Lasers in cutaneous and aesthetic surgery. Philadelphia: Lippincott-Raven, 1997: 25.

4. Bartels, K.E., Lasers in Veterinary Medicine – Where Have We Been, Where Are We Going, In Vet Clin Sm An Pract, W.B. Saunders, Philadelphia, PA, 2002; 32 (3): 495, 2002.

5. Lucroy, MD, Bartels, KE. Surgical lasers. In: Slatter, D, ed. Textbook of Small Animal Surgery (3rd ed.). Philadelphia: Saunders, 2003: 227.

6. Lucroy, MD, Magne, ML, et al. Low intensity laser light-induced closure of a chronic wound in a dog. Vet Surg, 1999; 28:292.

7. Peavy, GM, Lasers and laser-tissue interaction, In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 517.

8. Welch, AJ, van Gamert, MJC: Introduction to medical applications. In Welch, AJ, van Gamert, MJC (eds): *Optical-thermal Response of Laser-irradiated Tissue,* Plenum Press, New York, 1995: 609.

9. Lubatschowski, H, Heistrkamp, A, Will, F., et al. Medical applications for ultrafast lasers. RIKEN Review No. 50: Focused on laser precision microfabrication, January, 2003, 113.

10. Jacques, SL: Laser-tissue interactions. Photochemical, photothermal, and photomechanical. In Schwesinger, WH, Hunter, JG, (eds) *Surg Clin NA: Lasers in general surgery.* WB Saunders, Philadelphia, 1992; 72:531.

11. Lopez, AP, Phillips, TJ. Wound healing. Wound healing. In: Fitzpatrick, RE, Goldman, MP (eds.) Cosmetic Laser Surgery. St. Louis: Mosby, 2000: 31.

12. Taylor, DL, Schafer, SA, Nordquist, et al: Comparison of a high power diode laser with the Nd: YAG laser using in situ wound strength analysis of healing cutaneous incisions. Lasers Surg Med, 1991; 21:248.

13. Treat, MR, Oz, MC, Bass, LS. New technologies and future applications of surgical lasers. The right tool for the right job. In: Schwesinger, WH, Hunter, JG, eds. Surg Clin NA: Lasers in general surgery. WB Saunders, Philadelphia, 1992, 72: 705 - 747.

14. Hecht, J: Carbon dioxide lasers. In The Laser Guidebook, New York, McGraw-Hill, 1992: 159.

15. Judy, MM, Matthews, JL, Aronoff, BL, Hults, DF. Soft tissue studies with 805 nm diode laser radiation: Thermal effects with contact tips and comparison with effects of 1064 nm Nd: YAG laser radiation. Lasers Surg Med, 1993, 13: 528.

16. Katzir, A: Single optical fibers. In *Lasers and Optical Fibers in Medicine,* Academic Press, Inc., San Diego, CA, 1993:107.

17. Tullners, EP: Transendoscopic contact neodymium: yttrium aluminum garnet laser correction of epiglottic entrapment in standing horses. JAVMA, 1990; (144): 1971.

18. Gilmour, MA. Lasers in ophthalmology. In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 649.

19. Lucroy, MD, Photodynamic therapy for companion animals with cancer, In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 693.

20. May, K.A., Pleasant, R.S., Howard, R.D., Moll, H.D., Duesterdieck, K.F., MacAllister, C.G. and Bartels, K.E., Failure of Holmium: yttrium-aluminum Garnet Laser Lithotripsy in Two Horses with Calculi in the Urinary Bladder, JAVMA, 2001, 219:957.

21. Collier, M, Haugland, LM, Bellamy, J, et al: Effects of holmium: YAG laser on equine articular cartilage and subchondral bone adjacent to traumatic lesions: a histopathological assessment, J Arthroscopic and Related Surg1997, 9: 536.

23. Teichman, JM, Vassar, GJ, Glickman, RD, Holmium: yttrium-aluminum-garnet lithotripsy efficiency varies with stone composition. Urology 1998; 52: 392.

24. Bartels, K.E., Higbee, R.G., Bahr, R.J., Galloway, D.S., Healey, T.S., Arnold, C.S., Outcome of and Complications Associated with Prophylactic Percutaneous Laser Disk Ablation in Dogs with Thoracolumbar Disk Disease: 277 cases (1992-2001), JAVMA, 2003; 222: 1733.

25. Dickey, DT, Bartels, KE, Henry, et al: Use of the holmium yttrium aluminum garnet laser for percutaneous thoracolumbar intervertebral disk ablation in the dog paper, JAVMA, 1996; 208: 1263.

26. Sliney, DH. Laser Safety. Lasers Surg Med, 1995; 16: 215.

27. Fry, TR: Laser safety, In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 535.

28. Jako, GJ: Laser surgery of the vocal cords; an experimental study with the carbon dioxide laser on dogs, Laryngoscope, 1972; 82: 2204.

29. Sullins, KE. Diode laser and endoscopic laser surgery. In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 639.

30. Tate, LP, Sweeney, CL, Bowman, KF, et al: Transendosocpic Nd: YAG laser surgery for treatment of epiglottal entrapment and dorsal displacement of the soft palate in the horse. Vet Surg, 1990; 19: 356.

31. Holt, TL, Mann, FA, Soft tissue application of lasers. In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 569.

32. Young, WP. Feline onychectomy and elective procedures. In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 601.

33. Shelley, BA. Use of the carbon dioxide laser for perianal and rectal surgery. In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 621.

34. Bellows, J. Laser use in veterinary dentistry. In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 673.

35. Rupley, AE, Parrott-Nenezian, T. The use of surgical lasers in exotic and avian practice. In: Bartels, KE. ed. Vet Clin NA: Laser in medicine

surgery. WB Saunders, Philadelphia, 2002, 32(3): 535.

36. Hardie, EM, Stone, EA, Spaulding, KA, Cullen, JM. Subtotal canine prostatectomy with the neodymium: yttrium aluminum garnet laser. Vet Surg, 1990; 19: 348.

37. Feder, BM, Fry, TR, Kostolich, M, Bartels, KE, Bahr, R, Mandsager, R, et al. Nd: YAG laser cytoreduction of an invasive intracranial meningioma in a dog. Prog Vet Neuro, 1993; 4:3.

38. Ellison, GW, Bellah, JR, Stubbs, WP, Van Gilder, J. Treatment of perianal fistulas with Nd: YAG laser. Results in twenty cases. Vet Surg, 1995; 24:140.

39. Nasisse, MP, Davidson, MG, English, RV, Jamieson, V, Harling, DE, Tate, LP. Treatment of glaucoma by use of transcleral neodymium: yttrium aluminum garnet laser cylcocoagulation in dogs. JAVMA, 1990; 197:350.

40. Rizzo, L.B., Ritchey, J.W., Higbee, R.G., Bartels, K.E., Lucroy, M.D., Histologic Comparison of Skin Biopsy Specimens Collected by Use of Carbon Dioxide or 810-nm Diode Lasers from Dogs, JAVMA, 2004; 225:1562.

41. Davidson, E.B., Davis, M.S., Campbell, G.A., Williamson, K.K., Payton, Healey, T.S., and Bartels, K.E.: Evaluation of Carbon Dioxide Laser and Conventional Incisional Techniques for Resection of Soft Palates in Brachycephalic Dogs. JAVMA, 2001; 219:776.

42. Ellison, GW, Bellah, JR, Stubbs, WP, et al: Treatment of perianal fistulas with Nd:YAG laser. Results in twenty cases. Vet Surg, 1995; 24:140.

43. Feder, BM, Fry, TR, Kostolich, et al: Nd:YAG laser cytoreduction of an invasive intracranial meningioma in a dog. Prog Vet Neuro, 1993, 4: 3.

44. Hardie, EM, Carlson, CS, Richardson, DC: Effect of Nd: YAG laser energy on articular cartilage healing in the dog. Lasers Surg Med, 1989; 9: 595.

45. Lange, DN, Rochat, MC, Bartels, KE, et al: Comparison of carbon dioxide laser modalities for removal of polymethylmethacrylate cement. Vet Comp Ortho Traum, 1997, 10: 25.

46. Shelley, BA, Bartels, KE, Ely, RW, et al: Use of the neodymium: yttrium aluminum garnet laser for treatment of squamous cell carcinoma of the nasal planum in a cat. JAVMA, 1992; 201:756.

47. Spindel, ML, Moslem, A, Bhatia, KS, Jassemnejad, B, Bartels, KE, Powell, RC, et al. Comparison of holmium and flashlamp pumped dye lasers for use in lithotripsy of biliary calculi. Lasers Surg Med, 1992; 12: 482.

48. Davidson, E.B., Ritchey, J.W., Higbee, R.D., Lucroy, M.D., and Bartels, K.E., Laser Lithotripsy for Treatment of Canine Uroliths, Vet. Surg., 2004; 33:56.

49. Wynn, V.M., Davidson, E.B., Higbee, R.G., Ritchey, J.W., Ridgway, T.D., Bartels, K.E., Lucroy, M.D., In Vitro Effects of Pulsed Holmium Laser Energy on Canine Uroliths and Porcine Cadaveric Urethra, Lasers Surg. Med., 2003; 33:243.

50. Sapienza, JS, Miller, TR, Gum, GG, Gelatt, KN. Contact transcleral cyclophotocoagulation using a neodymium: yttrium aluminum garnet laser in normal dogs. Prog Vet Comparative Opthalmol, 1993; 2: 147.

51. Klein, MK, Roberts, WG. Recent advances in photodynamic therapy. Compendium - Sm An, 1993; 15: 809.

52. Roth, JE, Nixon, AJ, Gantz, VA: Pulsed carbon dioxide laser for cartilage vaporization and subchondral bone perforation in horse, Part I: Technique and clinical results. Vet Surg, 1991, 203(3): 190.

53. Nixon, AJ, Krook LP, Roth JE, et al: Pulsed carbon dioxide laser for cartilage vaporization and subchondral bone perforation in horses. Part II: Morphologic and histochemical reactions. Vet Surg, 1991, 203 (3): 200.

54. Peavy, GM, Reinisch, L, Payne, JT. Comparison of cortical bone ablations by using infrared laser wavelengths 2.9 to 9.2 micron, Lasers Surg Med 1999; 25(5): 421.

55. Haugland, LM, Collier, MA, Panciera, RJ, Bellamy, J. The effect of CO_2 laser neurectomy on neuroma formation and axonal regeneration. Vet Surg, 1992, 21(5): 351.

56. Montgomery, TC, McNaughton, SD. Investigating the CO_2 laser for plantar digital neurectomy in horses, Lasers Surg Med. 1995; 5(5):515.

57. Shultz, R, Cabello F, Harvey G. Bacterial side effects of neodymium YAG lasers. Lasers Surg Med, 1986; 6:162.

58. Hooks, WT: Use of CO_2 laser sterilization. Oral Surg, 1980; 49:263.

59. Mison, MB, Bohart, GH, Walshaw, R, et al. Use of carbon dioxide laser for onychectomy in cats JAVMA 2002; 221(5): 651.

60. Palesty, JA, Zahir, KS, Dudrick, SJ, Ferri, S, Tripodi, G. Nd: YAG laser surgery for the excision of pilonidal cysts: a comparison with traditional techniques. Lasers Surg Med. 2000, 26(4):380.

61. Mison, MB, Steicek, B, Lavagino, M, et al. Comparison of the effects of the CO surgical lasers and conventional surgical techniques on the healing and wound tensile strength of skin flaps in the dog, Vet Surg 2003; 32(2): 153.

62. Irwin, JR: The economics of surgical laser technology in veterinary practice, In: Bartels, KE. ed. Vet Clin NA: Laser in medicine surgery. WB Saunders, Philadelphia, 2002, 32(3): 559.

63. Aukri, R, Lubort, R, Taitel baum: Estimation of optimal wave lengths for laser-induced wound healing, Laser Surg Med. 2010, 42(8): 760.

Chapter 4

Oncologic Surgery

The Role of the Surgeon in Veterinary Oncology

Earl F. Calfee, III

Introduction

The discipline of oncology involves the study and treatment of cancer by medical, surgical, and radiologic modes. Surgical therapy may benefit the animal in many cases or be harmful especially if surgery is poorly planned. The expertise of every surgeon's care is related to effort, experience, and the knowledge of individual limitations. The purpose of this chapter is to provide perspective and direction for veterinarians in the decision making process for oncology patients. An important aspect of decision making involves consideration of individual surgical abilities prior to the surgical procedure for animals with cancer.

It is widely recognized that the role of domestic pets in modern society has changed considerably in recent decades. Animals have become a central figure and family member. They are no longer just a "pet" in many households. Concurrently, advances in human and veterinary medicine have made it possible to practice veterinary medicine at a much more sophisticated and intense level than ever before. Significant advances have occurred in many areas of veterinary medicine such as imaging techniques (i.e. nuclear scintigraphy, CT and MRI), to medical therapy (i.e. total parenteral nutrition) surgical procedures (i.e. limb sparing, joint replacement, open-heart surgery, hemipelvectomy).[1-9] The growth of the human-animal bond and advances in veterinary medicine have changed the treatment of oncology patients considerably. The "best practice" of veterinary oncology combines advanced diagnostics, complex surgical procedures and intensive medical therapy. To provide the best or ideal care for the patient and owner, professional collaboration is often necessary between the generalist and specialists in medical, surgical and radiation oncology. At times, a surgeon may act individually in delivering appropriate care especially if a surgical cure is possible. However, in many cases the surgeon is only one piece of the "treatment puzzle".

The most important challenge is to define the disease and develop the most appropriate treatment plan. To best define the disease the surgeon should be able to answer five questions regarding any particular type of tumor. These include:

1. What is the type, stage and grade of cancer to be treated?
2. What are the expected local and systemic biologic activity of this tumor type and stage?
3. Is a cure possible?
4. Is surgery indicated?
5. What adjunctive treatments are available or indicated?[10]

The answers to these questions are often difficult since data regarding specific neoplastic disease is continuously being collected and changes rapidly. Diagnosis of the disease process and consultation with referral specialists is recommended to formulate the most appropriate diagnostic and therapeutic decisions. It is emphasized that the treatment plan for oncology patients, even those with a similar disease, is not necessarily standardized. Each patient must be considered individually and that often requires professional consultation and coordination of efforts.

Diagnostic Approach to Veterinary Oncology Patients

A definitive diagnosis and accurate staging of the disease is essential to provide a logical approach to the work-up and treatment of each patient. Much of the diagnostic approach to patients with neoplastic disease is relatively standardized. Generally, hematologic evaluation (CBC and blood chemistries) is performed to evaluate overall patient health. In some cases, baseline blood work can provide specific prognostic information. An example is the association of increased alkaline phosphatase values with shorter survival times in dogs with appendicular osteosarcoma.[11,12] In addition to hematology, screening for evidence of metastasis is usually performed. This usually involves taking three-view thoracic radiographs. Other methods of evaluation for possible metastasis include lymph node aspiration, abdominal ultrasound, and advanced imaging techniques. Decisions about appropriate imaging modalities for individual cases such as computed tomography (CT), magnetic resonance imagine (MRI) and nuclear scintigraphy should be based on knowledge of specific tumor behavior.

Computed tomography is often used to define the extent of disease in maxillofacial tumors and to evaluate for pulmonary metastasis.[13,14,15] CT has been shown to be more sensitive than radiographs for the evaluation of pulmonary metastasis and intrathoracic lymph node enlargement. MRI has a greater ability than CT to differentiate soft tissue structures and is superior to CT for imaging of central nervous system structures.[16,17]

Nuclear scintigraphy is beneficial for evaluation of metastatic bone lesions. Scintigraphy is especially useful for cases of canine appendicular osteosarcoma where a bone metastasis rate of approximately 8% is reported at the time of diagnosis.[18] Bone metastases are rarely identified based on physical examination or survey radiographs. Scintigraphy is also useful in defining the extent of disease at the primary site for appendicular osteosarcoma prior to limb-spare procedures.[19] Diagnostic techniques that may be used more in the future include sentinel lymph node biopsy based on lymphoscintigraphy mapping, dynamic MRI and metabolic scanning techniques.[20,21,22]

Surgical Biopsy

An accurate differential diagnosis begins with the safe and appropriate collection of tissues for histologic evaluation. Several types of tissue collection methods can be used (i.e. fine needle aspiration, tru-cut, incisional wedge, marginal and

excisional biopsy) and are covered extensively in chapter 5. It is important to consider the consequences of tissue collection techniques because if not performed appropriately a biopsy can diminish the opportunity for a surgical cure during later, more definitive surgery.

One of the more common mistakes occurs while performing marginal tumor excision. There is a tendency to NOT remove as much of the mass and surrounding tissues as possible while performing a resection immediately adjacent to the palpable mass. There is no benefit to "modified marginal resection". The inevitable result is contamination of peripheral and deep tissue structures for locally aggressive tumors. The surrounding tissue contamination with "modified marginal resections" may eliminate the possibility of a clean surgical excision in the future. An incisional biopsy is preferred to a modified marginal resection. For benign tumors a true marginal resection is adequate.

Surgical Therapy

Several tumor types exist where a properly performed surgical procedure alone will provide long term survival times or a cure. Examples include complete surgical excision of grade 1 or 2 soft tissue sarcomas and grade 1 or 2 mast cell tumors, noninvasive canine thyroid carcinomas, canine intramuscular lipomas, canine ceruminous gland carcinomas, canine hepatocellular carcinomas, and feline thymomas.[23-33] With complete surgical excision of the aforementioned neoplasms extended survival times are expected. The term "complete excision" is important in reference to tumor excision. Typical recommendations for complete excision of a tumor are 2 to 3 cm peripheral margins and one deep fascial plane.[27] These recommendations are not appropriate or applicable to all tumor types. In some cases, marginal resection is all that is possible and reliably produces extended survival times. Examples include non-invasive thyroid carcinoma and feline thymoma. In these two examples, local anatomy prevents resection with wide margins, however, experience has shown that marginal resection is adequate and clearly beneficial with these two tumors.[29,33]

The ability to attain a clean surgical margin is primarily dependent on the location of the mass and the ability of the surgeon. Masses located on the distal extremities and the head and neck are surgical challenges because of a lack of redundant peripheral and deep soft tissues and the presence of joints in the extremities. A lack of soft tissue, particularly on the extremities, makes primary closure of excision sites impossible. It is emphasized that complete excision of the mass producing an open wound that must be managed or reconstructed is preferable to incomplete excision of the tumor and complete wound closure. In these cases, complete surgical excision is preferred and open wound management is performed until the formation of healthy granulation tissue occurs. After a healthy granulation bed has formed, free skin grafting can be performed. Alternatively, in some cases, closure can be accomplished through the application of skin flaps or free tissue transfer. Axial pattern flaps (i.e. thoracodorsal, caudal superficial epigastric, reverse saphenous conduit flap, etc) or skin fold flaps are especially useful for reconstruction of large defects.[34,35,36] Skin can also be transferred from distant sites through the use of microvascular free tissue transfer. Most reconstructive techniques are complex and require appropriate planning and surgical expereince prior to the initial surgical procedure.

Clean surgical excisions of masses located over appendicular joints also pose a surgical challenge. This is because of the lack of a single fascial plane over the joint space. This generally makes curative surgical excision of masses over the joint space impossible. The surgeon is then left with radical resection (i.e. amputation) or the combination of conservative (i.e. marginal) surgical excision followed by adjuvant therapies (i.e. external beam radiation).

Other problematic anatomic areas are the axilla, inguen, and perineum. Surgical wounds in the axilla and inguen are predisposed to complications. Healing is difficult because of high motion, dead space and the tendency for seroma formation. The perineum is a challenge because of its proximity to the anus. Prior to definitive surgery on masses in any of these regions careful consideration must be given to the potential detrimental effects of incomplete tumor excision. It is often advisable to consider consultation with a board certified surgeon prior to performing any surgical procedure for these cases. Incisional biopsy to obtain a definitive histologic diagnosis is almost always required in these anatomic regions.

Surgery as Part of Multimodality Therapy

In some cases of neoplastic disease, surgery as a single mode of therapy may provide short-term benefits, but additional modes of therapy can significantly extend disease free intervals or prolong life. Animals that have incomplete surgical removal of masses such as mast cell tumors or tumors located adjacent to appendicular joint spaces may benefit from radiation therapy. Two additional examples where multimodal therapy is of significant benefit are canine appendicular osteosarcoma and feline vaccine associated sarcoma. Canine appendicular osteosarcoma has been extensively studied and is known to have high metastatic potential. Early in the study of this disease, radical surgery (i.e. amputation) alone was shown to have no significant benefit on survival times and be a purely palliative procedure.[38] The benefits of chemotherapy combined with surgery have been demonstrated in several studies with an extension of survival times from a median of four months to a median of 11 to 12 months.[39,40,41,42]

Feline vaccine associated sarcomas benefit from a multimodal approach. This tumor has a relatively low metastatic (approximately 20% at time of the initial diagnosis) rate but has very aggressive local behavior. Conservative surgical excision (marginal resection) is futile. In many cases because of location (i.e. intrascapular) radical surgery is not possible, therefore a combination of surgery and radiation therapy is utilized. The combination of surgery and radiation therapy has been shown to increase survival times to approximately 2 years.[43,44,45,46]

In many animals with neoplastic disease, the benefits of adjuvant therapies have not been demonstrated. Canine anal sac apocrine gland adenocarcinoma, grade 3 soft tissue sarcoma and feline

oral squamous cell carcinoma are examples of tumors with aggressive behavior where adjuvant therapy has not been studied or shown to be beneficial. In some situations (i.e. grade 3 soft tissue sarcoma and apocrine gland ACA) appropriate studies do not exist to adequately evaluate the benefit of adjuvant therapies.[47,48,49] In other diseases such as feline oral squamous cell carcinoma, the benefits of adjuvant therapy have been more extensively evaluated and no survival benefit has been attained with aggressive adjuvant therapy in addition to surgery.[50]

Conclusion

The treatment of cancer is a constantly changing process. The veterinary surgeon can influence treatment of the patient with cancer either positively or in some cases negatively. The consequences of any tissue collection must be considered prior to biopsy or excisional surgery. Initial diagnostics, tissue sample collection, and in some cases definitive surgical procedures may be performed by general practitioners following appropriate principles. To provide the best care for the cancer patient, knowledge of the current literature and early communication with appropriate specialists in oncology is recommended.

Editor's Note: Adjunctive therapy of anal sac apocrine gland adenocarcinoma with chemotherapy following surgery has increased median survival times in dogs. Radiation has also proved valuable in some cases. An oncologist should be consulted.

Turek MM, Forrest LJ, Adams WM, et al: Postoperative radiotherapy and mitoxanthrone for anal sac carcinoma in the dog. Vet Comp Oncol 1:94-104, 2003.

Turek MM and Withrow SJ. Perianal tumors. In Withrow SJ, Vail D, and Page R eds: Small animal clinical oncology 5th ed, St.Louis, 2013, Saunders-Elsevier.

References

1. Wisner ER, Pollar RE: Trends in Veterinary Cancer Imaging. Veterinary and Comparative Oncology. 2:2:49, 2004.

2. Davis GJ, Kapatkin AS, Craig LE, et al: Comparison of Radiography, Computed Tomography and Magnetic Resonance Imaging for Evaluation of Appendicular Osteosarcoma in Dogs. JAVMA. 220:8:1171, 2002.

3. Ehrhart NE: Longitudinal Bone Transport for the Treatment of Primary Bone Tumors in Dogs: Technique Description and Outcome in 9 Dogs. Vet Sur. 34: 1: 24, 2005.

4. Rovesti GL, Bascucci M, Schmidt, et al: Limb Sparing using a Double Bone-Transport Technique for Treatment of Distal Tibial Osteosarcoma in a Dog. Vet Surg. 31:70, 2002.

5. Buracco P, Morello E, Martano M, et al: Pasteurized Tumoral Autograft as a Novel Procedure for Limb Sparing in the Dog: A Clinical Report. Vet Surg. 31:525, 2002.

6. Kuntz CA, Asselin TL, Dernell WS, et al: Limb Salvage Surgery for Osteosarcoma of the Proximal Humerus: Outcome in 17 Dogs. Vet Surg. 27:417, 1998.

7. Seguin B, Walsh PJ, Mason DR, et al: Use of an Ipsilateral Vascularized Ulnar Transposition Autograft for Limb-Sparing Surgery of the Distal Radius in Dogs: An Anatomic and Clinical Study. Vet Surg. 32:69, 2003.

8. Kirpensteifn J, Steinheimer D, Park RD, et al: Comparison of Cemented and Non-cemented Allografts in Dogs with Osteosarcoma. Veterinary Comp Orthop Traumatol. 11:178, 1998.

9. Straw RC, Withrow SJ, Powers BE, et al: Partial or Total Hemipelvectomy in the Management of Sarcomas in 9 Dogs and 2 Cats. Vet Surg. 21:3:183, 1992.

10. Withrow SJ: Small Animal Clinical Oncology. Philadelphia: Cancer of the Gastrointestinal Tract (Cancer of the Oral Cavity). 70, 2001.

11. Garzotto CK, Berg J, Hoffman WE, et al: Prognostic Significance of Serum Alkaline Phosphatase Activity in Canine Appendicular Osteosarcoma. J of Vet Int Med. 2000, 14, 587-592.

12. Ehrhart N, Dernell WS, Hoffmann WE, et al: Prognostic Importance of Alkaline Phosphatase in Serum from Dogs with Appendicular Osteosarcoma: 75 cases (1990-1996). JAVMA. 213:1002, 1998.

13. Zekas LJ, Crawford JT, O'Brien RT: Computed tomography-guided fine-needle aspirate and tissue-core biopsy of intrathoracic lesions in thirty dogs and cats. Vet Radio Ultrasound. 46:3:200, 2005.

14. Prather AB, Berry CR, Thrall DE: Use of Radiography in Combination with Computed Tomography for the Assessment of Noncardiac Thoracic Disease in the Dog and Cat. Vet Radiol Ultrasound. 46;2:114, 2005.

15. De Rycke LM, Gielen IM, Simoens PJ, van Bree H: Computed tomography and cross-sectional anatomy of the thorax in clinically normal dogs. Am J Vet Res. 66:3:512, 2005.

16. Garosi LS, Dennis R, Platt SR, et al. Thiamine deficiency in a dog: clinical, clinicopathologic, and magnetic resonance imaging findings. J Vet Intern Med. 17:5:719, 2003.

17. Taga A, Taura Y, Nakaichi M, et al: Magnetic resonance imaging of syringomyelia in five dogs. J Small Anim Pract. 41:8:362, 2000.

18. M. K. Jankowski, P. F. Stey2, S. E. Lana, et al: Nuclear scanning with 99mTc-HDP for the initial evaluation of osseous metastasis in canine osteosarcoma. Veterinary and Comparative Oncology. 1:3:152, 2003.

19. Liebman NF, Kuntz CA, Steyn PF, et al: Accuracy of Radiography, Nuclear Scintigraphy, and Histopathology for Determining the Proximal Extent of Distal Radius Osteosarcoma in Dogs. Vet Surg, 30: 240, 2001.

20. Krynyckyi BR, Kim SC, Kim CK: Preoperative Lymphoscintigraphy and Triangulated Patient Body Marking are Important Parts of the Sentinel Node Process in Breast Cancer. World J Surg Oncol. 24:3:1:56, 2005.

21. Payoux P, Dekeister C, Lopez R, et al: Effectiveness of Lymphoscintigraphic Sentinel Node Detection for Cervical Staging of Patients with Squamous Cell Carcinoma of the Head and Neck. J Oral Maxillofac Surg. 63:8:1091, 2005.

22. Hara N, Okuizumi M, Koike H, et al: Dynamic Contrast-enhanced Magnetic Resonance Imaging (DCE-MRI) is a Useful Modality for the Precise Detection and Staging of Early Prostate Cancer. Prostate. 62:2:140, 2005.

23. Kuntz CA, Dernell WS, Powers BE, et al: Prognostic Factors for Surgical Treatment of Soft Tissue Sarcomas in Dogs: 75 Cases (1986-1996) JAVMA. 211:9:1147, 1997.

24. Molander-McCrary H, Henry CJ, Potter, et al: Cutaneous Mast Cell Tumors in Cats: 32 Cases (1991-1994). JAAHA. 34:281, 1998.

25. Weisse CW, Shofer FS, Sorenmo K: Recurrence Rates and Sites for Grade 2 Canine Cutaneous Mast Cell Tumors Following Complete Surgical Excision. JAAHA. 38:71, 2002.

26. Seguin B, Leibman NF, Bregazzi VS, et al: Clinical Outcome of Dogs with Grade-II Mast Cell Tumors Treated with Surgery Alone: 55 Cases (19961999). JAVMA. 218:7:1120, 2001.

27. Simpson AM, Ludwig LL, Newman SJ, et al: Evaluation of Surgical Margins Required for Complete Excision of Cutaneous Mast Cell Tumors in Dogs. JAVMA. 224:236, 2004.

28. Lemarie RJ, Lemarie SJ, Hedlund CS: Mast Cell Tumors: Clinical Management. Compendium For Continuing Education. 17:9, 1085, 1995.

29. Klein MK, Powers BE, Withrow SJ, et al. Treatment of Thyroid Carinoma in Dogs by Surgical Resection Alone: 20 Cases (1981-1989). JAVMA. 207:7: 1007, 1995.

30. Thomson MJ, Withrow SJ, Dernell WS, et al: Intramuscular Lipomas of the Thigh Region in Dogs: 11 Cases. JAAHA. 35:165, 1999.

31. London CA, Dubilzeig RR, Vail DM, et al: Evaluation of dogs and Cats with Tumors of the Ear Canal: 145 Cases (1978-1992). JAVMA. 208:9:1413, 1996.

32. Liptak JM, Dernell WS, Withrow SJ: Liver Tumors in Cats and Dogs. Compendium for Continuing Education. 50, 2004.

33. Gores BR, Berg J, Carpenter JL, et al: Surgical Treatment of Thymoma in Cats:12 Cases (1987-1992). JAVMA. 204:11:1782, 1994.

34. Remedios AM, Fowler JD: Axial Pattern Flaps in the Cutaneous Reconstruction of Lower Limb Wounds. Compendium for Continuing Education. 17:11:1356, 1995.

35. Hunt GB, Tisdall PL, Liptak JM, et al: Skin-Fold Advancement Flaps for Closing Large Proximal Limb and Trunk Defects in Dogs and Cats. Vet Surg. 30: 440-448, 2001.

36. Cornell K, Salisburn K, Jakovljevic S, et al: Reverse Saphenous Conduit Flap in Cats: An Anatomic Study. Vet Surg. 24:202, 1995.

37. Fowler JD, Degner DA, Walshaw R, et al: Microvascular Free Tissue Transfer: Results in 57 Consecutive Cases. Vet Surg. 27:406, 1998.

38. Spodnick GJ, Berg J, Rand WM, et al: Prognosis for Dogs with Appendicular Osteosarcoma Treated by Amputation Alone: 162 Cases (1981988). JAVMA. 200:7:995, 1992.

39. Watson CL, Lucroy MD: Primary Appendicular Bone Tumors in Dogs. Compendium for Continuing Education. 128, 2002.

40. Chun R, Kurzman ID, Couto CG, et al: Cisplatin and Doxorubicin Combination Chemotherapy for the Treatment of Canine Osteosarcoma: A Pilot Study. J Vet Intern Med. 14:495, 2000.

41. Bailey D, Erb H, Williams L, et al: Carboplatin and Doxorubicin Combination Chemotherapy for the Treatment of Appendicular Osteosarcoma in the Dog. J Vet Int Med. 17:199, 2003.

42. Berg J, Weinstein MJ, Springfield DS, et al: Results of Surgery and Doxorubicin Chemotherapy in dogs with Osteosarcoma. JAVMA. 206:10:1555, 1995.

43. McEntee MC, Page RL: Feline Vaccine Associated Sarcomas. J Vet Int Med. 15:176, 2001.

44. Hershey AE, Sorenmo KU, Hendrick MJ, et al: Prognosis for Presumed Feline Vaccine-Associated Sarcoma after Excision: 61 Cases (1986 - 1996). JAVMA. 216:1:58, 2000.

45. Cohen M, Wright JC, Brawner WR, et al: Use of Surgery and Electron Beam Irradiation, with and without Chemotherapy, for Treatment of Vaccine-Associated Sarcomas in Cats: 78 Cases (1996-2000). JAVMA. 219:11:1582, 2001.

46. Bregazzi VS, LaRue SM, McNiel E, et al: Treatment with a Combination of Doxorubicin, Surgery and Radiation Versus Radiation Along for Cats with Vaccine-Associated Sarcomas: 25 Cases (1995-2000). JAVMA. 218:4:547, 2001.

47. Ross JT, Scavelli TD, Matthiesen DT, et al: Adenocarcinoma of the Apocrine Glands of the Anal Sac in Dogs: A Review of 32 Cases. JAAHA. 27:349, 1991.

48. Williams LE, Gliatto JM, Dodge RK, et al: Carcinoma of the Apocrine Glands of the Anal Sac in Dogs: 113 Cases (1985-1995). JAVMA. 223:825, 2003.

49. Bennett PT, DeNicola DB, Bonney P, et al. Canine Anal Sac Adenocarcinomas: Clinical Presentation and Response to Therapy. J of Vet Int Med. 16:100, 2002.

50. Withrow SJ: Small Animal Clinical Oncology. Philadelphia: Cancer of the Gastrointestinal Tract (Cancer of the Oral Cavity). 305, 2001.

Chapter 5

Tumor Biopsy Principles and Techniques

Nicole Ehrhart, Stephen J. Withrow and Susan M. LaRue

The diagnosis of neoplastic and other pathologic conditions in animals depends on the procurement of an accurate biopsy specimen. Without an appropriate histologic diagnosis, it is impossible to plan appropriate therapy. Histopathologic results aid the clinician in providing an accurate prognosis and thereby guide the owner in the selection of various treatment options.

The ideal biopsy should procure enough tissue for specific pathologic diagnoses without jeopardizing the patient's well being or the surgeon's ability to achieve local tumor control. Many biopsy techniques can be used on any given mass. The procedure used is determined by 1) the clinician's goals for the patient (i.e., diagnosis with no treatment versus diagnosis with treatment); 2) the skill and preference of the clinician; 3) the anatomic site of the mass; and 4) the general health status of the patient.[1] Cytologic preparations obtained by fine needle aspirate are often helpful in guiding the selection of the optimal biopsy technique.

General Considerations

Biopsies can be obtained before the initiation of definitive therapy (pretreatment biopsy) or histologic specimens may be evaluated after the mass is removed in its entirety. In most situations, pretreatment biopsy is the optimum route of action because it provides a diagnosis before the institution of invasive or aggressive therapeutics.

Pretreatment biopsy is warranted when the type of treatment would be significantly altered by knowing the tumor type. For example, if an animal presents with a mediastinal mass, the distinction between a thymoma (responsive to surgery) and lymphoma (responsive to chemotherapy) would be important to make before instituting treatment.

If the *extent* of treatment would be altered by knowing the tumor type, pretreatment biopsy should be performed. Certain cancer types (e.g., mast cell tumors and soft tissue sarcomas) have high local recurrence rates and therefore require removal with wider margins than benign or lower grade malignant tumors. Many studies in both animals and human patients have shown that the best chance for surgical cure is to remove the lesion completely the first time. Clinicians who are tempted to "peel out" or "shell out" a lesion without knowing the histologic diagnosis are playing a dangerous game that may leave microscopic disease in the patient. If the lesion is malignant and incompletely excised, it will often grow back more quickly and invasively than the initial mass, thus potentially compromising further attempts at treatment.

Pretreatment biopsy should be considered when the tumor is in a difficult location for surgical reconstruction, such as a distal extremity, tail, or head and neck, or when the procedure could carry significant morbidity (e.g., maxillectomy or hemipelvectomy).

Finally, pretreatment biopsy is warranted when knowledge of the diagnosis would change the owner's willingness to treat the disease. An owner may be more willing to allow the veterinary surgeon to perform a thoracic wall resection for a low grade soft tissue sarcoma (slow to metastasize) than for a high-grade osteosarcoma (metastasizes quickly).

In two situations, pretreatment biopsy is *not* indicated. The first is when knowledge of the tumor type would not change the surgical therapy. Examples of this are a splenectomy for a localized splenic mass or a lung lobectomy for a solitary lung mass. The second situation is when the biopsy procedure is as dangerous or as difficult as the definitive treatment (brain biopsy). In these cases, biopsy information is obtained after surgical removal of the lesion.

Soft Tissue Biopsy

Needle Core Biopsy

The most common use of the needle core biopsy is for externally palpable masses. This procedure can be done on an outpatient basis with local anesthesia and sedation. The method uses various types of needle core instruments (Tru-Cut [Tru-Cut biopsy needle, Travenol Laboratories, Inc., Deerfield, IL 60015] or A.B.C. Needles [A.B.C. Needles, Monoject, St. Louis, MO 63310]) to obtain a piece of tissue 1 to 2 mm in width and l to 1.5 cm long. The most commonly used size is a 14 gauge diameter needle; however, these needles are available in 16 and 18 gauge sizes as well. Any mass larger than 1 cm in diameter can be sampled using this instrument. These instruments can also be used for deep tissues, such as kidney, liver, and prostate, in a closed method or an open method at the time of surgery. Despite the small sample size, the pathologist is usually able to discern tissue architecture and tumor type. With experience, the clinician can usually tell whether representative samples have been obtained. Fibrous and necrotic tumors may not yield diagnostic tissue cores. If the clinician believes that representative samples have not been obtained, an incisional biopsy is indicated.

The area to undergo biopsy is clipped and prepared as for minor surgery. Sensation in overlying skin and muscle can be blocked using a local anesthetic along the area that the needle will penetrate. The mass is fixed in place with one hand, and a 1-mm stab incision is made in the overlying skin. The needle biopsy instrument is introduced through the stab incision, and several needle cores are removed from different sites in the tumor through the same skin hole (Figure 5-1). The tissue is then removed from the trough of the instrument with a hypodermic needle and is placed in formalin. Samples can be gently rolled on a glass slide for a cytologic preparation before fixation if desired. Skin sutures are usually not required. The biopsy tract, including the stab incision, should be removed at the time of definitive surgery.

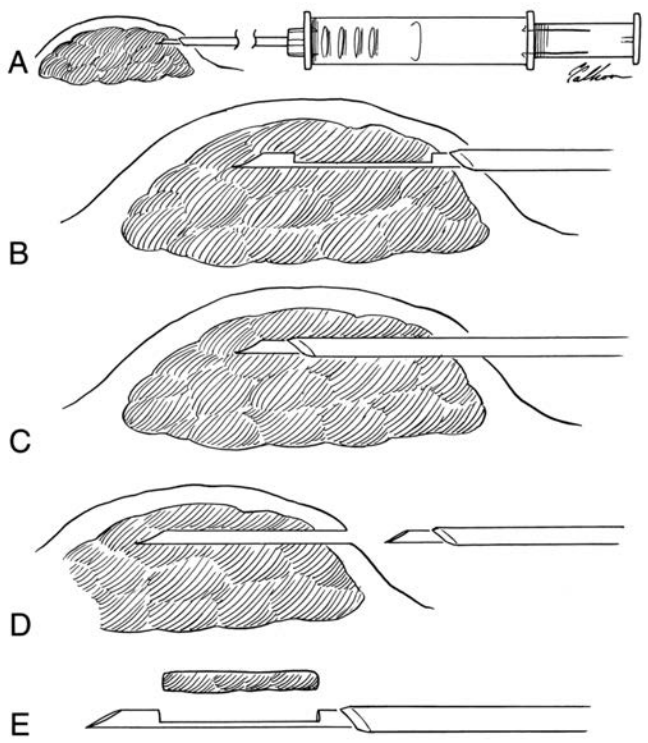


Figure 5-1. Needle core biopsy technique. **A.** A stab incision is made, and the instrument is inserted through the tumor capsule with the outer sleeve closed over the inner cannula. **B.** The outer sleeve is held fixed while the inner cannula is thrust forward into the tumor. **C.** The outer sleeve is pushed forward to slice off the specimen, which is protruding into the trough. **D.** The instrument is removed closed. **E.** The inner cannula is exposed, revealing the tissue specimen in the trough. (Modified from Withrow SJ, MacEwen EC. Small animal clinical oncology. 2nd ed. Philadelphia: WB Saunders, 1996.)

Punch Biopsy

Another simple biopsy technique is the punch biopsy method (Figure 5-2). This technique uses Baker's biopsy punch (Baker Cummons, Key Pharmaceuticals, Inc., Miami, FL 33169) instrument to obtain the specimen. The skin is prepared for minor surgery, and the overlying skin is anesthetized with a local anesthetic. Baker's punch is applied to the mass in a manner that will yield a composite of normal and abnormal tissue. Pressure is applied as the instrument is twisted. The specimen is grasped and lifted with forceps while the operator uses scissors or a scalpel blade to cut the base. Care should be taken to not deform the tissue. Impression smears can be made for cytologic evaluation before placement in formalin. Multiple specimens may be taken from a single mass. A single skin suture per biopsy site is usually sufficient to close the defect and to control hemorrhage.

Incisional Biopsy

Incisional biopsy (Figure 5-3) is used when neither cytologic examination nor needle core biopsy yields a diagnosis. As mentioned, incisional biopsy is preferred for ulcerated or necrotic tissue because core biopsy rarely yields a diagnosis. Tumors are often poorly innervated, and as long as overlying skin is anesthetized, a wedge of tissue can often be removed without general anesthesia. Externally located tumors that are ulcerated

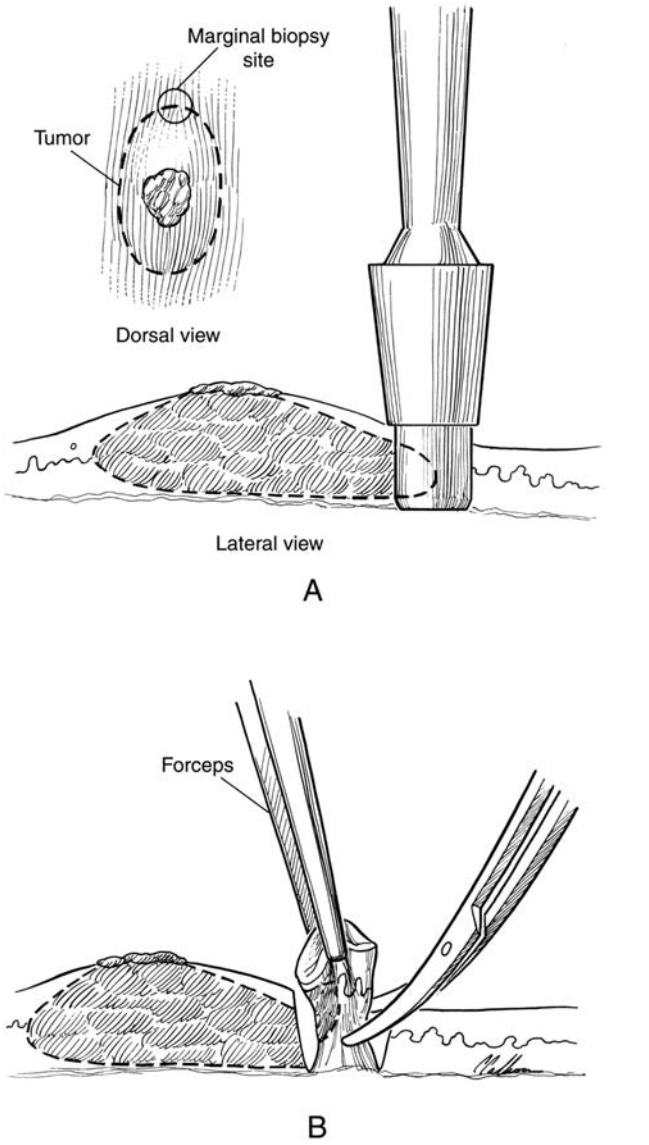


Figure 5-2. Punch biopsy technique. **A.** Baker's punch biopsy instrument is applied directly to the mass, and downward pressure is exerted while the instrument is twisted. When the metal end is buried up to the plastic hub, the instrument is removed. **B.** Forceps are used to lift the biopsy specimen gently, and scissors are used to cut the base.

may undergo biopsy without even the use of local anesthetics. The goal is to obtain a composite biopsy of abnormal tissue and adjacent normal tissue without compromising subsequent resection. The incisional biopsy tract always must be removed with a tumor at curative resection. Thus, the surgeon must not open uninvolved tissue planes that can become contaminated with tumor cells. In general, any normal tissue that the scalpel or surgical instruments have touched during an incisional biopsy is considered contaminated with tumor cells and is at risk for eventual tumor growth.

Excisional Biopsy

Excisional biopsy (See Figure 5-3) can be both diagnostic and therapeutic. Excisional biopsy is best used when the treatment would not be altered by knowledge of the tumor type. Benign skin tumors and small malignant dermal lesions located in an area where reexcision (2 to 3 cm margins in all directions including deep) can be reasonably obtained are also amenable to excisional biopsy. All other masses should undergo biopsy before the curative surgical procedure. Additional uses of excisional biopsy are for solitary lung, splenic, and retained testicular masses.

Endoscopic Biopsy

Endoscopic biopsy is used most commonly in the gastrointestinal, respiratory, and urogenital systems. It is convenient, safe, and cost effective; however, it has several limitations. Visualization may be inadequate, resulting in nonrepresentative biopsy samples. Full-thickness biopsy specimens are often impossible to acquire in these organs, and therefore, inflamed tissue or normal tissue overlying a tumor may undergo biopsy, not the tumor itself. A histopathologic diagnosis of inflammation in an animal suspected of having neoplasia should be interpreted with caution.

Laparoscopy and Thoracoscopic Biopsy

These techniques are best used when all staging and diagnostic procedures suggest inoperable and diffuse disease or when precise staging is indicated and an open procedure is not desired. Laparoscopic and thoracoscopic biopsy can yield important information regarding the extent of disease. Its disadvantages are that it can take as long as an exploratory laparotomy, it requires general anesthesia, and it does not give the clinician visualization as clear as that attained during open exploratory. In most cases, it cannot provide for excision. This procedure also carries some risk of hemorrhage and leakage of fluid from hollow organs and tumors. Animals staged by whatever means as having resectable disease are often best served by open exploratory laparotomy or thoracotomy, whereby resection with curative intent can be performed.[1]

Image-Guided Biopsy

The use of fluoroscopy, computed tomography, and ultrasonography has greatly expanded the clinician's ability to stage and diagnose neoplasia. Image guided biopsy may result in the avoidance of more invasive diagnostic procedures. A disadvantage of image-guided biopsy is that the technique requires specialized equipment and training. Biopsy in a closed space with limited visualization of the lesion carries some risk. As with laparoscopy and thoracoscopy, image guided biopsy is best done when the clinician is fairly certain that an excisional attempt would be unsuccessful or when pretreatment biopsy results would change the owners' willingness to pursue more aggressive medical or surgical therapy.

Tissue Procurement and Fixation Guidelines

The concept that performing a biopsy releases tumor cells and leads to early metastasis and decreased survival has proved false. Although biopsy procedures do release tumor cells into the circulation, neoplastic cells are constantly shed into vessels and lymphatics on a day to day basis.[1] No evidence in either human patients or animals indicates that a properly performed biopsy leads to a decrease in survival or early metastases. On the other

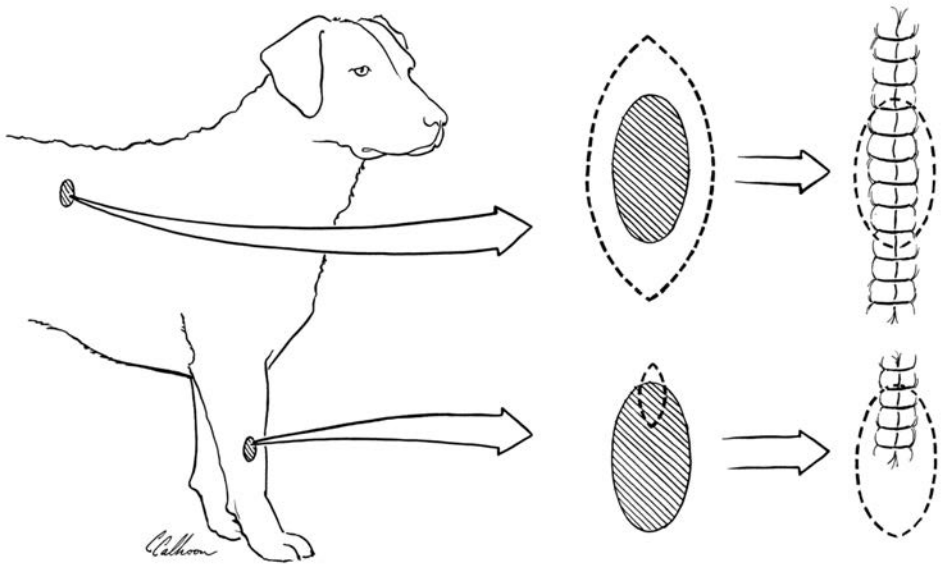


Figure 5-3. Excisional (top) and incisional (bottom) biopsy. The location of the top tumor would be amenable to wide excisional margins with an option to pursue a re-resection if needed. The location of the bottom tumor is less amenable to wide excisional margins. Attempts to excise this tumor with close margins may leave residual disease in this patient and may compromise the optimum surgical course of treatment. The bottom tumor should undergo biopsy before resection with curative intent. The axis of the biopsy incision is parallel to the long axis of the leg. (Modified from Withrow Sj, MacEwen EC. Small Animal clinical oncology. 2nd ed. Philadelphia: WB Saunders, 1996.)

hand, a poorly planned or improperly executed biopsy can result in significant alterations in the optimum treatment plan.

Biopsies should be planned so the tract may subsequently be removed with the entire mass. The ideal circumstance is when the biopsy is performed by the surgeon who will eventually perform the curative intent procedure. Biopsies performed within a body cavity (either open or closed) should be done so tumor cells are not "spilled" into the cavity. This precaution prevents seeding of peritoneal or pleural cavities. The sample size of the specimen affects the accuracy of the diagnosis. Because tumors are not homogenous and often contain areas of necrosis and inflammation, larger samples or multiple samples from different areas in a mass are more likely to yield a diagnosis. The smaller the sample, the less representative it is of the whole tumor. Thus, if needle core biopsy specimens are obtained, several samples should be submitted. Biopsies should not be obtained with electrocautery because this technique will disturb and deform the tissue architecture. Likewise, the clinician should take care not to deform the sample with forceps, suction, or other handling methods. Cautery can be used after blade removal of a specimen to control hemostasis if necessary.

The junction of normal and abnormal tissue is frequently the best area for sampling. This aids the histopathologist in comparing normal and abnormal tissue architecture. It is important to plan the incision so the normal tissue incised during the biopsy can easily be removed and is not necessary for reconstruction of the surgical defect. (The exception to the tissue junction rule is bone biopsies, discussed later in this chapter.) Biopsies performed on the legs or the tail should be done using an incision parallel to the long axis of the structure. This technique aids in resection of the biopsy scar if needed.

Excisional specimens submitted for biopsy should be evaluated for surgical margins. The surgeon should mark any areas of question or submit a margin from the patient in a separate container. It is good practice to mark all excisional margins routinely with ink. The pathologist samples tissue from several areas of the specimen. If tumor cells extend to the inked margin microscopically, the excision should be considered incomplete ("dirty"). Lateral and deep margins of an excised mass can be painted with India ink and allowed to dry before placement in formalin. Commercially available colored inks can be used to denote different sites on the tumor if desired (Davidson Marking System, Bloomington, MN).

Ultimately, the surgeon has the responsibility to communicate to the pathologist what is expected when evaluating margins on an excisional sample. Of course, incisional biopsies, needle core biopsies, and punch biopsies have incomplete margins by definition. Pathologists may not know whether the sample is intended to be excisional and do not always evaluate margins unless asked. Good communication between the pathologist and the clinician is vital to the care of the patient. Waiting until recurrence of the tumor to reoperate on a known malignancy that has been incompletely resected is a disservice to the client and the animal. Incomplete surgical resection of malignant disease is best dealt with early so further surgery or adjuvant therapy can be instituted immediately.

Tissues should be fixed in 10% neutral buffered formalin in a ratio of I part specimen to 10 parts fixative. Proper fixation is vital for accurate pathologic diagnosis. Tissue thicker than 1 cm does not fix deeply. Large masses can be sliced like a bread loaf, leaving one edge intact to allow for orientation. Alternatively, representative samples from the tumors can be sent while the larger portion of tumor is saved in formalin and further sections submitted if the pathologic diagnosis is in question. It is possible, especially in some large splenic masses, for only a

small portion of the mass to be neoplastic and for the rest to consist of hematoma, necrosis, or fluid. This possibility emphasizes the need to submit several representative samples or, when possible, the entire mass. Tissue that is prefixed over 2 to 3 days in formalin can be mailed with a tissue - to - formalin ratio of 1:1.

For the pathologist to provide the most accurate diagnosis, each sample must be accompanied by a complete history. Whenever the histopathologic diagnosis does not concur with the history, clinical signs, or clinician's impression, a call to the pathologist is warranted. In some cases, a small but vital piece of information left out of the patient's history can drastically change the pathologist's impressions. Pathology is a combination of art and science, and diagnoses are only as accurate as the information provided by the clinician.

A veterinary trained pathologist is always preferable to a pathologist trained in human disease. Although similarities exist across species lines, there are enough histologic differences to result in interpretive errors.

Frozen Sections

Frozen sections are becoming more common in the perioperative setting in veterinary medicine. This process provides a rapid means to a diagnosis at the time of surgery, as well as information on adequacy of tumor resection and the presence or absence of metastases. Although the use of this technique in veterinary medicine is limited to those institutions with specialized personnel and equipment, it is of potentially great value to the surgeon. Accuracy rates are high (93%) when results are compared with those from traditional paraffin embedded tissues.[2]

Bone Biopsy

Bone biopsy is essential in the diagnosis of proliferative and lytic bone lesions. Results of a bone biopsy often determine the course of treatment and may drastically change proposed operative intervention. As with all biopsies, the clinician must plan the biopsy with the intended curative treatment in mind. The most common instruments used for bone biopsies are the Michelle trephine (Michelle trephine, Kirschner Co., Timonium, MD) and the Jamshidi type bone marrow biopsy needle (Jamshidi bone marrow/aspirate needle, American Pharmaseal, Valencia, CA 91335; Bone marrow biopsy needle, Sherwood Medical, St. Louis, MO 63130). When used properly, both instruments provide a suitable sample with minimal complications. The small size of the Jamshidi biopsy needle cannula is advantageous in that it requires a smaller skin approach (1-mm stab incision) and leaves a small diameter bone defect, making biopsy related fractures less likely than with a trephine. Trauma to soft tissue structures and hemorrhage are minimal with the Jamshidi method.

Jamshidi needles are available in single use and reusable models.[3] The reusable model is "self sharpening" and steam sterilizable. In our experience, the single use model may be reused 10 to 15 times after gas sterilization. Jamshidi type needles are available in various sizes, but the 8 and 11 gauge needles (4 inches long), are most commonly used. A Jamshidi-type needle features a pointed stylet that facilitates passage through the soft tissues (Figure 5-4). The stylet is secured by a screw on cap. The tip of the cannula is tapered, allowing the specimen to be locked into the cannula. This tapering eliminates the rocking motion necessary to break off and retrieve a tissue specimen when using a trephine. A small probe is also provided to assist in removing the specimen from the needle. The specimen must be pushed out the handle because damage and compression distortion of the specimen will occur if it is pushed out the tapered cannula tip.

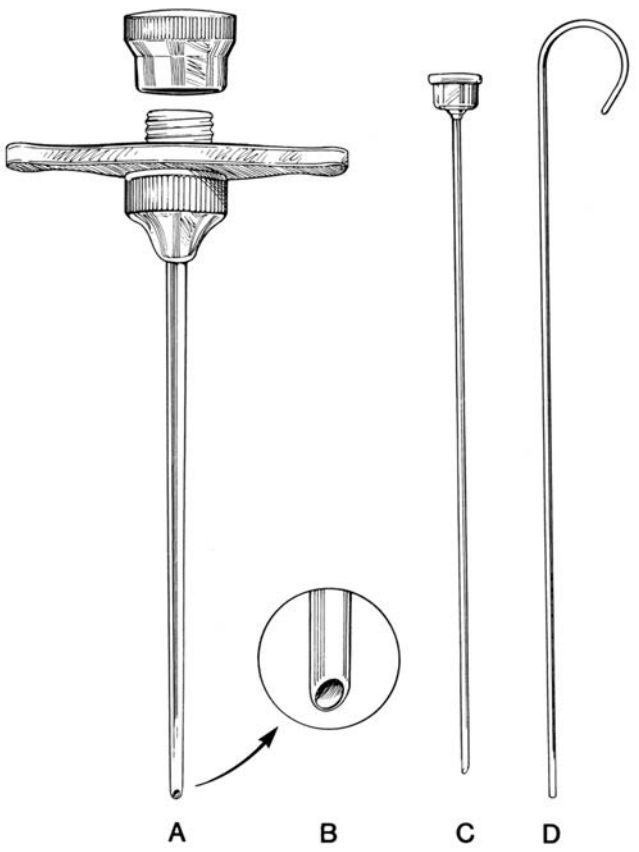


Figure 5-4. Jamshidi type biopsy device. **A.** Cannula and screw on cap. **B.** Tapered point to "lock in" the biopsy specimen. **C.** Pointed stylet to advance the cannula through soft tissue structures. **D.** Probe to expel the specimen out of the cannula base. (From Powers BE, LaRue SM, Withrow SJ, et al. Jamshidi needle biopsy for diagnosis of bone lesions in small animals. J Am Vet Med Assoc [in press].)

Indications and Preoperative Considerations

Bone biopsies are most often performed to confirm the presence of a neoplasm suspected on radiographic and clinical evaluation. Primary malignant tumors of bone in dogs include osteosarcoma, chondrosarcoma, fibrosarcoma, and hemangiosarcoma. Plasma cells, myeloma, and other round cell tumors can also originate from bone. Metastatic spread to bone from other primary tumors must also be considered. Metastasis to bone can occur with almost any type of tumor. The clinical and radiographic signs of primary and metastatic bone tumors can be similar; they include lameness of the affected limb, a warm swelling that is sensitive when palpated, and lytic and proliferative changes, which are apparent on radiographs. Other conditions that can

mimic bone tumors include fungal and bacterial osteomyelitis. Dogs with fungal infection have generally traveled in fungus-endemic areas. Dogs with bacterial osteomyelitis usually have intermittent drainage from the lesion and a history of penetrating trauma or previous surgery.

Although history, clinical signs, and radiographic changes can aid in making a presumptive diagnosis, the definitive diagnosis of bone lesions can be obtained only through histologic evaluation of a tissue specimen. Radiographic evaluation before biopsy should include two different views (craniocaudal and lateral) of the lesion. As previously mentioned, biopsies are traditionally obtained at the junction of tumor and normal tissue. However, in bone, the center of neoplastic lesions is most likely to yield diagnostic material.[4] Bones surrounding almost any insult, including trauma, infection, and tumor, can become reactive. Although biopsy specimens obtained at the center of bone tumors often contain considerable necrotic tissue, tumor identification is not impeded.[4] Inadequate sampling may result in a report of reactive bone. In these cases, the clinician should consider rebiopsy, especially if the diagnosis of reactive bone does not fit the clinical picture. The center of the lesion can be measured on the radiograph with reference to a nearby landmark, generally the adjacent joint. The radiograph should be in view and a sterile ruler available at the time of biopsy.

The skin incision and route of the biopsy needle should be made with subsequent surgical procedures in mind (i.e., limb sparing operations). Questions of preferred location of biopsy are best directed to the referral institution that would perform the definitive surgery. In any case, a joint should never be entered and dissection through the planes or neurovascular bundles should be avoided. If evidence points toward primary bone tumor and if the clients are interested in pursuing limb sparing surgery, referral for biopsy may be the best alternative. General anesthesia is usually necessary for bone biopsy. Selection of the anesthetic regimen depends on the general condition of the animal, on personal preference, and on experience. Because many of these patients are geriatric, complete blood count, serum biochemistry, and urinalysis are indicated. In some cases, particularly in animals with a lytic lesion, heavy sedation and local anesthesia may suffice.

Surgical Technique

The surgical site should be aseptically prepared and routinely draped. Adhesive drapes covering the biopsy site offer excellent protection allowing palpation and manipulation of the limb. A 1 - to - 2 mm stab incision in the skin is made at the desired location. The Jamshidi cannula, with the stylet locked in place, is gently pushed through the soft tissue structures. When bone is reached, the location of the cannuta should be evaluated using the radiographs as reference (Figure 5-5). The cannula can be shifted to a different location if desired. The stylet is removed. With a gentle twisting motion and the application of firm pressure, the cortex is penetrated. The cannula is advanced through the medullary cavity, taking care to avoid penetrating the opposite cortex (Figure 5-6). After the instrument is removed, the specimen is pushed from the tip out through the base of the cannula with the probe, not with the stylet (Figure 5-7). The procedure is repeated, following the soft tissue tract previously established. The instrument can be angled in different positions after reaching the bone. Two or three specimens should be obtained. If the center of the lesion is so soft that a core of tissue cannot be obtained, the cannula should be directed toward the peripheral aspect of the lesion. Hemostasis is generally not a problem with this technique; however, if bleeding occurs, direct pressure is sufficient to control it. The Jamshidi instrument bends if excessive pressure is applied.

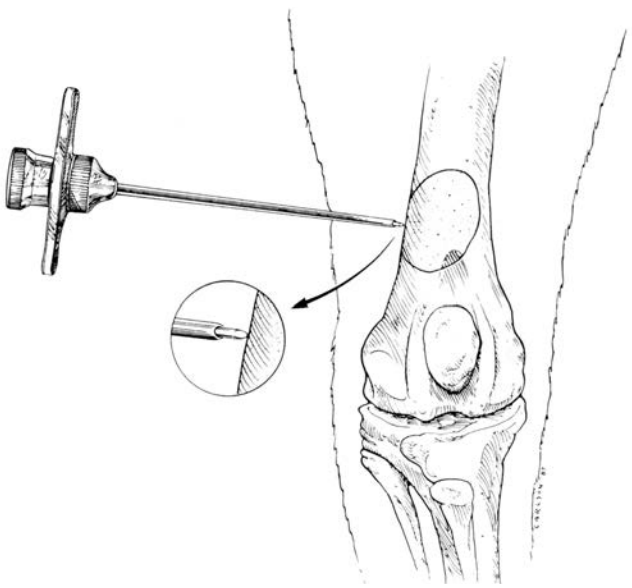


Figure 5-5. With the stylet locked in place, the cannula is advanced through soft tissue structures until bone is reached. The cannula should point toward the center of the tumor.

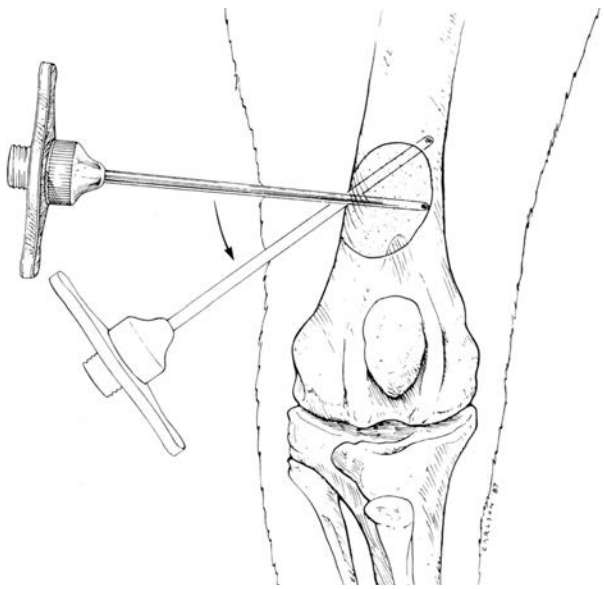


Figure 5-6. After the stylet has been removed, using a twisting motion and applying gentle pressure the cortex is penetrated. The cannula is advanced until the opposite cortex is reached and then is withdrawn. The procedure is repeated with the cannula pointed toward the periphery of the lesions.

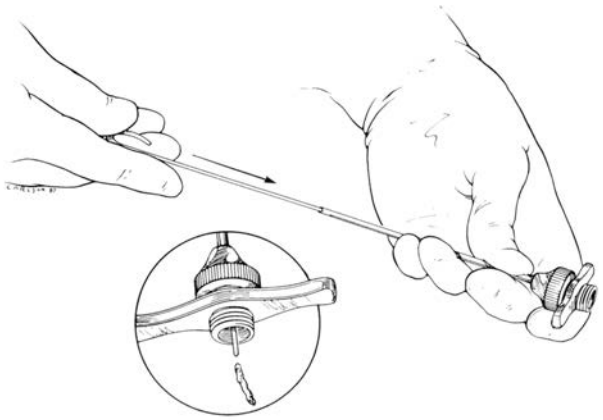


Figure 5-7. The probe is inserted into the tip of the cannula, and the specimen is expelled through the cannula base (inset).

Damage to the cannula and stylet can occur during biopsy of normal cortical bone or of an extremely proliferative and organized bony lesion. If the cannula cannot be inserted, its position should be reevaluated to ensure that the cannula is not on adjacent normal bone. If the position appears correct, a trephine may be indicated to obtain an adequate sample. A skin suture may be placed after the procedure. For biopsies of the lower extremities, a soft wrap may be applied.

Biopsy specimens should be placed in a 10% neutral buffered formalin solution as soon as possible to prevent desiccation. Specimens can also be placed in culture medium if desired. Samples should be sent to a pathologist and laboratory experienced in evaluating and processing bone specimens.

Nasal Biopsy

A nasal biopsy requires that the animal be anesthetized, with an endotracheal tube inserted. The cuff of the endotracheal tube should be inflated and checked periodically to prevent aspiration of blood during the procedure. Several procedures have been used to procure nasal biopsies. In our experience, the easiest and most successful procedure in dogs is the use of a rigid plastic tube, such as the outer sleeve of a Sovereign catheter (Sovereign indwelling catheter, Monoject, Division of Sherwood Medical, St. Louis, MO) or spinal needle.[5] The actual catheter portion is discarded, and the metal stylet is cut off at the hub using bandage scissors. The catheter sleeve is slid over the remaining hub, and a 12-mL syringe is attached. The location of the tumor is visualized on radiographs, and the plastic sleeve is measured from the medial canthus of the eye to the tip of the nose. The sleeve can be marked or cut off so the clinician does not introduce the biopsy device further than this distance. This technique prevents disruption of the cribriform plate and invasion of the brain. The tube is introduced past the wing of the nostril using gentle pressure. It is then reamed in and out of the tumor repeatedly while suction is applied to the syringe. Hemorrhage is common but usually self limiting and should not deter the clinician from being aggressive. The device is withdrawn from the nose, and the syringe is removed and filled with air. The specimen is then forced out by flushing the air through the tube using the syringe. Samples should be placed on a gauze sponge to allow blood to drain away. Tumor tissue is usually white to tan, although it may be hemorrhagic and mucoid. All tissues are placed in 10% buffered formalin for evaluation. Smaller pieces can be placed on filter paper before placement in formalin to preserve architecture.

In cats, smaller dogs, and brachiocephalic breeds, a curette can be used followed by flushing the nose with saline. Care is taken to properly inflate the endotracheal tube cuff to prevent aspiration. The instrument should not be introduced further than the distance from the tip of the nose to the medial canthus. It is helpful to mark the instrument with a piece of tape at this distance. Sponges should be placed above the soft palate and at the external nares to catch bits of tissue. The curette is then introduced into the nasal cavity and a scooping action is used to dislodge tumor fragments. Cool saline is used to flush out specimen pieces using a pulsing action. All tissue is submitted for histopathologic evaluation.

Mild hemorrhage is noted for several hours after the biopsy. Sneezing after the biopsy can aggravate this hemorrhage. Patients should undergo recovery in a quiet area with supervision and should be kept for several hours or overnight after anesthetic recovery. These techniques are safe, they have minimal morbidity when compared to open biopsies, and they yield excellent specimens.[5]

Interpretation of Results

The biopsy should be reviewed with respect to other data concerning the patient, such as clinical signs, history, and physical examination. A clinician should expect to receive the following information in a biopsy report: a determination of neoplasia versus no neoplasia; a diagnosis of benign versus malignant; a histologic type; grade of tumor if applicable; and margins if excisional. Interpretive errors can occur at any level of diagnosis. An estimated 10% of biopsy results may have some clinically significant inaccuracy. If the biopsy result is inconclusive or is inconsistent with the clinical findings, one of several actions should be taken. At the very least, the pathologist should be called and the concern expressed. This exchange should be looked on as welcome and helpful for both parties, not as an affront to the pathologist's expertise. In many cases, added information may lead to resectioning of the available paraffin tissue block, use of special stains for certain tumors, or a second opinion. Rebiopsy is also a possibility if the tumor is still present in the patient.

A properly performed biopsy and interpretation are the most important steps in the management of the cancer patient. The decision to submit a tissue specimen for histopathologic examination should not be left to the owner. If necessary, the charge for submission and interpretation of the biopsy should be included in the surgery fee. Mass excision without interpretation is no longer considered the standard of care. Because of increasing legal concerns, much more is at stake than the satisfaction of medical curiosity.

References

1. Withrow SJ, MacEwen EC. Small animal clinical oncology. 2nd ed. Philadelphia: WB Saunders, 1996.

2. Whitebait JG, Griffey SM, Olander HJ, et al. The accuracy of intraoperative diagnoses based on examination of frozen sections: a prospective comparison with paraffin embedded sections. Vet Surg 1993;22:255 259.

3. Jamshidi K, Swain WR. Bone marrow biopsy with unaltered architecture: a new biopsy device. J Lab Clin Med 1971;77:335.

4. Wykes PM, Withrow SJ, Powers BE, et al. Closed biopsy for diagnoses of long bone tumors: accuracy and results. J Am Anim Hosp Assoc 1985;21:489.

5. Withrow SJ, Susaneck SJ, Macy DW, et al. Aspiration and punch biopsy techniques for nasal tumors. J Am Anim Hosp Assoc 1985;21:55 1.

Chapter 6

Supplemental Oxygen Delivery and Feeding Tube Techniques

Nasal, Nasopharyngeal, Nasotracheal, Nasoesophageal, Nasogastric, and Nasoenteric Tubes: Insertion and Use

Dennis T. Crowe and Jennifer J. Devey

Indwelling tubes that enter the nose and stop in the ventral nasal meatus (nasal), pharynx (nasopharyngeal), or trachea (nasotracheal) are effective for the delivery of supplemental oxygen (O_2). Those that continue on through the ventral nasal meatus and pharynx and stop in the caudal thoracic esophagus (nasoesophageal [NEO]) are useful for the delivery of fluids and nutritional supplements or for the aspiration of air and fluids to provide decompression of the esophagus in conditions causing megaesophagus. Tubes that continue on into the stomach and either stop there (nasogastric [NG]) or continue into the duodenum or jejunum (nasoenteric [NET]) are useful for delivery of fluids and nutrients or for removal of accumulated air and fluids. All these tubes are placed initially into the nasal passage and are passed into the ventral meatus using the same technique. The type of tube selected depends on its intended use. Placement of each of the types of tube is simple to perform. In rare instances, placement under fluoroscopic guidance may be required (i.e., placing an NG tube past an esophageal stricture or placing an NET tube). After insertion, all indwelling tubes are generally well tolerated by most patients, even patients that are completely alert. On occasion, an Elizabethan collar is recommended to prevent the patient from dislodging the tube. Sedation is not necessary in most patients. The nose generally accommodates up to three to four types of tubes at the same time. When more than one type of tube is placed in the nose, the tubes must be labeled appropriately to avoid complications.

Oxygen Administration

Nasal Tubes

Indications

Supplemental oxygen (O_2) should be provided as a first line of treatment to dogs and cats in shock (septic, traumatic, cardiogenic) and cardiac failure and those with respiratory compromise. This supplementation is also a useful treatment in postoperative critically ill patients during the anesthetic recovery period and in anemic animals.

The use of O_2 cages has been helpful in providing an O_2-enriched atmosphere for animals. However, these cages are expensive, and available sizes often cannot house large to giant breed dogs adequately. They also are inefficient to operate because a considerable amount of O_2 is dissipated into the room each time

the door is opened. Furthermore, once a patient is placed into an O_2 cage, careful evaluation, continued monitoring, and treatment are difficult in the "forced" isolation that this form of O_2 therapy requires. Much time is also required to generate the higher levels of O_2 recommended in patients placed in O_2 cages. The law of displacement dictates the time required. The cubic volume of commercial O_2 cages varies from 300 to 500 L. If O_2 is provided at a flow rate of 20 L/minute into the cage, and no leakage occurs, it will take a minimum of 12 minutes to achieve the O_2 concentration of near 100% that is recommended in patients suffering from life-threatening conditions. O_2 cages are also inefficient at providing sustained concentrations of O_2 higher than 50% because of unavoidable leaks. In investigations with one O_2 cage, the O_2 concentration could not be held above 40%.

Other available means of providing supplemental O_2 therapy include the use of face masks, O_2 hoods, bilateral human nasal cannulas, and transtracheal catheters. Difficulties with the use of a mask in nervous and apprehensive animals are all too familiar. O_2 hoods are well tolerated and provide up to 80% O_2 concentrations, but access to the face is restricted, and the animal is unable to drink or eat (Figure 6-1). These collars can, however, be used in conjunction with nasal catheters or short nasal cannulas to increase tracheal O_2 concentration.

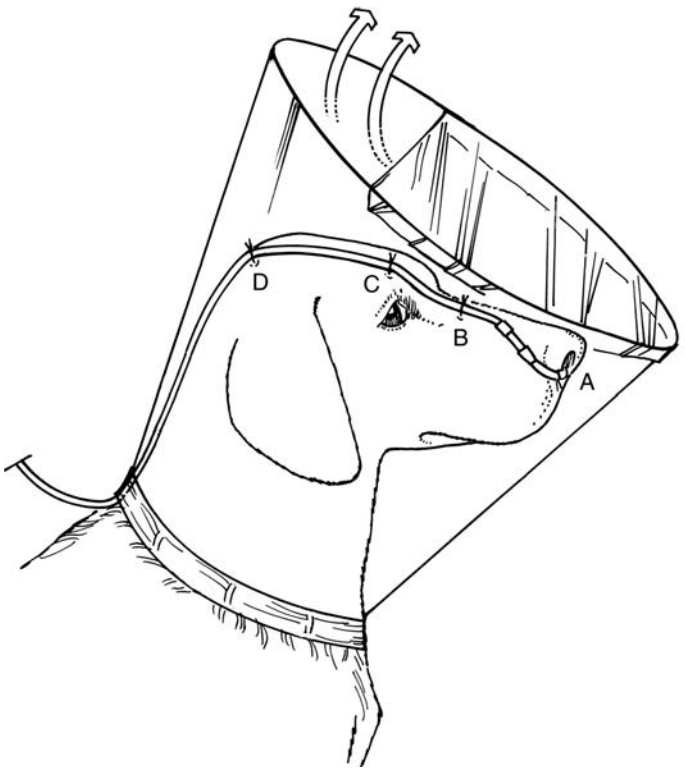


Figure 6-1. Detailed drawing showing suture at: the base of the nose in the skin, then going around the tube and tied tightly **A.** the mid dorsal region of the nose in the skin, then going around the tube and tied tightly **B.** eye level on the dorsum of the head in the skin, then going around the tube and tied tightly **C.** ear level on the dorsum of the head in the skin, then going around the tube and tied tightly **D.** The tube is then brought behind the neck and is secured with a section of tape around the neck (inset). A section of oxygen tubing or intravenous administration tubing is used to connect the tube to the oxygen source with a regulator. For animals that are extremely active, a section of tape can also be placed around the chest and the tube secured to this tape.

Short human nasal cannulas are inserted into the nares and are secured around the neck using a drawstring. These devices are well tolerated, but they frequently dislodge if the patient is active. Complications with transtracheal catheters have been reported. Nasal O_2 administration is an efficient and effective means of providing high inhalational concentrations of O_2 (up to 85 to 95%). *The deeper the placement of the end of the tube in the respiratory tract, the more efficient the device is in elevating the concentration of O_2.* Nasal tubes are not as effective as nasopharyngeal tubes in raising the inhaled tracheal O_2 concentration. The highest concentrations of O_2 are achieved with the use of nasotracheal tubes.

Insertion Technique

The animal's head is held gently restrained upward, and 1 mL of 2% lidocaine (dogs) (Animal Health Associates, Kansas City, MO) or 5 drops of 0.5% proparacaine ophthalmic Solution (dogs and cats) (Ophthaine, ER Squibb & Sons, Princeton, NJ) are administered into either nostril. The right nostril generally is preferred for right handed operators and the left nostril for left handed operators. The local anesthetic solution is allowed to run down the nasal passage. This procedure is repeated after 10 to 20 seconds. After another short waiting period to allow for desensitization, the tip of the selected catheter is lubricated on its outer surface with a commercial water soluble lubricant (Xylocaine Jelly 2%, Astra Pharmaceutical Products, Inc., Worcester MA). The catheter can be a 3.5- to 8-French red rubber (Sovereign, Sherwood Medical Products, St. Louis, MO) or polyvinyl chloride (Cook Critical Care, Bloomington, IN) tube, or for extremely small patients, a long flexible 17-gauge polyethylene intravenous catheter. The addition of small side holes helps to disperse the stream of O_2 more evenly within the nasal passage; however, these holes are not usually required.

For nasal O_2 tube placement, the tube is premeasured alongside the patient's face so the tube's tip, after placement, extends into the nasal cavity to the level of the first or second premolar. This facilitates flow through the ventral nasal meatus. This tube can be measured alongside the animal's teeth or by measuring from the tip of the nose to the medial canthus of the eye. After premeasuring, the tube is introduced into the nasal orifice while the patient's head is held firmly. Cats have a straight nasal passage, and the tubes generally pass easily. In the dog, pushing the tip of the nose upward allows the tube to be passed more easily into the ventral meatus. The tip is directed ventromedially (Figure 6-2). In the cat, the tube can be simply inserted straight in most cases. After this initial introduction, the tip, in both the dog and the cat, is directed ventromedially until the desired length has been inserted (Figure 6-3). Most animals object to the initial passage of the tube by sneezing and trying to shake their heads, but then they remain quiet after tube passage has been completed. If an animal objects to the insertion of the tube, slight sedation is recommended using low doses of intravenous neuroleptanalgesia (e.g., butorphanol [Torbugesic], 0.1 to 0.4 mg/kg, and diazepam [Valium], 0.05 to 0.2 mg/kg, or acepromazine .02 to .04 mg/kg).

After insertion to the level required, the tube is fixed to the skin using 3-0 or 2-0 silk suture with a swaged-on cutting needle. The

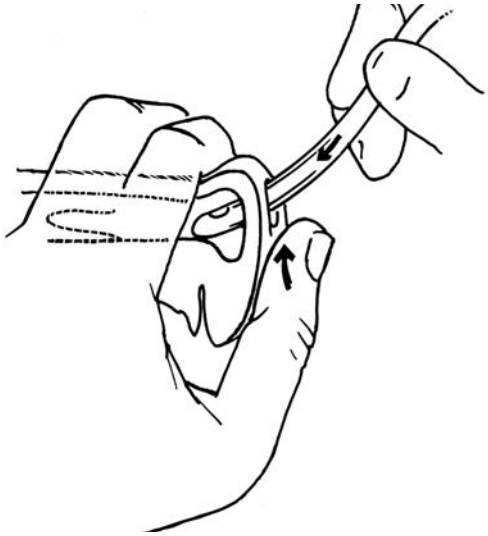


Figure 6-2. Parasagittal section showing insertion of a nasal tube through the nares. Note the ventral protuberance at the base of the nostril and the ventral direction of the tube after it passes over the small ventral protuberance. (Modified from Crowe DT. Clinical use of an indwelling nasogastric tube for enteral nutrition and fluid therapy in the dog and cat. J Am Anim Hosp Assoc 1986;22:675-678.)

most critical area requiring initial fixation is the first 0.5 cm after the tube exits from the nostril. This suture is usually *preplaced* to facilitate securing the tube immediately after it is placed. Several sutures are used to secure the tube (Figure 6-4). Each suture is placed through the skin in a "quick pass" fashion without hair clipping, aseptic preparation, or local anesthesia. After a loose simple interrupted suture is tied, the ends are wrapped around the tube and are tied again. An alternative fixation method is to apply a few drops of cyanoacrylate glue to the tube and tufts of hair on the nose and along the face, or skin staples can be used to secure the tube. Elizabethan collars are only required in patients objecting to the tube.

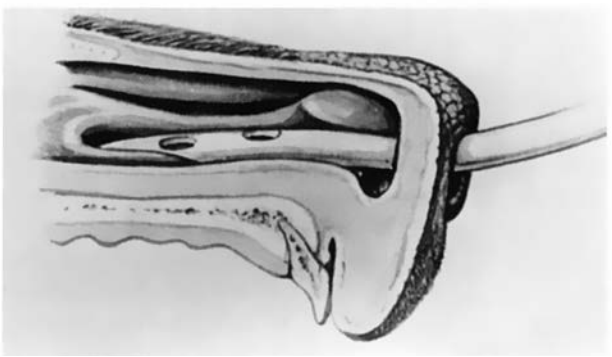


Figure 6-3. Parasagittal section showing completion of the insertion of a nasal tube to be used for oxygen delivery. The tube stops in the ventral nasal meatus just before the level of the maxillary turbinate. (From Crowe DT. Clinical use of an indwelling nasogastric tube for enteral nutrition and fluid therapy in the dog and cat. J Am Anim Hosp Assoc 1986;22:675-678.)

Oxygen Delivery Protocol

Tubing for O_2 administration (Tomac, American Hospital Supply Corp., Chicago) or an intravenous administration set is connected to the external end of the tube. The other end, in turn, is attached to the O_2 source with a standard O_2 flow meter. If O_2 supplementation for more than 24 hours is anticipated, use of a commercial humidification chamber is recommended. Alternatively, a homemade humidifier can be fashioned using a crated intravenous fluid infusion bottle. The O_2 source is attached to the vent hole, and O_2 is bubbled through warm water. Additional tubing, as necessary, is used between the patient and the humidifying unit to allow the animal freedom to move without fear of tube disconnection. The homemade humidification chamber full of water must not tip over, because this would result in rapid delivery of water into the patient's nasal passage.

For patients being resuscitated, flow rates that generate at least 60 to 80% O_2 concentrations are recommended. In patients that have hemodynamic and pulmonary stability, flow rates are decreased 50% to provide approximately 40% inspired O_2. The flow rate to provide 60 to 80% O_2 concentrations is approximately 50 mL/kg body weight per minute in small dogs and cats and approximately 100 mL/kg body weight per minute in large dogs when delivering O_2 using properly placed nasal catheters. A proportionally greater amount probably is required in large breed dogs because of a concomitant increased amount of anatomic dead space in larger animals.

After O_2 administration is begun, the patient should be observed carefully to determine the response to therapy and to identify adverse effects, which are rare. Clinical signs such as decreased anxiety and decreased respiratory rate and effort indicate an improvement in response to the O_2. Pulse oximetry can also be used to assess oxygenation. O_2 supplementation is indicated whenever O_2 saturation is below 92%. Accurate measurements are, however, sometimes difficult to obtain in the awake patient because of probe placement difficulties. In the critically ill patient, arterial blood gases should be monitored whenever possible. Partial O_2 pressures considered sufficient should be at least 60 to 65 mm Hg. If hypercapnia exists (PCO_2 greater than 50 mm Hg), mechanical ventilation rather than simple O_2 supplementation should be performed. Provided sufficient volume exchange is taking place to prevent hypercapnia, the O_2 flow rate can be increased to provide greater inspiratory O_2 concentrations if no favorable clinical response is observed or arterial PO_2 values remain below 65 mm Hg. Permissible flow rates and the corresponding O_2 percentages in the inspired air are given in Table 6-1. If after increasing the flow rates arterial O_2 values do not increase above 70 mm Hg, intermittent positive pressure ventilation (IPPV) with positive end-expiratory pressure should be instituted. If the patient's work of breathing does not improve with the high concentration of O_2, then control of breathing with IPPV should be provided. *The use of mechanical ventilation in these patients is important; otherwise, ventilatory failure and death will ensue.*

Complications

Complications with the use of nasal O_2 administration are uncommon. O_2 is dry and cool; therefore, prolonged use (more

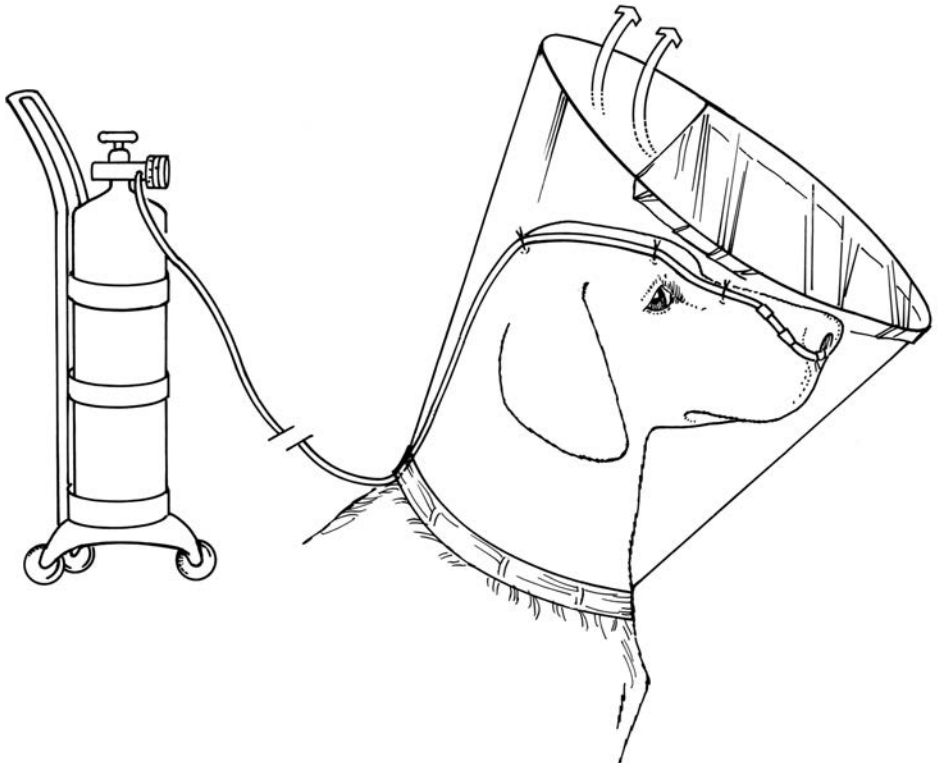


Figure 6-4. Nasal oxygen tube in place and fixated with a skin suture close to the external nares. The tube is also secured with other skin sutures. The tube could also be secured ventral to the eye and ear. Elizabethan collars with clear plastic wrap over the front can be used to increase oxygen concentrations if required. This "Crowe collar" can also be used independently to provide a rapid means of increasing inspired oxygen levels. (Modified from Fitzpatrick RK, Crowe DT. Nasal oxygen administration in dogs and cats: experimental and clinical investigation. J Am Anim Hosp Assoc 1986;22:293-297.)

Table 6-1. Oxygen Flow Rates and Estimated Corresponding Inspired Oxygen Concentrations

Flow Rate (mL/min/kg)	Inspiratory O_2 Conc. (%)
Animals weighing under 25 kg:	
50	30-40
100	40-50
I5O	50-60
*200	60-70
*250	70-80
*300	80-90
Animals weighing 25 kg or more:	
100	30-40
150	40-50
200	50-60
*250	60-70
*300	70-75
*350	75-80
*400	80-90

*** Flow rates over 200 mL/min/kg may result in gastric distension. Therefore, at high flow rates, patients should be watched for distension and the condition treated by decompression if it occurs.**

than 3 to 5 days) may cause rhinitis and sinusitis. When these complications do occur, they usually are mild and become evident as a persistent serous nasal discharge. The discharge usually clears within several days after the nasal tube is removed. The use of nasal O_2 in patients with nasal bone fractures may lead to subcutaneous emphysema. If blood is present in the nose, nasal O_2 administration is not recommended because bubble formation and foam may interfere with air exchange. In these patients, nasotracheal or transtracheal O_2 is recommended.

Tube dislodgment is an infrequent complication if the catheter is placed in the nose for a sufficient distance and if fixation of the tube is performed correctly. Persistent sneezing and continued irritation are rare and necessitate the use of repeated local anesthetic instillation, an Elizabethan collar, or light intravenous chemical sedation (e.g., oxymorphone at 0.02 mg/kg or diazepam at 0.1 mg/kg). Mild epistaxis caused by misdirection of the tube into the maxillary or ethmoid turbinates during placement may occur, but in our experience this occurs rarely and is not severe enough to warrant discontinuation of a tube's insertion or use.

Contraindications

Patients with severe tracheobronchial froth or fluid accumulation, as observed in animals with severe pulmonary edema, should receive nasotracheal or transtracheal O_2 rather than nasal O_2. Nasal tubes should be avoided in those patients with severe epistaxis or mucopurulent nasal discharge, suspicion of maxillary or cranial vault fracture after head injury, or head injury or any condition in which elevation of intracranial pressures

secondary to sneezing or struggling is contraindicated. Ineffective ventilation requiring other primary care (intubation and positive-pressure ventilation) is also a contraindication to the placement of nasal O_2 tubes.

Nasopharyngeal Tubes

Nasopharyngeal tubes allow delivery of O_2 into the nasopharynx. This method can provide high concentrations of O_2 and, if flows are high enough, some level of continuous positive airway pressure (CPAP). CPAP is even more effective if bilateral nasopharyngeal tubes are placed. As the patient exhales, it exhales against some force created by the flow of the O_2 in a caudal laryngeal direction. The goal is to create an increase in the patient's functional residual volume. This can be done with CPAP.

A nasopharyngeal tube is placed in a fashion similar to that of a nasal catheter, but the lubricated tip of the tube is continued through the ventral meatus past the maxillary turbinate. The tube is held alongside the face and neck and is premeasured from the external naris to just proximal to the larynx. In dogs, some resistance may be encountered at the maxillary turbinate region because of a narrowing of the ventral meatus in a dorsoventral direction. If the tube cannot be passed farther than the level of the eyes in dogs or cats, the tube is assumed to be in the dorsal meatus with its tip in the ethmoid turbinate. The tube must be withdrawn and redirected ventrally if this occurs. After the tip is past the maxillary turbinate in the ventral meatus, resistance to the tube's passage decreases, and the tube can be passed into the nasal pharynx and pharyngeal isthmus. The ideal location is just dorsal to the rima glottis (Figure 6-5).

High O_2 flow rates (greater than 200 mL/kg per minute) should be administered carefully when providing O_2 through nasopharyngeal tubes. Rarely, gastric distension occurs if flow rates are exceedingly high (greater than 200 mL/kg per minute) or if the nasopharyngeal catheter migrates into the esophagus. Bradycardia, believed to be vagally mediated, can also occur.

Nasotracheal Tubes

Nasotracheal tubes provide an effective means of providing O_2 to the patient that has laryngeal palsy or a collapsing cervical trachea. These catheters also generate some degree of CPAP when high flow rates are used. Patient tolerance is usually good, with little coughing. In animals that do not tolerate the tubes, mild sedation may be required.

Before placement of a nasotracheal tube, the tube should be premeasured such that the tip will rest at the level of the tracheal bifurcation or fifth intercostal space. A 3.5- to 8-French feeding tube is generally used. The tube is placed in a fashion similar to that of a nasopharyngeal catheter. The tube is passed blindly into the trachea through the larynx by hyperextending the patient's head and neck and advancing the tube (Figure 6-6). If coughing is noted, another 0.33 mL of local anesthetic is infused through the tubing, with the tubing in the mid distal pharynx. Once the membranes around the larynx are anesthetized, the tube is advanced as inhalation occurs. If the tube does not pass after several attempts, a short-acting neuroleptoanalgesic can be

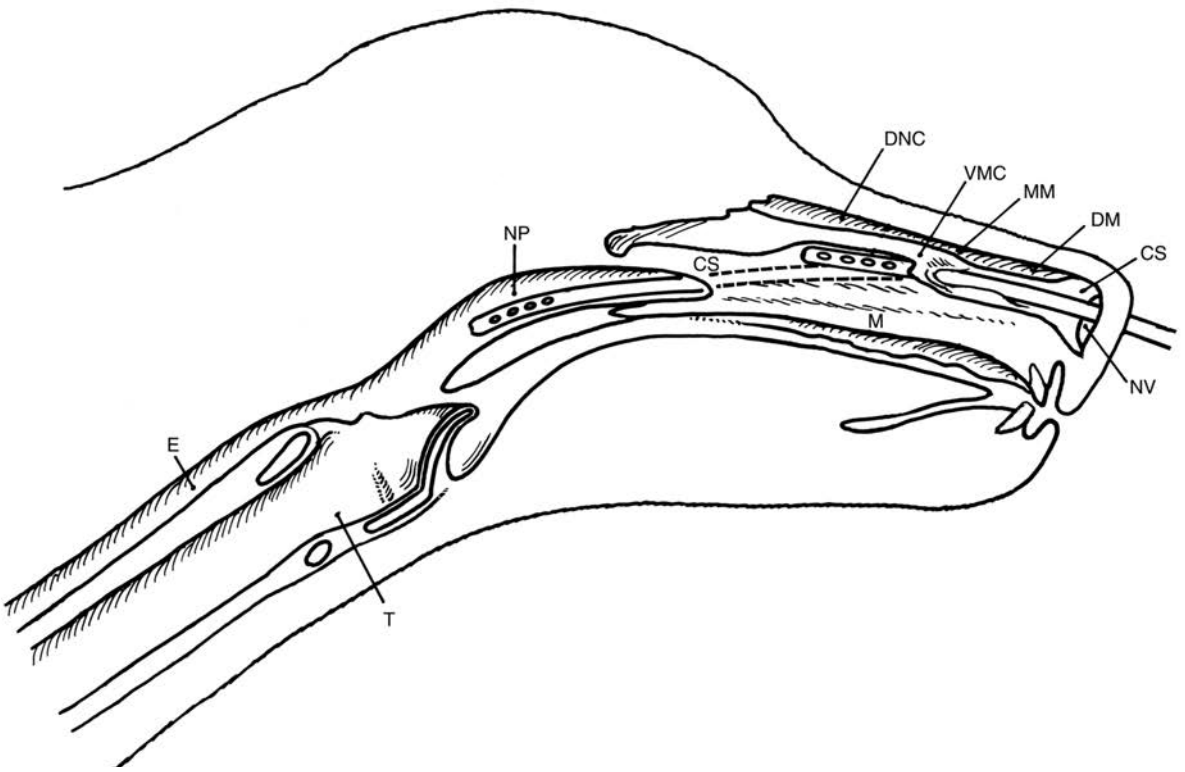


Figure 6-5. Parasagittal section showing the insertion of a nasopharyngeal oxygen tube through the nasal passage and into the nasopharynx. Structures identified include the nasal vestibule (*NV*), cartilaginous septum (*CS*), maxilia (*M*), dorsal meatus (*DM*), middle meatus (*MM*), ventral nasal concha (*VNC*), dorsal nasal concha (*DNC*), and nasopharynx (*NP*). (Modified from Crowe DT. Clinical use of an indwelling nasogastric tube for enteral nutrition and fluid therapy in the dog and cat. J Am Anim Hosp Assoc 1986;22:675 678.)

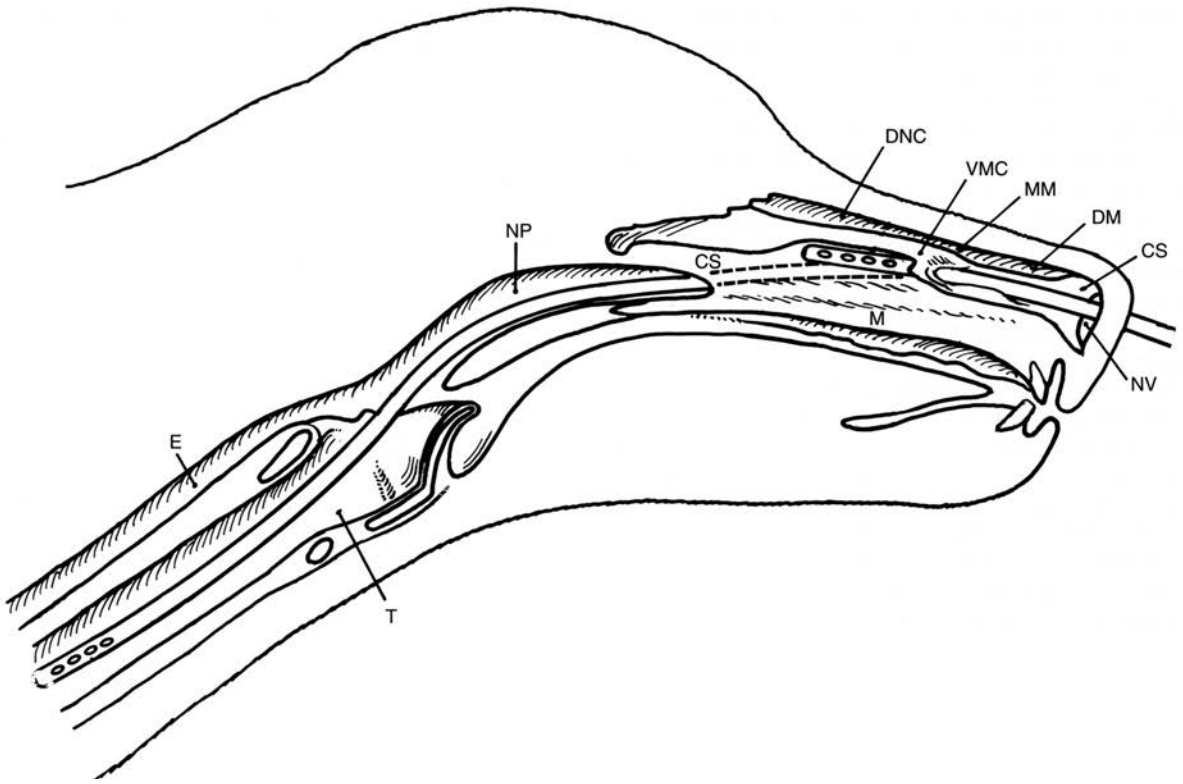


Figure 6-6. Parasagittal section showing the insertion of a nasotracheal oxygen tube through the nasal passage and into the trachea. Structures identified include the nasal vestibule (*NV*), cartilaginous septum (*CS*), maxilla (M), dorsal meatus (*DM*), middle meatus (*MM*), ventral nasal concha (*VNC*), dorsal nasal concha (*DNC*), nasopharynx (*NP*), esophagus (*E*), and trachea (*T*). (Modified from Crowe DT. Clinical use of an indwelling nasogastric tube for enteral nutrition and fluid therapy in the dog and cat. J Am Anim Hosp Assoc 1986;22:675-678.)

administered to the patient, and the tube can be placed by direct visualization using a laryngoscope and something to grasp the tip of the tube and direct it through the rima glottis into the trachea.

The position of the tube should be confirmed with a radiograph or by aspiration using a 60-mL syringe. If the tube is in the trachea, air should continue to be aspirated easily. If the catheter is in the esophagus, air may be initially aspirated, but it should stop.

The nasotracheal tube is used in a fashion similar to that of nasal and nasopharyngeal tubes. For nasotracheal catheters, flow rates are decreased by 50% from those recommended for nasal O_2 tubes to provide equivalent O_2 concentrations. Humidification of the O_2 is essential with the use of nasotracheal tubes, to prevent mucosal drying and dysfunction of the mucociliary apparatus, which can lead to an inability to clear secretions and possible pneumonia. Infusion of saline through the nasotracheal tube can be used to help loosen secretions in patients with dysfunction of the mucociliary apparatus or pneumonia.

Tubes for Gastrointestinal Access

Indications

NEO, NG, and NET tubes can be used for decompression and feeding. Smaller bore NEO, NG, and NET tubes are useful for the administration of water, electrolytes, and liquid enteral support diets. Because dehydration and protein–energy malnutrition frequently are encountered in seriously ill or injured animals, the use of these indwelling tubes for rehydration and nutritional support often is a key component in successful overall patient management. Contraindications to use of NEO or NG fluid and nutritional therapy support include persistent vomiting and high gastric residual volumes. The presence of stupor or coma is a relative contraindication to NEO and NG feeding, particularly if bolus feeding is provided. If slow, continuous-rate infusions result in minimal residual volumes, then the risk of regurgitation and aspiration is low enough that NEO or NG feeding can be used.

Decompression of a dilated esophagus, stomach, or intestinal tract can be accomplished by use of large-bore single lumen or double-lumen (sump) NEO, NG, or NET tubes. Decompression of the esophagus alleviates some of the risk of aspiration in the patient with megaesophagus and actively decreases the stretch in the skeletal muscle that results in dilatation. In the stuporous or comatose patient, or in the patient receiving mechanical ventilation, active decompression helps to prevent aspiration. In the patient having difficulty ventilating, decompression of the stomach improves ventilation because of reduced impedance to diaphragmatic excursions. This is particularly helpful in cats and small dogs because they breathe primarily using the diaphragm. Clinically, NG decompression has been helpful in the temporary management of gastric dilation–volvulus syndrome when the gastric distension has been due primarily to air and fluid. Decompression of the stomach after abdominal surgery helps to decrease the time to return to normal gastric motility. After placement, the NG tube is periodically aspirated (e.g., once every 1 to 2 hours). The tube is left in place until bowel sounds return or the patient is believed to be out of danger of postoperative redistension. Antral dilation

is a strong stimulus for vomiting. The use of NG tubes decreases the incidence of vomiting in the patient with gastrointestinal or pancreatic disease and is especially useful in the patient with canine parvovirus infection.

Tube Selection and Insertion

The techniques for inserting an NEO, NG, or NET tube for decompression or feeding are the same. Polyvinyl chloride (Argyle nasogastric feeding tube, Sherwood Medical Products), polyurethane (Cook Critical Care), or red rubber tubes from 3.5 French (cats and small dogs) to 12 French (medium to large dogs) are used. Specially designed tubes that are weighted on their proximal ends with either tungsten or mercury are useful to ensure that the tube will stay in the stomach lumen (Travasorb dualport feeding tube, Baxter Health Care Corp., Deerfield, IL). The smaller the tube, the more difficult it is to use for decompression. A nylon stylet that accompanies commercial polyurethane tubes provides added stiffness necessary for insertion. With smaller polyvinyl chloride tubes, a woven angiographic wire stylet (Wire guide, Cook Critical) is used to provide added stiffness. One or two milliliters of vegetable or mineral oil is injected into the lumen of a tube to facilitate ease of insertion and withdrawal of the woven wire through the lumen.

After selection of the tube and placement of the stylet, the length necessary to reach the distal thoracic esophagus (NEO) or the stomach (NG) is determined by measuring alongside the patient's neck and body from the tip of the nose to the eighth or ninth rib for NEO tubes or to the thirteenth rib for NG tubes (Figure 6-7). For NET tubes, length is added to ensure that the tip of the proximal end of the tube will reach the area of the bowel lumen selected. Most often, the tube for enteral feeding is a nasoduodenal tube with a tip that ends near the pelvic flexure of the duodenum. The tube in these cases is premeasured to extend from the nose to the wing of the ilium (See Figure 6-7).

The lubricated tip of the tube is introduced into the patient's nostril in the same manner as described for nasopharyngeal tubes. After the tip is past the maxillary turbinate in the ventral meatus, resistance to the tube's passage decreases, and the tube can be passed into the nasal pharynx and pharyngeal isthmus. At this point, the patient's head must be kept in a neutral position, with the neck gently flexed to facilitate passage of the tube into the esophagus (Figure 6-8). If the neck is hyperextended, the tube may enter the larynx and trachea. With continued advancement of the tube, the patient is often observed to swallow several times. Once the tip of the tube has been advanced into the caudal thoracic esophagus (NEO tube) or into the proximal portion of the stomach (NG tube), the lubricated stylet is withdrawn. The

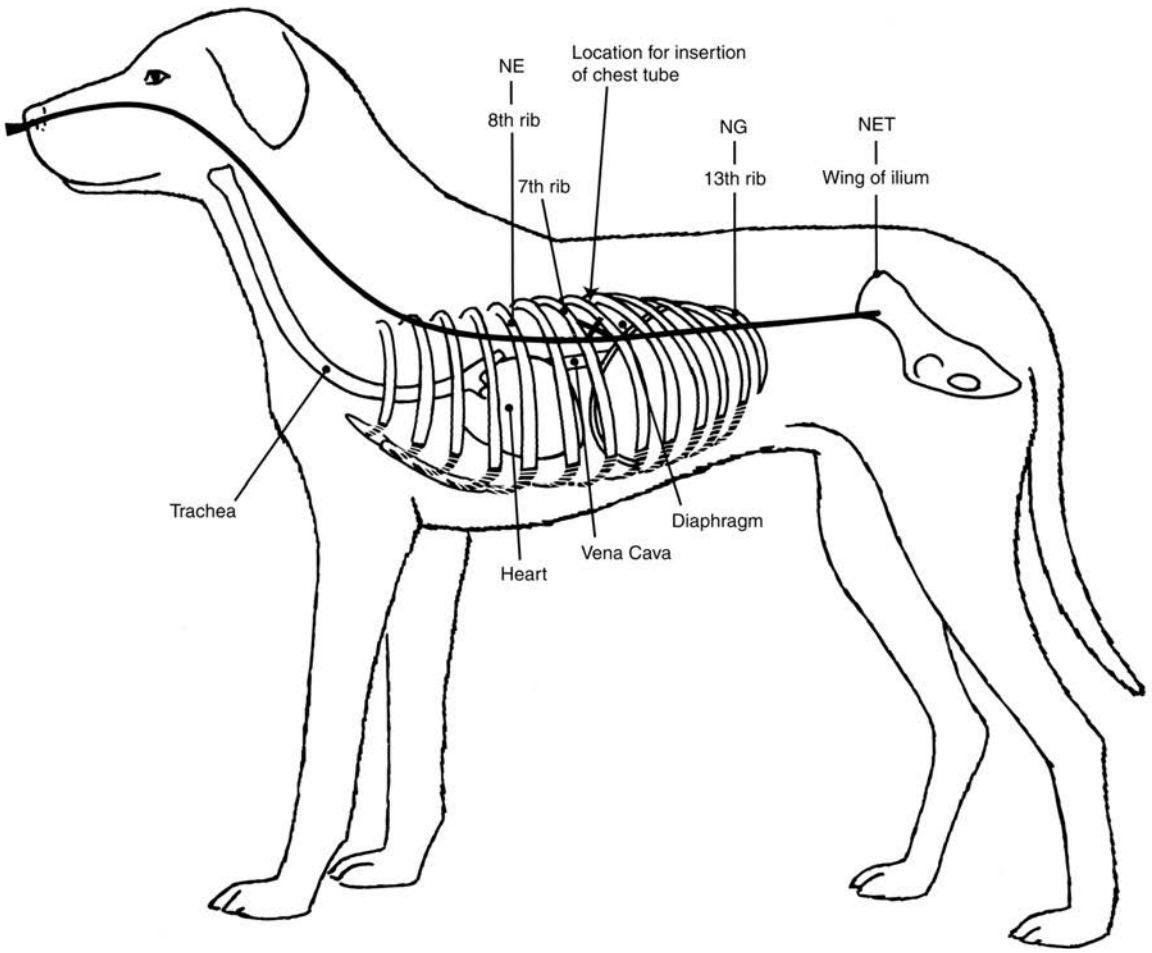


Figure 6-7. Drawing depicting landmarks used to premeasure the various feeding or decompression tubes. The tube should be premeasured from the tip of the nose of the animal to the eighth rib for nasoesophageal (*NE*) tubes, to the thirteenth rib for nasogastric (*NG*) tubes, and at least to the wing of the ilium for nasoenteric (*NET*) tubes.

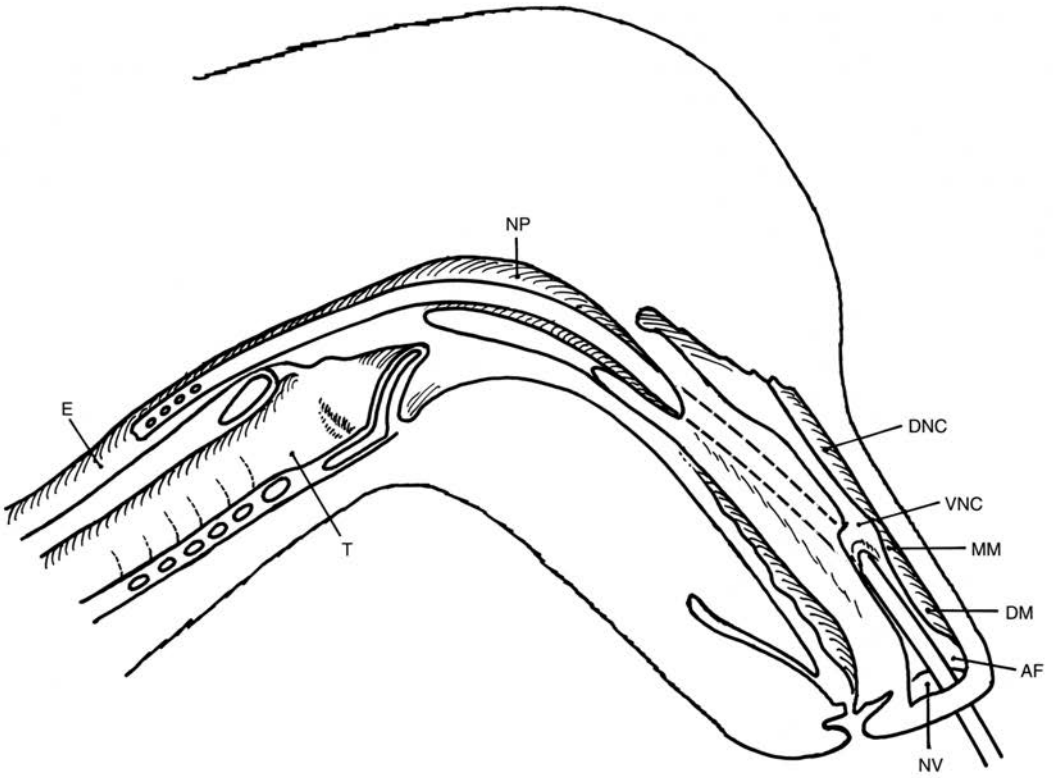


Figure 6-8. Parasagittal section showing the insertion of a nasogastric tube through the nasal passage and into the esophagus. The head is bent to help the tube follow the dorsum of the wall of the pharynx and then course dorsally into the esophagus. Structures identified include the nasal vestibule (*NV*), cartilaginous septum (*CS*), dorsal meatus (*DM*), middle meatus (*MM*), ventral nasal concha (*VNC*), dorsal nasal concha (*DNC*), alar fold (*AF*), nasopharynx (*NP*), esophagus (*E*), and trachea (*T*). (Modified from Crowe DT. Clinical use of an indwelling nasogastric tube for enteral nutrition and fluid therapy in the dog and cat. J Am Anim Hosp Assoc 1986;22:675-678.)

use of a stylet also helps to facilitate the passage of the tube into the stomach through the cardia.

Air is injected into the tube while auscultation of the left chest wall and left paralumbar fossa is performed; the presence of gargling sounds during this procedure indicates that the tube is in the distal esophagus or stomach, respectively. In most cases, a lack of coughing during injection of 5 to 10 mL of sterile saline down the tube indicates that the tube is not in the trachea. However, the result of this test may vary with the individual animal, and the position of all tubes should be radiographically confirmed if they are to be used for infusion of fluids or liquid diets.

Special tubes or manipulations are required for placement of NET tubes into the duodenum or jejunum. The tube can be guided by peristaltic action into the duodenum, but this is often difficult to accomplish. The tubes can be guided through the pylorus using endoscopy or fluoroscopy. NET tubes have been most successfully placed at the time of abdominal surgery by the surgeon guiding the tip of the tube, which is palpated and guided through the stomach and intestine into the portion of the bowel intended. Weighted tungsten or mercury tubes have been used to help in guiding tubes through the stomach into the intestine (Travasorb dualport feeding tube, Baxter Health Care Corp.). The weighted tip also may help to ensure that the tube will stay in the bowel lumen and not curl or kick back into the stomach. Passage of the tube into the small intestine through the action of peristalsis has been unreliable, particularly in sick patients with at least some degree of gastroparesis. Metoclopramide, 0.4 mg/kg per day intravenously, has been used to help stimulate gastric motility to facilitate the tube's passage into the duodenum.

Once the tip of the tube has been placed in the desired location, the tube is secured with several sutures placed at the base of the nostril and around the tube, or with glue as described previously for nasal O_2 tubes. If the tube demonstrates a tendency to back out of the nose, 1 to 2 cm of coated copper wire (18 gauge telephone wire) can be used to support the bend in the tube as it exits from the nose. On occasion, the tube may back out of the intestine, or the dog or cat may vomit the tubes into the mouth. In this case, the tube must be removed. A narrow gauge flexible wire can sometimes be left in the tube to help prevent tube migration. Specially designed catheters are also available that allow the delivery of nutrients while the wire is left inside the catheter lumen.

The remaining length of the tube or an attached extension tube (intravenous administration extension set) is secured to the top of the patient's head or the side of the face. An Elizabethan collar can be applied if necessary. The end of the tube is capped to prevent air from entering the gastrointestinal tract by diaphragmatic movement until its use is required.

Protocol for Using Tubes for Decompression

A 60-mL syringe is attached to the end of the tube, and aspiration is done as often as required to keep a slight amount of negative

pressure on the hollow viscus aspirated. For prevention of recurrence of gastric dilation or for decompression of the small intestine, aspiration generally is performed every 1 to 2 hours until a negative pressure is reached each time. If the fluid aspirated is viscous, dilution with sterile water or saline may be required. The tube should be flushed with a small amount of saline or water each time the tube is used, and then the tube should be capped. Holding the column of water in the tube helps to prevent clogging. Maintenance of decompression usually is required only for 24 to 48 hours because most intestinal ileus or gastroparesis is resolved by then.

The efficiency of gastrointestinal decompression achievable with a simple single lumen tube (Argyle stomach tube (Levine Type), Sherwood Medical Products) and intermittent aspiration with a syringe can be improved by the use of a double lumen sump tube (Salem sump tube, Sherwood Medical Products) with continuous 20- to 30-mm Hg suction or intermittent mechanical 80- to 90-mm Hg suction. This type of suction requires the use of specially designed equipment. Automatic intermittent suction, for example, is often best performed with the use of a thermotic drainage pump that is electronically driven (Thermotic drainage pump, GOMCO, Allied Healthcare Inc., Buffalo, NY). Fortunately, in most clinical patients, this type of special equipment is not necessary, and simple intermittent syringe decompression is sufficient.

Protocol for Using Tubes for Feeding

For the administration of fluids and liquid enteral diets, a syringe is used for slow bolus delivery. Slow bolus delivery of fluids and liquid enteral diets can be done safely through NEO and NG tubes in animals that are conscious. However, bolus feeding is not recommended in unconscious or semiconscious patients because of the higher risk of pulmonary aspiration. Bolus feeding should not be done through an NET tube initially because of the high occurrence of vomiting and diarrhea, which can be caused by the acute overload of hyperosmolar nutrients in the small intestine. Drip infusion is the preferred method of the delivery in these circumstances. A pediatric intravenous fluid administration set and bottle are used for the delivery of enteral diets. The use of an enteral or intravenous infusion pump or a syringe facilitates the delivery of these enteral liquid diets.

Initially, an electrolyte and glucose mixture is administered at a rate of 0.25 to 0.5 mL/kg per hour. This rate can be used in all patients including those that have had gastrointestinal surgery; however, it may be too fast for those patients that have undergone massive bowel resections or have pancreatitis. In such patients, the initial rate infused should be no greater than 0.1 to 0.2 mL/kg per hour. The drip rate is steadily increased until caloric requirements are met. Rates higher than 4 mL/kg per hour are usually associated with severe, osmotically induced diarrhea; therefore, the maximum rate usually used for constant rate infusions is 2.0 to 3.0 mL/kg per hour.

Many monomeric and polymeric liquid diets are available for tube feeding. Monomeric or elemental diets are composed of amino acids (Vivonex, Sandoz Nutrition, Minneapolis MN; Alitraq, Ross Laboratories, Columbus, OH) or dipeptides and tripeptides (Peptamen, Clintec Nutrition Co., Deerfield, IL) and require no digestion before absorption. The amino acid–based diets tend to be hyperosmotic and may require dilution initially to a 50% concentration. They usually are more expensive than polymeric diets, but they may be useful in patients with decreased digestive ability. The dipeptide- and tripeptide- based diets tend to be isosmolar and can generally be given initially at full strength concentration. Polymeric diets (Impact, Sandoz Nutrition; Jevity, Ross Laboratories) are made of complex carbohydrates and proteins and require digestion before absorption, but they are usually isosmotic unless they are flavored. Special polymeric diets designed specifically for cats and dogs (CliniCare and RenalCare, Pet Ag Inc., Hampshire, IL) have been developed and have been clinically effective in providing nutritional support to critically ill or injured dogs and cats. Polymeric diets are usually administered either full strength if plasma proteins are normal and anorexia has not been present for longer than 3 days. If plasma protein levels are below normal or anorexia has been present for longer than 3 days the diets should be initially diluted to a 50% concentration with water. The monomeric diets may require dilution to 25% concentration for initial administration. After the rate of administration is stabilized at 2 to 3 mL/kg per hour and the diet is found to be tolerable (no abdominal pain, vomiting, or diarrhea), the concentration of the diet can be gradually increased.

Complications

Complications with feeding and decompression tubes are primarily associated with tube migration, especially dislodgment. Dislodgment is usually caused by vomiting or by the animal's pawing at the tube or rubbing its face.

When concern exists about the location of the tip of the tube, a radiograph should be taken to ensure that the location is correct. Disaster can occur if a tube is displaced into the trachea and food is administered.

Suggested Readings

Crowe DT. Clinical use of an indwelling nasogastric tube for enteral nutrition and fluid therapy in the dog and cat. J Am Anim Hosp Assoc 1986;22:675 678.

Crowe DT. Use of a nasogastric tube for gastric and esophageal de compression in the dog and cat. J Am Vet Med Assoc 1986; 188:1178 1182.

Crowe DT. Enteral nutrition for critically ill or injured patients. Part I. Compend Contin Educ Pract Vet 1986;8:603.

Crowe DT. Enteral nutrition for critically ill or injured patients. Part II. Compend Contin Educ Pract Vet 1986;8:826.

Fitzpatrick RI, Crowe DT. Nasal oxygen administration in dogs and cats: experimental and clinical investigations. J Am Anim Hosp Assoc 1986;22:293 297.

Esophagostomy Tube Placement and Use for Feeding and Decompression

Dennis T. Crowe and Jennifer J. Devey

Esophagostomy tubes provide a simple and effective means of administering fluid and nutritional support to the small animal patient. The tubes can also be used for esophageal or gastric decompression.[1] Esophagostomy tubes can be rapidly placed (generally within 5 minutes) and require minimal surgical equipment (a scalpel blade, a pair of curved forceps, and nonabsorbable suture material). Simple red rubber feeding tubes are most frequently used. Patients have been fed for up to 2 years using these tubes. No cases of esophageal stricture or permanent esophagocutaneous fistula have been observed.

Indications

Esophagostomy tubes are indicated whenever nutritional support is required and the stomach is functional but the patient is unwilling or unable to ingest food or water. Esophagostomy tubes can also be used to keep the stomach and esophagus decompressed because aspiration of these tubes helps to prevent air or fluid from accumulating. This may be useful in the management of patients with megaesophagus or those that have undergone surgical correction of gastric dilatation–volvulus.

Esophagostomy tubes were developed and first used in clinical veterinary medicine by Crowe.[2] They were developed and used to avoid the airway difficulties associated with pharyngostomy tubes (Figure 6-9).[3] With pharyngostomy tubes, a portion of the tube can interfere with laryngeal function, even after careful placement using modified techniques. The surgical approach for placement of the esophagostomy tube is simpler than that of the pharyngostomy tube, with less likelihood of damage to vital vascular and neurologic structures. Percutaneous gastrostomy tubes require special feeding tubes and because of penetration of the stomach and peritoneal cavity, the risk of leakage and subsequent development of peritonitis always exists. From our experience, the patient does not need to be subjected to these risks, and, whenever possible, an esophagostomy tube should be selected over a gastrostomy tube. Most conditions for which clinicians use percutaneous gastrostomy tubes for feeding can be also managed with esophagostomy tubes. Esophagostomy tubes can be used in patients that have had esophageal surgery; however, care should be taken to ensure that a smaller bore flexible feeding tube is used and that the end of the tube is not rubbing against a wound site or surgical incision.

Contraindications

In general, esophagostomy tubes should not be used for feeding or decompression if the patient 1) is vomiting, 2) has cervical or thoracic esophageal disease that will be worsened by the placement of a tube passing through the affected area, and 3) has

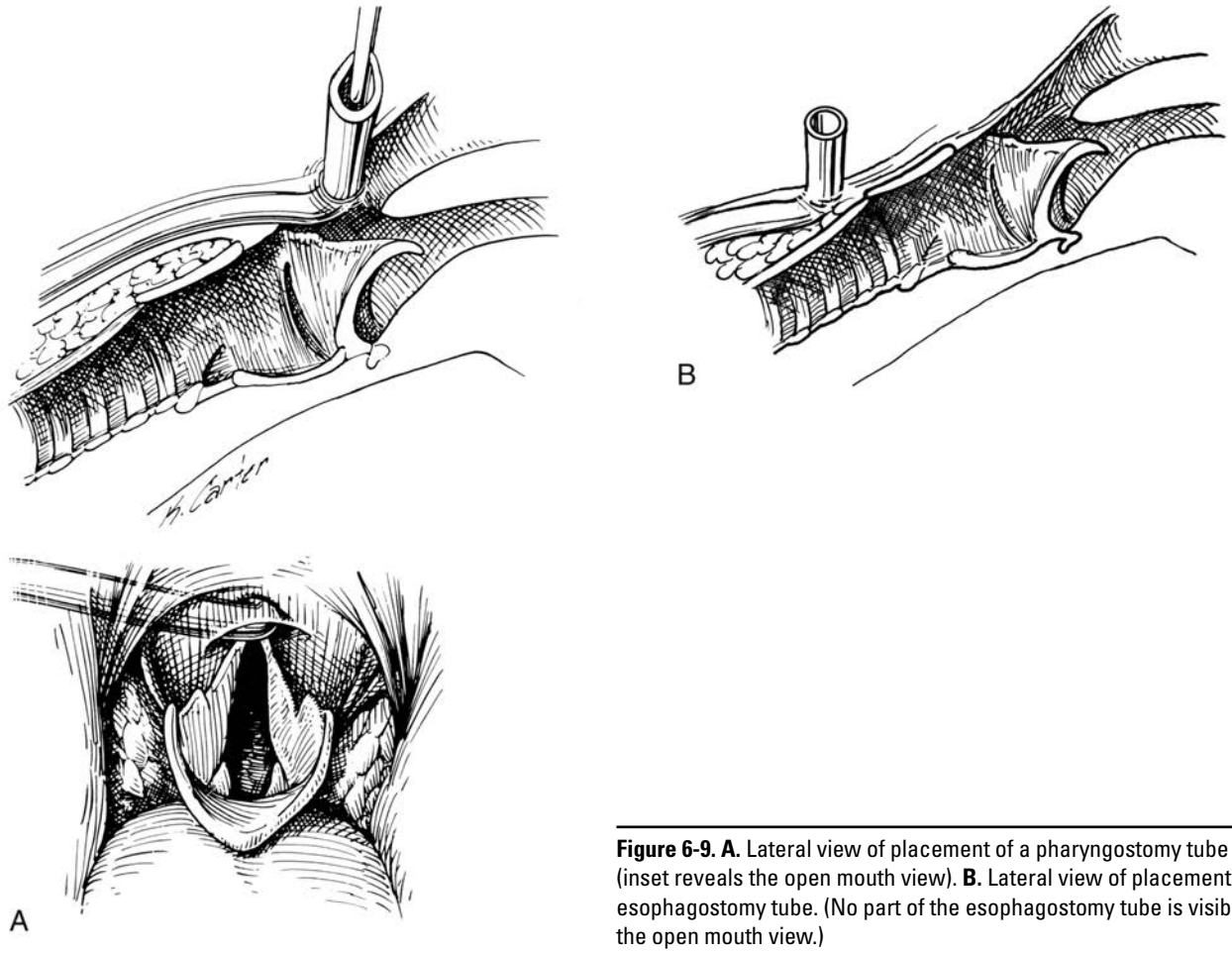


Figure 6-9. A. Lateral view of placement of a pharyngostomy tube (inset reveals the open mouth view). **B.** Lateral view of placement of an esophagostomy tube. (No part of the esophagostomy tube is visible in the open mouth view.)

an infection involving the cervical region close to the tube exit site. Because placement of esophagostomy tubes requires light general anesthesia, the risks of anesthesia should be weighed against the benefits of the placement of esophagostomy tubes in critically ill animals.

Tube Selection

The type and length of tube selected depends on the intended use of the tube. Esophagostomy tubes used for feeding or for esophageal decompression (i.e., for long term management of megaesophagus) should end in the distal thoracic esophagus. Tubes that pass through the lower esophageal sphincter increase the risk of gastroesophageal reflux in some patients. For gastric decompression or feeding, whenever the esophagus needs to be bypassed, an esophagogastric tube is placed with the tip of the tube resting in the midfundic region of the stomach. An esophagoenteral tube can also be placed at the time of abdominal surgery if the stomach needs to be bypassed. The proximal end of the tube should be shortened as required, so only sufficient tubing protrudes from the skin to permit attachment to a syringe for feeding or decompression. Excessive tube length protruding from the skin may be annoying to the animal and may catch on objects.

Esophagostomy tubes used for feeding or decompression should be flexible and in general of as large a bore as possible. This provides less chance for kinking and occlusion. The actual size of each tube selected depends on the size of the animal and on the intended purpose for the tube (Table 6-2). Generally, no tube smaller than 10 French should be used for decompression or if a canned or gruel diet is to be used for feeding. For small cats and dogs, a 10- to 12 French tube is used. For medium sized dogs, a 12- to 18 French tube is used, and for large to giant breed dogs, an 18- to 30 French tube is inserted. When using the tube only for the delivery of liquids, smaller-diameter tubes can be used. Tubes should be flexible yet stiff enough to resist kinking. Commonly, tubes made of red rubber (Sovereign, Sherwood Medical Products, St. Louis, MO), polyvinyl chloride (Argyle feeding catheter, Sherwood Medical Products; Cook Critical Care, Bloomington, IN), polyurethane (Cook Critical Care), Teflon (Cook Critical Care), and silicone (Baxter Health Care Corp., Deerfield, IN) are used. Tubes made of polyurethane or silicone resist the hardening caused by gastric fluids and are recommended if one anticipates that the tube will be used for longer than 1 week. Commercially available tubes frequently require the addition of three to five side holes. These holes can be made carefully using curved scissors. The diameter of the holes should not exceed approximately 20% of the tube's circumference.

Table 6-2. Guidelines for Esophagostomy Tube Size Selection*

	Decompression	Feeding	
Body Weight (kg)	Gastric or Esophageal	Gruel	Liquids Only
< 1	8-10	10	3.5-6
1-3	10	10	6
3-5	10-12	10-12	6
5-10	12-18	12-18	8
10-20	14-20	14-20	8
20-30	20-26	20-26	10
30-40	26-28	26-28	10
> 40	28-30	28-30	12

*** All tube sizes are in French.**

Surgical Technique

Tube Esophagostomy

Light general anesthesia is induced and is maintained throughout the procedure. The airway is protected with a cuffed endotracheal tube. The entire lateral cervical region from the ventral midline to near the dorsal midline is clipped and is aseptically prepared for surgery. Usually, the left side is chosen; however, both sides can be used. The procedure is illustrated in Figure 6-10. Curved forceps are inserted into the pharynx and then into the proximal cervical esophagus. Curved Kelly forceps are recommended for use in cats and small dogs. In larger dogs, longer curved Carmalt, Mixter, or Schnidt forceps are recommended. The tips of the forceps are turned laterally, and pressure is applied in an outward direction, thereby tenting up the tissues so the tips can be seen and palpated (Figure 6-10A). A small skin incision (just large enough to accommodate the tube) is made over the tips of the forceps using a scalpel blade, and the tips of the forceps are bluntly forced to the outside (Figure 6-10B). In larger animals, as continued pressure is applied, the scalpel blade is used to cut through the thicker esophagus and to allow passage of the forceps.

The selected tube is premeasured and marked using the landmarks listed in Table 6-3. Esophagostomy tubes are usually measured to the level of the xiphoid or ninth intercostal space. Esophagogastrostomy tubes are measured to the thirteenth rib.

The tip of the tube is grasped by the forceps (Figure 6-10C) and is pulled into the esophagus and out through the mouth (Figure 6-10D). The aboral tip of the tube is turned around and is redirected into the esophagus. The tube is then pushed into the esophagus with the aid of the forceps (Figure 6-10E) By retracting the external end of the tube 2 to 4 cm, the tube is felt to "straighten," and then it passes more easily. The tube is then passed to the premeasured mark. The oropharynx is visually examined to confirm location of the tube in the esophagus. Ideally, the location of the tip should be confirmed with a lateral radiograph in patients with megaesophagus, esophageal stricture, or any other unusual condition involving the esophagus.

An alternative method of confirming appropriate location of the tube in the distal esophagus involves passing the tube into the stomach. Placement is checked by infusing 30 mL or more of air (using a syringe) and ausculting for bubbles over the stomach region. Once bubbles are heard, the tube is retracted to locate the tip in the distal esophagus. If bubbles are not ausculted in the desired location, a chest radiograph should always be taken to confirm appropriate location.

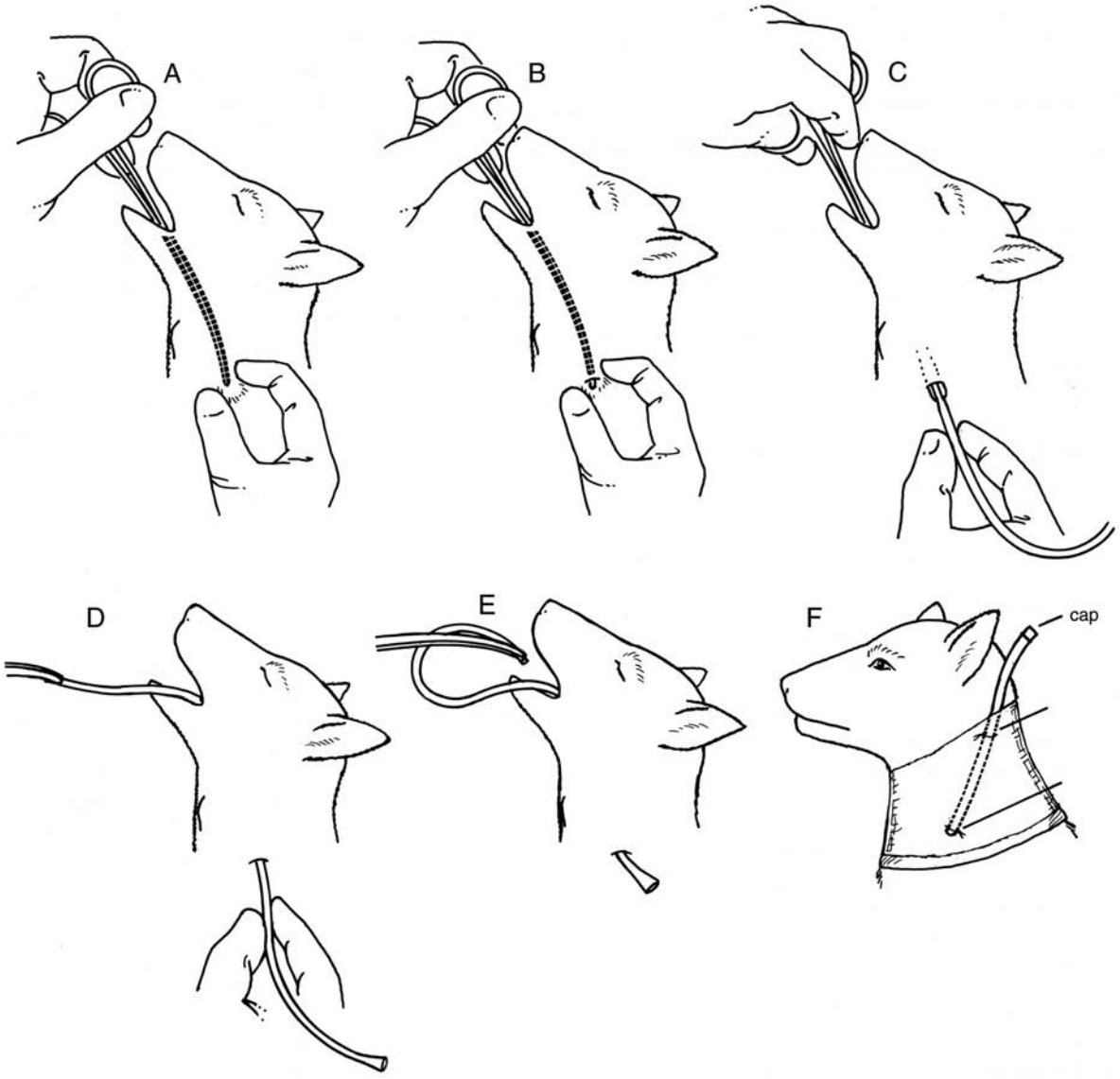


Figure 6-10. Drawing illustrating placement of a large bore esophagostomy tube using curved hemostats. **A**. The hemostats are inserted into the oral cavity, oropharynx, and proximal esophagus; then the tips are pushed laterally. **B.** A skin incision is made, and the tips of the hemostats are pushed through the wall of the esophagus and the subcutaneous tissues. **C.** The flexible feeding tube is grasped with the tips of the hemostats. **D.** The tube is pulled out through the mouth with the hemostats. **E.** The tube's tip is regrasped with the hemostats and is guided down the pharynx and esophagus. **F.** The tube is pulled gently to straighten the curve in the tube, and after it is advanced so the tip is in the midthoracic esophagus, it is anchored with a suture that enters the fascia and periosteum around the wing of the atlas.

The tube is secured to the periosteum of the wing of the atlas or deep fascia using nonabsorbable suture (Figure 6-10F). The suture is secured to the tube by using several wraps of the suture around the tube. The tube should also be secured to the skin where the tube exits. Care should be taken not to tighten the suture to the point that it binds the skin to the tube because this may cause irritation and necrosis.

Percutaneous Esophagostomy Tube Placement

An alternative technique for placement of smaller-bore esophagostomy tubes that are only used for administration of water and other liquids involves percutaneous insertion of a long 10- to 14-gauge venous catheter (Intracath, Becton Dickinson, Sandy, UT) into the esophagus.[4] This "needle" esophagostomy tube can be inserted under sedation without passage of an endotracheal tube. Curved Kelly forceps are passed into the pharynx and proximal esophagus similar to the procedure described for surgical esophagostomy tube placement. The tips of the forceps are then turned outward and are opened slightly so they can be palpated. The needle is inserted through the skin into the target location between the tips of the forceps. Once a popping sensation is felt, indicating puncture of the esophagus, the catheter, with the stylet backed out slightly, can be passed through the needle and down to the premeasured location in the distal third of the esophagus. The catheter is sutured to the cervical fascia and skin in a manner similar to that described for surgical esophagostomy tubes. Sterile saline is then injected through the catheter to ensure good fluid flow. If one has any question about the location of the catheter, a lateral radiograph should be taken.

Table 6-3. Premeasured Landmarks Where Distal End of Tube Should Reach

Type of Tube	Landmark
Esophagoesophagostomy for decompression	Slightly caudal to point of maximum intensity of heart tones (ninth ICS)
Esophagoesophagostomy for feeding	Point of maximum intensity of heart tones (6th ICS)
Esophagogastrostomy for decompression	Thirteenth rib corresponding to midgastric region
Esophagogastrostomy for feeding	Thirteenth rib corresponding to midgastric region
Esophagoenterostomy for feeding	Wing of ilium (or whatever is necessary for surgeon manipulating the tube)

ICS, intercostal space.

Bandaging

A 4x4 gauze dressing containing chlorhexidine, povidone–iodine, or triple antibiotic ointment is placed over the tube's exit site in the skin, and a light circumferential wrap is placed. The end of the tube should be capped to prevent spontaneous air or fluid movement through the tube. Commercial feeding tubes are supplied with caps. For most noncommercial tubes, the cap to a hypodermic needle makes a tight fit and easily can be removed.

Care of the Tube

A "trap door" is made in the bandage to allow inspection, cleaning, and 4x4 gauze dressing changes (Figure 6-11). The ostomy site should be inspected on a daily basis for the first 5 days after insertion, then every other day for 10 days, then every 3 days thereafter. The ostomy site should be cleaned of exudate with a dilute bactericidal solution suitable for using on wounds or a 50:50 mixture of 3% hydrogen peroxide and sterile saline.

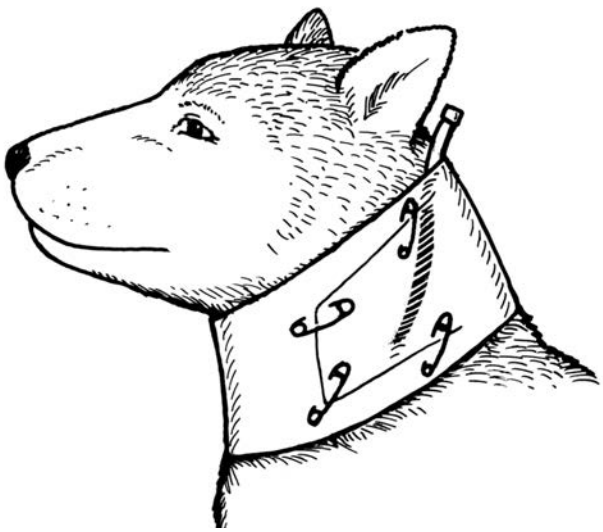


Figure 6-11. Drawing illustrating the cervical dressing covering the esophagostomy tube. A trap door over the tube's exit site at the skin is made and is held closed with four safety pins when it is not needed.

Triple antibiotic ointment is then applied, and the 4x4 gauze dressing is replaced.

Procedure for Administration of Fluids and Liquids

Fluids (crystalloids, oral rehydrating solutions, water) and liquid diets can be infused as a constant rate infusion using an administration set and pump similar to that used for intravenous crystalloids. Rates should be set at 1 mL/kg per hour initially. The infusion can be gradually increased by 1 mL/kg per hour until the desired infusion rate is achieved. The infusion rate should not exceed 6 mL/kg per hour.

Fluids, liquid medications, and liquid diets can also be infused slowly using a syringe. The esophagostomy tube should be flushed with water (5 to 60 mL, depending on the size of the tube and patient) after every bolus feeding or every 6 hours in patients fed by constant rate infusions.

Procedure for Administration of Gruel Diets

Gruel diets should be blenderized to ensure that no large particles that may cause an obstruction are infused. If one has any doubt about whether the gruel is liquid enough to pass through the tube, the gruel should be infused through a tube of equivalent diameter first. Boluses should be limited to less than 5 mL/kg initially. Rates can be slowly increased based on patient tolerance. The feeding should be stopped if one sees evidence of salivation, regurgitation, or vomiting or if the animal appears nauseated or uncomfortable. Boluses should not be larger than 25 mL/kg at one time. A bolus should not be given rapidly, and extremely hot or cold materials should not be infused. Immediately after the conclusion of the bolus feeding, the tube should be flushed with water. This helps to prevent the gruel from remaining in the tube where, over time, it may become inspissated and cause an obstruction. A plastic shield or plastic wrap should be used to cover the bandage when infusions are administered to prevent soiling of the dressing.

Procedure for Use for Decompression

Esophagostomy tubes ending in the esophagus can be used to keep the esophagus decompressed in the patient that has poor esophageal motility. Patients with chronic megaesophagus, persistent right aortic arch, or acute megaesophagus are at increased risk for pulmonary aspiration and may benefit from esophageal decompression.[2] Decompression is performed by aspirating the tube periodically until all the retained air, fluid, and other material is removed. Esophagostomy tubes ending in the esophagus or stomach can also be used to prevent the recurrence of gastric dilatation in patients recovering from surgery to correct gastric dilatation–volvulus. Studies in human patients have shown that, by preventing passage of air into the stomach, patients return to full oral feeding much more rapidly.[5] This finding is assumed, but not proved, to be true in dogs and cats. The tube can be hand suctioned as frequently as needed or connected to a continuous suction device (GOMCO, Allied Healthcare, Buffalo, NY). If viscous or tenacious fluids are suctioned, small volumes

of saline or water should be infused into the tube to prevent tube obstruction. An esophagogastric tube can be used for gastric decompression. If gastric secretions are tenacious, saline can be infused initially to break up the secretions before aspiration.

Removal of the Tube

As opposed to gastrostomy tubes, which must remain in place at least several days before removal to allow for a good seal to form between the stomach and the abdominal wall, esophagostomy tubes can be safely removed the same day they are placed. The dressing and the sutures are removed while the tube is held in place. The tube is then occluded and pulled out. The ostomy site should be cleaned, bactericidal ointment should be applied, and a light bandage should be placed around the patient's neck. The bandage should be removed in 24 hours and the wound inspected. If the ostomy site has not sealed yet, the bandage should be replaced. In patients requiring a new bandage, changes are done every 1 to 2 days until the ostomy site has sealed. This generally takes only a few days.

Long Term Feeding

On occasion, animals require the use of an esophagostomy feeding tube for weeks or months. A fistula usually develops after a few weeks. If the feeding tube needs to be replaced, it is generally a simple procedure because the old tube is removed and a new one is directly fed into the fistula. This usually only requires a local anesthetic block for suture placement. Once these tubes are no longer needed, they are removed as described previously. The fistula closes quickly (within a maximum of a few days), but it may take a week or more to completely heal.

Complications

Most complications relate to skin irritation and inflammation. These problems usually can be prevented by ensuring that the skin sutures are not placed too tightly and that the skin is not pinched or folded during suture placement. If the tube is not secured to the periosteum or deep fascia, the tube will retract and move as the animal moves around, leading to possible inadvertent tube removal and significant skin irritation. If mild dermatitis is present, it will usually resolve with time and regular wound cleaning. On occasion, the dermatitis may not resolve until the tube is removed.

By pushing the forceps out in a lateral direction, the esophagus is approximated to the skin. If this maneuver is not performed adequately, the surgeon risks lacerating the external jugular vein as well as creating additional tissue trauma. This complication is rare when proper technique is used. Bleeding from a lacerated jugular vein has occurred in one known patient; this bleeding was controlled easily and definitively using direct pressure.

In extremely debilitated animals, care must be taken to adhere closely to the technique described. Serious complications can result, with dissection of the tube alongside the esophagus, if the tube is not brought out into the patient's mouth after grasping of the tip of the tube with the forceps. Because the surrounding soft tissues are more easily penetrated, the tube can then course alongside the esophagus instead of in the esophageal lumen. Because the clinician may not be aware of this situation, the tube must be brought out into the patient's mouth before being passed back into the esophagus.

Comments

The use of esophagostomy tubes for both feeding and decompression is both a practical and a life saving procedure. More than 500 of these tubes are estimated to have been used to feed dogs and cats since 1988, with beneficial results. The technique has also been used in other mammalian species including the rat, ferret, and monkey. Esophagostomy tubes can also be used effectively in the nutritional support of birds. When comparing the technique with percutaneous gastrostomy tube placement, the use of esophagostomy tubes is less costly, requires no special equipment or special tubes, takes less operative and anesthetic time, is easier to perform, and is associated with fewer complications. No threat of peritonitis exists, and the tube can be removed safely at any time.

References

1. Crowe DT. Use of a nasogastric tube for gastric and esophageal decompression in the dog and cat. J Am Vet Med Assoc 1986;188:1178-1182.

2. Crowe DT. Feeding the sick patient. In: Proceedings of the Eastern States Veterinary Conference. Orlando, FL. 1988;3:95-96.

3. Crowe DT, Downs MO. Pharyngostomy complications in dogs and cats and recommended technical modifications: experimental and clinical investigations. J Ain Anim Hosp Assoc 1986; 22:493-496.

4. Crowe DT. Nutritional support for the hospitalized patient: an introduction to tube feeding. Compend Contin Educ Pract Vet 1990; 12:1711-1721.

5. Moss G. Maintenance of gastrointestinal function after bowel surgery and immediate enteral full nutrition. II. Clinical experience, with objective demonstration of intestinal absorption and motility. JPEN J Parenter Enteral Nutr 1981;5:215-220.

Use of Jejunostomy and Enterostomy Tubes

Chad M. Devitt and Howard B. Seim III

Metabolic support has become an integral part of surgical critical care in veterinary medicine.[1] Jejunostomy or enterostomy tubes are methods of nutritional supplementation in patients after abdominal surgery. Small animal patients undergoing abdominal surgical procedures are often compromised and are likely in need of nutritional support.

Nutritional support is indicated in patients that are unable to meet nutritional demands by oral consumption of food. Malnutrition can be defined by one or more of the following criteria: anorexia for longer than 5 days, weight loss of more than 10% body weight, increased nutrient loss (i.e., vomiting, diarrhea, protein-losing nephropathy), low albumin, and increased nutrient demands (i.e., surgical stress, sepsis, cancer, chronic infections).

A basic premise "if the gut works, use it" may seem an oversimplification of the benefits of providing nutritional support by physiologic routes (i.e., the gastrointestinal tract versus parenteral administration). In general, the more orad nutrients are placed in the gastrointestinal tract, the better patients are able to assimilate complex diets into essential nutrients. Conversely, bypassing a functional segment of the gastrointestinal tract (i.e., stomach) results in necessary alteration of the dietary composition to accommodate for the loss of the portion of gastrointestinal tract.

General Considerations

Whenever a surgeon enters the abdominal cavity, one question should be answered: Could this patient benefit from a feeding tube? Surgically placed feeding tubes carry little additional operative risk, are economical, and are simple to place and manage; therefore, they pose little risk to the patient while providing a large potential benefit. Special equipment is not required for placement of enteral feeding tubes. The tubes used are 3.5- to 5 French infant feeding tubes at least 36 inches in length. If intestinal surgery is performed, the catheter is placed aboral to the site of surgery. Appropriate diets include commercially available polymeric and monomeric diets. The preferred mode of administration is by slow, continuous rate infusion; however, small frequent boluses can suffice.

Indications

Placement of an enterostomy feeding tube may be indicated in any patient undergoing an abdominal operation. The major criteria are a functional small intestine and the need for nutritional support.[2,3] Choosing the appropriate method and determining the need for nutritional support are based on applying the least invasive technique that carries the greatest likelihood of success with the least amount of morbidity.

Feeding through an enterostomy tube has induced pancreatic secretion and therefore was previously contraindicated in patients with pancreatitis.[4,5] Acute pancreatitis induces a hypermetabolic state with increased caloric and nitrogen demands and at the same time renders the gastrointestinal tract unable to meet these increased needs.[4,5] Because the exocrine function of the pancreas is stimulated by the vagus nerve and by release of gastrointestinal hormones in response to food, one can reasonably expect that if the diet is administered into the jejunum, thereby bypassing the cephalic, gastric, and duodenal source of pancreatic stimulation, no significant increase will occur in the exocrine activity of the pancreas.[6] Patients with pancreatitis experience modulation of bacterial flora within the intestinal tract and increased bacterial translocation, and they suffer from a negative energy balance. Early alimentation through an enterostomy tube in human patients with pancreatitis results in improved immune status and fewer complications.[4,6,7] A jejunostomy tube may allow aggressive nutritional support at an earlier time in the postoperative period. Although these issues are controversial, enteral nutrition is considered an integral part of aggressive treatment of acute pancreatitis in human patients.[4,6,7]

Contraindications

The major contraindication to the use of a jejunostomy tube is any disorder causing a nonfunctional gastrointestinal tract (i.e., ileus or neoplastic obstruction of the intestine).[2,3]

Operative Technique

From a midline laparotomy incision, a segment of proximal jejunum that is easily approximated to the ventrolateral body wall is isolated. The direction of ingesta flow (orad to aborad) is determined by tracing the bowel segment from a known anatomic landmark (i.e., stomach or duodenum). A 2- to 3 cm longitudinal seromuscular incision is made in the antimesenteric border of the isolated segment of jejunum. At the aboral end of the seromuscular incision, a stab incision is made through the submucosa and mucosa into the lumen of the jejunum (Figure 6-12A). A 5 French Argyle feeding tube (Sherwood Medical Products, St. Louis, MO) is directed through the stab incision aborally into the lumen of the jejunum. Approximately 20 cm of feeding tube is threaded aborally into the small intestine (Figure 6-12B). The seromuscular incision is closed with 3-0 or 4-0 monofilament synthetic absorbable suture in an interrupted Cushing pattern (Figure 6-12C). The surgeon should close this incision in such a manner that the feeding tube is buried in the submucosa of the incision, effectively creating a submucosal tunnel (Figure 6-12, *inset*). The remaining catheter is exteriorized through a small stab incision in the ventrolateral body wall. Care is taken to select a site that will not result in excessive tension or radial directional changes of the bowel. The enterostomy site is sutured to the peritoneal surface of the adjacent body wall (Figure 6-13). Care is taken to create a watertight jejunopexy on all sides of the enterostomy. The catheter is secured to the skin of the adjacent body wall with a Chinese finger trap friction suture. Abdominal wall closure is routine. A protective bandage is placed on the patient after the procedure, and an Elizabethan collar is used to prevent premature removal of the jejunostomy tube.

Diet Selection, Dose, and Administration

The ideal enteral diet formulation is isotonic, has a caloric density of 1 kcal/mL, a protein content of 4.0 g/100 kcal (16% of total calories), and approximately 30% of calories as fat. Commercially available diets designed for humans are the best diets for small animal patients. Liquid enteral diets can be categorized as polymeric diets or monomeric diets. Polymeric diets contain large molecular weight proteins, carbohydrates, and fats. They require normal intestinal digestion. Most are relatively isotonic, contain about 1 kcal/mL, and are readily available. Monomeric diets are composed of crystalline amino acids as the protein source, glucose and oligosaccharides as the carbohydrate source, and safflower oil as the essential fatty acid source. They are hyperosmolar and expensive. A summary of polymeric and monomeric diets is included in Table 6-4.

For patients with impaired digestive or absorptive function (pancreatitis, enteritis, hepatic disease) or suspected food allergy, a commercial polymeric, enteral liquid diet may be indicated. Patients should be closely monitored for formula intolerance. Jevity (Ross Laboratories, Columbus, OH) is the initial

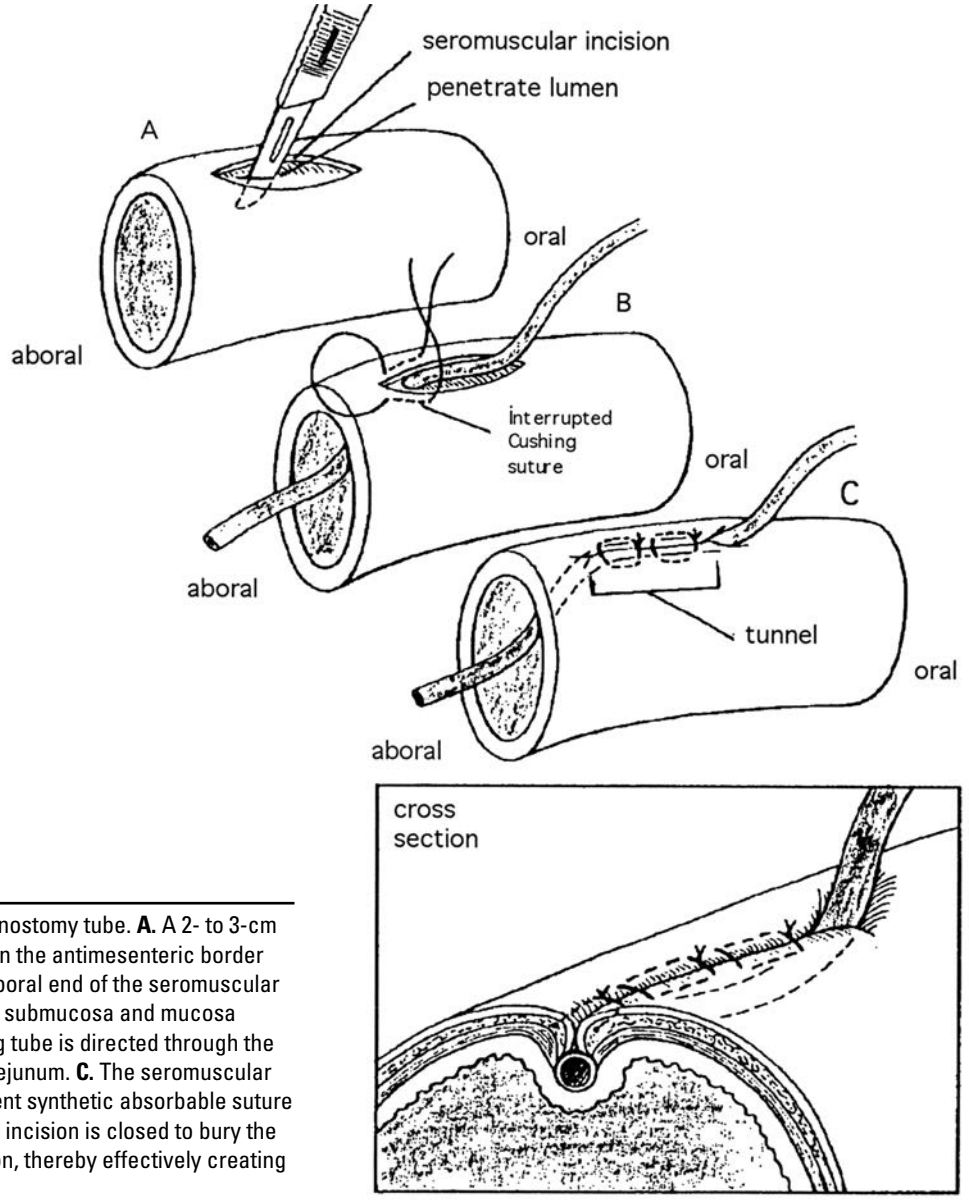


Figure 6-12. Steps in the placement of a jejunostomy tube. **A.** A 2- to 3-cm longitudinal seromuscular incision is made in the antimesenteric border of the isolated segment of jejunum. At the aboral end of the seromuscular incision, a stab incision is made through the submucosa and mucosa into the lumen of the jejunum. **B.** The feeding tube is directed through the stab incision aborally into the lumen of the jejunum. **C.** The seromuscular incision is closed with 3-0 or 4-0 monofilament synthetic absorbable suture in an interrupted Cushing pattern. **Inset.** The incision is closed to bury the feeding tube in the submucosa of the incision, thereby effectively creating a submucosal tunnel.

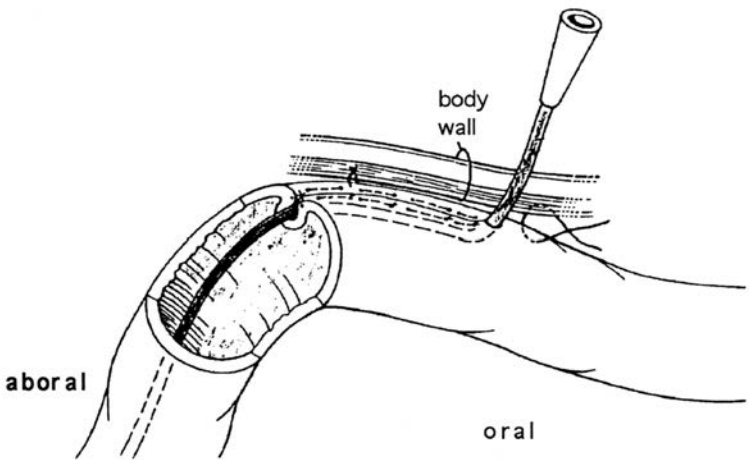


Figure 6-13. The remaining catheter is exteriorized through a small stab incision in the ventrolateral body wall. Care is taken to select a site that will not result in excessive tension or radial directional changes of the bowel. The enterostomy site is sutured to the peritoneal surface of the adjacent body wall. The catheter is secured to the skin of the adjacent body wall with a Chinese finger trap friction suture. Abdominal wall closure is routine. A protective bandage is placed on the patient after the surgical procedure, and an Elizabethan collar is used to prevent premature removal of the jejunostomy tube.

Table 6-4. Commercially Available Polymeric and Monomeric Diets and Their Composition

Diet	Calorie content (kcal/mL)	Protein (g/100 kcal)	Protein (g/mL)	Fat g/100 kcal	Osmolality (mOsm/kg)
Polymeric					
Jevity	1.06	4.20	0.045	3.48	310
Osmolite HN	1.06	4.44	0.047	3.68	310
Impact	1.00	5.50	0.055	2.80	375
Clincare feline	0.92	7.0	0.064	4.60	368
Clincare canine	0.99	5.0	0.050	6.10	340
Monomeric					
Vivonex HN	1.00	4.60	0.042	0.90	810
Vital HN	1.00	4.17	.046	1.08	460

formula of choice, owing to the potential benefits of its fiber content. If the patient becomes intolerant to Jevity, Osmolite HN (Ross Laboratories) should be used. The protein sources of many human products may not provide adequate arginine and sulfur-containing amino acids for cats, and additional protein supplementation is required for long term use.

Monomeric diets are indicated for patients with exocrine pancreatic insufficiency, short bowel syndrome, or inflammatory bowel disease or when polymeric diets are not tolerated. Monomeric diets promote maximal nutrient absorption and minimal digestive and absorptive work. In addition, monomeric diets are less stimulatory for exocrine pancreatic secretion and may have a role in nutritional support of pancreatitis patients.[8] To match the caloric density of polymeric formulas, their osmolality must be two to three times higher, a feature that can create disorders of gut motility or fluid balance. Their cost is about seven times more per calorie compared with polymeric formulas. In most cases, a polymeric diet may be tried first, owing to the decreased cost, ease of preparation, and physiologic benefits to enterocyte function.

To determine the dosage of diet to feed, one must first calculate the basal energy requirement (BER, resting energy requirement) based on body weight. The BER is calculated from the following formulas for dogs weighing less than 2 kg:

$$BER\ (kcal/day) = 70(wt_{kg}0.75)$$

The following formula is used for dogs weighing more than 2 kg:

$$BER\ (kcal/day) = 30(wt_{kg}) + 70$$

After determination of the BER, additional factors can be multiplied depending on the condition of the animal:

$$ER\ (kcal/day) = BER\ X\ 1.25\ to\ 1.5$$

Protein supplementation should be considered in patients with significant negative nitrogen balance. Commercially available polymeric and monomeric enteral diets are designed for human patients and have significantly lower protein levels. ProMod (Ross Laboratories) is a readily available protein supplement and contains approximately 75% high quality protein (5 g/6.6 g scoop). The guideline for dietary protein requirements in dogs is 5 to 7.5 g/100 kcal, the guideline for cats is 6 to 9 g/100 kcal. Patients with renal or hepatic insufficiency should be reduced to less than 3 g/100 kcal in dogs and less than 4 g/100 kcal in cats.

Feeding can begin immediately in patients with good peristalsis noted at surgery, a secure jejunopexy, and an adequate submucosal tunnel of the feeding tube. However, if uncertainty exists, waiting 18 to 24 hours after placement allows a fibrin seal to form at the jejunostomy site and gut motility to normalize. The calculated volume of diet is gradually administered over 4 days (Table 6-5). These are only guidelines, however, and each patient requires a feeding regimen tailored to fit individual needs.

Table 6-5. Recommended Enterostomy Feeding Schedule

Day	Fraction of Calculated Volume*	Dosing Interval
> 1	1/4	qid
2	1/2	qid
3	3/4	qid
4	full dose	qid

*** Calculated dose is diluted to the full volume with tap water**

Complications

Complications of jejunostomy tubes include leakage of intestinal contents or diet and are rare; however, they can be devastating.[2,3] Therefore, critical placement and monitoring of the tubes in the early postoperative period are imperative. Peritonitis can result from leakage of intestinal contents from the jejunostomy site or from tube displacement into the peritoneal cavity. Clinical signs of peritonitis include vomiting, tachycardia, pyrexia, and abdominal pain. Patients in which a leak is suspected should be evaluated and treated immediately, because progression of clinical signs can be rapid.

Abdominal discomfort, nausea, vomiting, and diarrhea can occur if the diet is infused too rapidly, if a large dose is given, or if the formula is not tolerated by the patient. Decreasing the amount, rate, or concentration of diet infused may alleviate these problems. If gastrointestinal upset persists, one should consider changing the diet or method of nutritional support.

Metabolic complications can occur and include transient hyperglycemia as a result of the insulin resistance present in many critically ill patients. Occasionally, these patients require additional insulin supplementation. Hypophosphatemia has been reported to develop subsequent to enteral alimentation in severely debilitated cats.[9] Complications associated with hypophosphatemia include hemolytic anemia and neurologic signs. Investigators have hypothesized that cats in a state of chronic malnutrition have phosphorus depletion despite normal serum phosphorus levels. The institution of enteral alimentation stimulates insulin secretion and cellular uptake of phosphorus and glucose for glycolysis. Phosphorylation of adenosine diphosphate to adenosine triphosphate results in further phosphorus depletion and severe hypophosphatemia. This condition is referred to as the refeeding phenomenon in humans and was first described in World War II victims. One should begin feeding cautiously in debilitated, hypophosphatemic patients.

References

1. Carnevale JM, et al. Nutritional assessment: guidelines to selecting patients for nutritional support. Compend Contin Educ Pract Vet 1991;13:255-261.

2. Orton EC. Needle catheter jejunostomy. In: Bojrab MJ, ed. Current techniques of small animal surgery. Philadelphia: Lea & Febiger, 1990:257.

3. Moore EE, Moore FA. Immediate enteral nutrition following multisystemic trauma: a decade perspective. J Am Coll Nutr 1995;10:633 648.

4. Marulenda S, Kirby DF. Nutrition support in pancreatitis. NutrClin Pract 1995;10:45-53.

5. Freeman LM, et al. Nutritional support in pancreatitis: a retrospective study. J Vet Emerg Crit Care 1995;5:32-41.

6. Bodoky G, et al. Effect of enteral nutrition on exocrine pancreatic function. Am J Surg 1991;161:144-148.

7. Simpson WG, Marsino L, Gates L. Enteral nutritional support in acute alcoholic pancreatitis. J Am Coll Nutr 1995;14:662-665.

8. Guan D, Ohta H, Green GM. Rat pancreatic secretory response to intraduodenal infusion of elemental vs. polymeric defined formula diet. JPEN J Parenter Enteral Nutr 1994;18:335-339.

9. Justin RB, Hohenhaus AE. Hypophosphotemia associated with enteral alimentation in cats. J Vet Intern Med 1995;9:228-233.

Chapter 7

Minimally Invasive Surgery

Endosurgery

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Minimally invasive surgery (MIS) includes surgical techniques that are designed to minimize the invasiveness of the anatomic approach while maintaining or improving surgical precision and efficiency. Endoscopic surgery (endosurgery) involves performing a minimally invasive surgical procedure with visualization provided by an endoscope. Laparoscopic and thoracoscopic surgery include endoscopic approaches to the abdominal and thoracic cavities, respectively. The purpose of this chapter is to introduce the fundamentals of endosurgery to surgeons untrained in these techniques and to encourage the adept surgeon to do more.

Advantages and Disadvantages

Every veterinary surgeon is charged to restore biologic form and function. Of equal importance is the veterinary surgeon's management of pain associated with the procedure. Advantages of the endosurgical techniques include reduced incision size, decreased closure times, minimal scar formation, and improved visualization of the surgical site. Evidence of a more rapid return to work and better cosmetic appearance in human patients does not necessarily apply to veterinary patients although attempts to compare postoperative activity levels of animals undergoing minimally invasive surgery have demonstrated that dogs undergoing laparoscopic ovariectomy with minimally invasive techniques recover more quickly than those undergoing open surgery.[1] The improved visualization provided by MIS is dramatic and is an invaluable teaching tool. Although moderate cost savings have been demonstrated when endosurgery is chosen in human medicine, the same issues do not apply to veterinary medicine. In fact, the initial investment for equipment purchase is considerable and the extra supplies needed for each case add to the cost of each procedure. These disadvantages, along with the greater learning curve, with its associated complications, often deter veterinarians from attempting MIS procedures. So why should veterinary surgeons consider endosurgical methods as an alternative, let alone a principal choice? The veterinary surgeon's innate hunger for precision and technical skill may be enough to answer this question. Minimally invasive surgery is a state of mind–a creed. Furthermore, as the pioneer endosurgeon Nadeau pointed out in 1925, "How often is not the surgeon or the diagnostician confronted with a case in which the difficulties of reaching a decision urge the desire to get a glimpse of the body interior!"[2] Still more important is the issue of pain management. The surgical entry wound with endosurgery is considerably smaller than with traditional surgical approaches. A surgical entry wound often causes greater associated morbidity and pain than the internal operation itself. The simple reduction in entry wound size of endosurgery has led to reduced postoperative pain, reduced requirements for narcotic analgesics, fewer

respiratory difficulties, reduced adhesion formation, earlier ambulation and return to feeding, and rapid return to self-sufficiency. The veterinary surgeon should investigate all means of pain management for their patients.

Indications and Contraindications

If the surgeon is proficient in performing minimally invasive surgery, endosurgery is simply an alternative approach to a surgical problem. The indication for a specific surgical procedure is no different from an open approach, except that with MIS there may be less postoperative pain, faster recovery time, and decreased wound infection rates and adhesion formation. The reduction in postoperative morbidity and enhanced visualization obtained with endosurgery may be relatively greater for animals with a very thick body wall. The primary contraindication for endosurgery is the anticipated failure to provide an adequate optical cavity. Significant adhesions, thoracic or abdominal effusion, or very large space-occupying masses are relative contraindications for an endoscopic approach. The presence of a diaphragmatic hernia is another relative contraindication. If a defect is present in the diaphragm, pneumothorax or pneumomediastinum may develop when abdominal insufflation is used to establish an optical cavity.

Safety and Efficacy

The veterinary surgeon should have a thorough understanding of each specific surgical therapeutic technique, including associated complications and contraindications. Those same complications and contraindications also apply to the endosurgical approach. Because the number of possible endosurgical procedures is almost endless, no purpose exists in listing all associated complications here. However, a few complications are specific to endosurgical approaches. Although the incidence of these complications is extremely low, some may be lethal and understanding such complications is mandatory. Client consent should be obtained for procedure conversion and the animal should always be surgically prepared for conversion to an open technique.

The anesthesiologist or anesthetist should be prepared for the unique aspect of anesthesia in the endosurgical patient. Several complications are associated with patient positioning and the use of insufflation gases in laparoscopy. Trendelenburg positioning (head-down tilt) and pneumoperitoneum (abdominal gas insufflation) increases the risks of gastrointestinal reflux and acid aspiration. Proper fasting, endotracheal intubation with a cuffed tube, and prompt attention to reflux are necessary. Abdominal distension produced by gas insufflation used in laparoscopy can trigger vasovagal reflexes, decrease venous return and cardiac output leading to hypotension. With compression of the diaphragm, there can be ventilation-perfusion mismatch and decreased vital capacity, functional residual capacity, and compliance. Positioning (head-up or head-down) contributes to this cardiopulmonary insult. Ventilatory support is mandatory in most cases. Thoracoscopic techniques provide additional challenges to the anesthesiologist in providing proper anesthesia and ventilation while establishing a working space within the thorax. In most cases, the space is established by decreasing the tidal volume of both lungs or by ventilating only one lung without insufflation of the thorax. An intimate knowledge of one-lung ventilation techniques is necessary for advanced thoracoscopic techniques. Anesthetic considerations for endosurgery are reviewed in the literature.[3]

Troubleshooting

Equipment failure that cannot be resolved during MIS will dictate conversion of the procedure to an open approach. Since veterinarians are generally directly responsible for hospital equipment and maintenance, a review of common equipment disorders is presented. An interruption or incompatibility of any one of these components will cause procedural delay. Hospital personnel need to be trained to set up, trouble-shoot, and solve issues efficiently. If inadequate light is encountered, the surgeon should ensure that the system has been white balanced prior to use, that the light source is taken off stand-by, and that the light guide cables are of sufficient diameter and compatible with the light source. A 5 mm scope will deliver less light than a 10 mm scope. In general, a smaller laparoscope needs to be positioned closer to a structure for the image to appear as bright as when using a larger scope from further away. When the camera image fails to appear on the monitor, it is usually caused by incorrect output to input connections. The output of the camera should be connected to the input of the monitor. If a video recorder is used, it is typically inserted between the output of the camera and the input of the monitor to ensure that the highest quality image is recorded.

Gas insufflation is used during endosurgery to create a viewing cavity, or to lift the body wall, thereby producing a protective distance between the viscera and instruments being inserted into the cavity. Automatic insufflators are used to regulate the body cavity gas pressure to a pre-set value, usually 8 to 15 mm Hg. When pressures exceed 20 to 25 mm Hg, there can be significant cardiopulmonary embarrassment. Carbon dioxide is the most commonly used gas for insufflation because it is cheap, it is most soluble (perhaps reducing the likelihood of gas embolus), it is rapidly resorbed and eliminated by the lungs, and it does not support combustion when electrocautery is used. However, CO_2 may cause irritation to the body cavity through formation of carbonic acid on visceral surfaces and is absorbed into the blood, possibly leading to hypercarbia, stimulation of the sympathetic nervous system, vasodilation, hypertension, tachycardia and other arrhythmias. Surgeons should try to use the lowest pressure that enables sufficient visualization. If inadequate insufflation of the abdominal cavity occurs, the gas supply to the insufflator, the pressure and flow settings on the insufflator, and tubing attachment at the trocar and at the insufflator should be checked. Further, all trocars should be examined for open stopcocks or inadequate seals.

The surgeon must be attentive to the introduction and position of their surgical instruments within body cavities at all times. Each instrument should be monitored by camera as it is introduced into the body cavity and followed to the target organ, keeping the tip of the instrument centered on the monitor. The surgeon should never coagulate or cut unless clear visualization of the target tissue is obtained. Most injuries to viscera (spleen, stomach, bowel, ureters, and lung) are due to blind placement of insuf-

flation needles and trocars. Splenic injuries caused by Veress needle placement are usually self-limiting. Large vessel injury can occur as well, causing severe bleeding, or worse, venous air embolism through entrainment of insufflation gases. Diagnosis and treatment of air embolism requires cooperation between the surgeon and anesthesiologist. Monitoring for a precipitous drop in end-tidal CO_2 can be invaluable in these cases.

Equipment Needed

Light, Optics, Video: The multicomponent surgical video system

The standard video tower has a light source, light guide cable, rigid operating telescope, video camera, one or two video monitors, and often, a video recorder. For laparoscopy, a high-flow insufflator, CO_2 tank, yoke for the gas supply, and tubing are also used. The purpose of the system is to provide live, full color images of the interior of the body, as well as capture and storage of images for review.

General Considerations

Image quality is the foremost consideration. The video system component with the lowest resolution capabilities defines the resolution for the entire system. The final image is affected by a number of variables, including camera design, signal format, video processor, monitor capabilities, and user settings. The controls should be easy to identify and activate, providing easily interpretable feedback. Some degree of automation will further simplify use. Compatibility with existing equipment and hospital sterilization methods is important. Prior experience with the manufacturer is also invaluable.

Light Source

Purpose: Supplies light to surgical site via the endoscope.

Recommendations: Xenon or advance LED lamp with a minimum 500 hour lamp life and backup lamp. Lamp standby mode and bulb-life meter. Auto-illumination.

Explanation: Adequate illumination of the endosurgical field is essential to safely completing the procedure. Light transmitted from the tip of the endoscope must reflect off anatomic structures and be picked up by the lens system of the endoscope. Light emitted into the body cavity reduces in intensity by the square of the distance traveled. Changing focal points changes reflected light intensity. Such changes demand an adjustable or automatic light source output control. Automatic brightness control helps maintain a constant image brightness regardless of the target distance. Usually xenon, or more recently advanced LED light sources, are used over halogen or metal halide bulbs. Although these modern external light sources may operate at very high temperatures, little of this heat ever reaches the patient. However, if a xenon light source is used, burns and fires induced by excessive heat production at the interface between the fiberoptic light cable and the rigid operating endoscope are still quite possible. For this reason, the light source should not be left turned on when the fiberoptic cable is detached from the rigid operating endoscope. Auto-illumination, low-intensity default settings and lamp standby mode can help minimize this risk.

Fiberoptic Light Cable

Purpose: Carries light to surgical endoscope.

Recommendations: Secure connections and connector compatibility with multiple manufacturers (universal clamp). Adequate size, durable and flexible construction.

Explanation: The development of fiberoptics in the 1960s made it possible to present intense light to the endosurgical field without burning the patient. An incoherent bundle of glass fibers, 10 to 25 μm in diameter, connects the light source to the rigid surgical endoscope. Fiberoptic bundles fan around the inner core lens system of the endoscope, carrying light to the surgical field. Due to air-to-glass interface at connecting points and fiber mismatching, only approximately one-quarter of the original light is transmitted, making bright light sources necessary. Secure connections are necessary to prevent cable disconnections and burns. Durable, flexible construction is necessary to limit light fiber fracture and subsequent loss of delivered light.

Surgical Endoscope (Laparoscope)

Purpose: Directs light into surgical site and directs reflected light back to camera head.

Recommendations: Hopkins rod-lens system. Autoclave compatible. Compatible with all common light sources, light cables and video processors.

Explanation: Reflected light, incident with the operating endoscope, is captured by a lens system. The diameter of the standard lens system ranges from 1 to 5.5 mm, with the large lens providing better resolution. Laparoscopes vary in their depth of focus, magnification, color differentiation, brightness and resolution, as well as their angle of vision and field of view. Superior light capture is accomplished with the now commonplace Hopkins glass rod-lens system, and high quality lens systems. Laparoscopes also vary in their sensitivity to reuse and sterilization methods.

Video Camera

Purpose: Generates an electrical signal from reflected light captured

Recommendations: Three-CCD (3-chip) cameras will generally provide superior image quality and color differentiation. Auto-white balance. Camera zoom control. Camera head with integrated, easy to use, imaging controls. Universal optical coupler will attach to a variety of surgical endoscopes.

Explanation: Light captured by the rigid operating endoscope can be viewed directly or with greater ease and resolution using a miniature video camera, also called a charge-coupled device (CCD). The CCD or "chip" is a photosensitive silicone sensor composed of thousands of photoelectric picture elements

(pixels). Quality cameras use from one to three CCD chips. A single chip camera uses color-filter overlays or rotating filter wheels to produce color separation. Three chip cameras use a prism to separate the incoming light into the additive primary colors of red, blue and green (RBG), with each chip dedicated to one color, thus producing superior color reproduction. However, light sensitivity is more important than color separation. A high-quality single-chip camera can outperform some three-chip systems. Still–in general–three chip systems offer better color reproduction and image quality than single chip systems. The camera head can also have controls for light source control, image zoom and peripherals like a video recorder.

Camera resolution is based on the number of pixels available (called the "native resolution") and is generally less than that of the video processor. Resolution is compromised in cameras with less than 400 horizontal rows of pixels. One-chip cameras typically generate signals with a maximum of 400 to 500 lines of horizontal resolution, whereas three-chip cameras can create signals with 700 or more. The camera is often the limiting factor for the overall resolution.

An optical coupler is used to attach the camera to a surgical endoscope. Video endoscopes have the camera situated at the tip of endoscope (so-called chip-on-the-tip configuration), but are less commonly used for laparoscopic surgery at this time.

Video Processor (Camera Control Unit or CCU)

Purpose: Translates the signal from the camera head into video signal and routes the video signal to the video monitor.

Recommendations: Variety of video format outputs (composite, S-video, RBG). Digital output for high definition systems (DVI). Matching outputs to display and camera inputs. Brightness and color controls.

Explanation: The overall resolution is affected by the method of communicating the image. The standard one-wire, composite video signal is simple and familiar. Component video signals (two-wire Y/C or S-video, and three-wire RBG) reproduce more monochrome and color image detail. High definition (HD) systems are becoming standardized at this time. To be considered HD, the system should have a 16:9 picture aspect ratio and either 720 horizontal progressive scan lines (720p), 1080 horizontal interlaced scan lines (1080i) or 1080 horizontal progressive scan lines (1080p) digital output formats. Progressive scan shows fewer artifacts with rapid movement, but interlaced is equally effective in laparoscopy. Since video processors cannot provide greater resolution than offered by the video camera, the CCD pixel arrays will also have to be larger or the resolution will not improve. The video processor will need to be paired with a flat-panel liquid crystal display (LCD) with a similar aspect ratio, horizontal lines and input formats. The monitor resolution should reflect the resolution of the camera or image quality may be lost. In general, the field is rapidly moving towards HD systems at this time.

Video Monitor

Purpose: Displays the live image

Recommendations: HD flat panel LCD with a number of video format inputs (composite, S-video, RBG, and DVI). Consider using more than one LCD for alternate viewing. Horizontal lines of resolution or pixel density, as well as video inputs to match video processor outputs.

Explanation: A flat panel LCD will be necessary for HD video processor output. However, flat panel screens are also light weight and easy to mount even when used with a lower resolution input. Flat panel screens of various types have essentially replaced the traditional cathode ray tube monitor.

The US standard, NTSC (National Television System Committee) format has 525 horizontal scan lines, 4:3 picture aspect ratio and runs 30 fields or frames per second (fps). Many surgical monitors in use today have at least 550 to 700 horizontal lines of resolution, a 13-inch diagonal screen, and are medical grade to limit chassis electrical current leakage. However, the introduction of flat panel fixed-pixel array monitors has changed the game. Resolution of these flat panel monitors is determined simply by the physical number of columns and rows of pixels creating the display. The monitor must be compatible with the method of communicating the image from the camera (composite, S-video, RBG or digital), but then uses a digital video processor with memory array, called a scaling engine, to match the incoming image format. Again, the image resolution will be no better than the input from the camera regardless of the flat panel pixel density. The digital signal can be communicated through a standard Bayonet Neill-Concelman (BNC) connector using serial digital interface (SDI) or high-definition serial digital interface (HD-SDI). However, the industry has moved to digital communication via Digital Visual Interface (DVI). DVI is also compatible with High-Definition Multimedia Interface (HDMI) with no signal loss using DVI-to-HDMI adapter.

Video Image Capture

Purpose: Document and archive procedures, teaching

Recommendations: Large hard-drive with DVD archiving and input/output for additional storage attachment (eg. Universal Serial Bus - USB). Digital capture device for instantaneous and continuous capture. Capture resolution should match image resolution for equivalent replay (with alternative setting available).

Explanation: Picture archiving and communication systems (PACS) are computer-based systems that can store and retrieve images in digital format from several different diagnostic imaging modalities including endoscopic surgery. Digital-image storage does help organize storage of large volumes of images (such as radiographs) and video, however communication with a PACS is likely unnecessary for the average endosurgeon. Temporary storage to a large hard-drive and subsequent download to a DVD for storage will usually suffice, with the understanding that the average DVD lifespan is limited by the quality of the materials and manufacturing methods, as well as the storage and handling.

However, in general, manufacturers performing non-standardized accelerated age testing claim life spans ranging from 30 to 100 years for high quality DVD-R and DVD+R discs and up to 30 years for DVD-RW, DVD+RW and DVD-RAM. Alternatively, additional portable hard-drives may be connected to the primary hard-drive for archive download (if connectivity provided). HD image capture will require larger storage space.

Trends and the Future

Natural orifice "scarless" surgery is being evaluated for surgical access to organs deep inside the body, without external incisions in the abdominal wall. Operating room automation systems designed to control multiple operating-room devices using a single, common interface are available. Three-dimensional endoscopic surgical techniques have developed more slowly with concerns regarding surgeon's perception of depth and scaling. Telepresence including telemedical training and telerobotic endoscopic surgery are well established. Telerobotic systems like the da Vinci robotic surgical system (Intuitive Surgical, Inc., Sunnyvale, CA, USA) are being used in more and more human community hospitals with more and more surgery going "robotic". Small, wireless robots about 3 inches in length have been developed which when inserted into a body cavity can be controlled wirelessly by the physician to perform biopsy, drug delivery, and control of hemorrhage.

Endosurgical Instrumentation

Basic veterinary endosurgical hand-held instrumentation has not changed dramatically since it was introduced in the late 1990s. Endoscopic clip appliers, surgical staplers, and automatic suturing devices were introduced between 1990 and 2000 and are continuing to be refined for use in human surgery. Endoscopic clips have greatly facilitated endosurgical procedures and provide secure hemostasis and sealing of viscus structures. Multiple clip appliers enable rapid and repeated application of clips. These clips are used to occlude blood vessels and other small, hollow structures. They are useful in controlling acute bleeding; however, secure ligation is only accomplished with complete skeletonization of the vessel. Endosurgical stapling devices place six rows of linear staples that provide closure and hemostasis, and incision between the middle rows of staples. Staple leg length varies according to anticipated tissue thickness. Newer staplers have staggered staple heights with the outer rows forming larger staples and the inner rows forming smaller tighter staples. Cartridges are available in 30, 45, and 60 mm lengths.

Although monopolar and bipolar electrocautery have been used extensively in MIS, recent major advances have been made in methods for achieving hemostasis and cutting of tissue. The Harmonic Scalpel uses ultrasonic energy to coagulate and cut tissue, reducing lateral thermal injury and has an advantage because no electrical current passes through the patient's body. The vibrating blade creates cavitation in the tissue which opens up planes of dissection that are not initially apparent. Dissection is facilitated by appropriate tissue tension. Water vapor generated during coagulation must be vented to ensure a clear surgical field. The LIGASURE bipolar sealing device, like the Harmonic Scalpel, can be used for dissection without precise skeletonization of vessels. The tissue to be coagulated and cut is grasped in the jaws of the instrument and current is applied while the tissue impedance is monitored by the instrument. When current flow drops below threshold, an audible alarm sounds to signal complete hemostasis and an internal knife can then be activated to cut the tissue. The LIGASURE is capable of effectively ligating vessels up to 7 mm in diameter. The Ethicon ENSEAL device also uses bipolar energy to simultaneously cut and seal tissue up to 7 mm in diameter. A unique polymer temperature control feature is provided within the jaws of the device to precisely heat tissue to 100 C and limit the lateral thermal spread outside the electrode area. Care should be taken to close the device prior to withdrawal from the trocar to prevent damage to insulation of the wires to the electrodes. The insulation of all monopolar devices should be inspected to ensure that it is intact, as burns may occur where a defect in insulation contacts tissues.

Endoscopic Suturing

The cost of materials for endoscopic suturing is less than for clips, staplers, and energy devices, but manual suturing is more time-consuming. A description of all aspects of laparoscopic suturing is beyond the scope of this chapter and the reader is referred to recent publications[4,5] and the following illustrations of extracorporeal ligation with Roeder knot, ligation with a pre-tied loop ligature, such as ENDOLOOP, and classic intracorporeal instrument knot tying.

Extracorporeal Knot Tying

Equipment

Pretied endoknot or long suture (endosuture) (at least 48 cm)
Knot Pusher
One endoscopic needleholder and one endoscopic grasping forceps
Endoscopic scissors

Technique

This technique is defined as throws created outside of the body under direct vision which are then transferred to the body cavity by a knot pusher. This technique, unlike the pre-tied loop ligature, can be used on skeletonized structures, and does not require a free end. The structure to be ligated is identified and isolated. The free end of a 48 cm suture is grasped with a needle driver and passed into the body cavity through a cannula. The ligature is passed around the structure with assistance of a second grasping forceps entering the body from another port. The ligature is then transferred to the original needle driver and pulled out through the cannula. The remainder of the ligature is fed into the cannula while the surgeon simultaneously pulls the free end of the ligature from the body cavity. The grasping forceps is used to prevent pulling and sawing to the tissue being ligated. The free ends of the ligature are tied in a Roeder knot (Figure 7-1A-F). The knot is then transferred to the body cavity with a knot pusher.

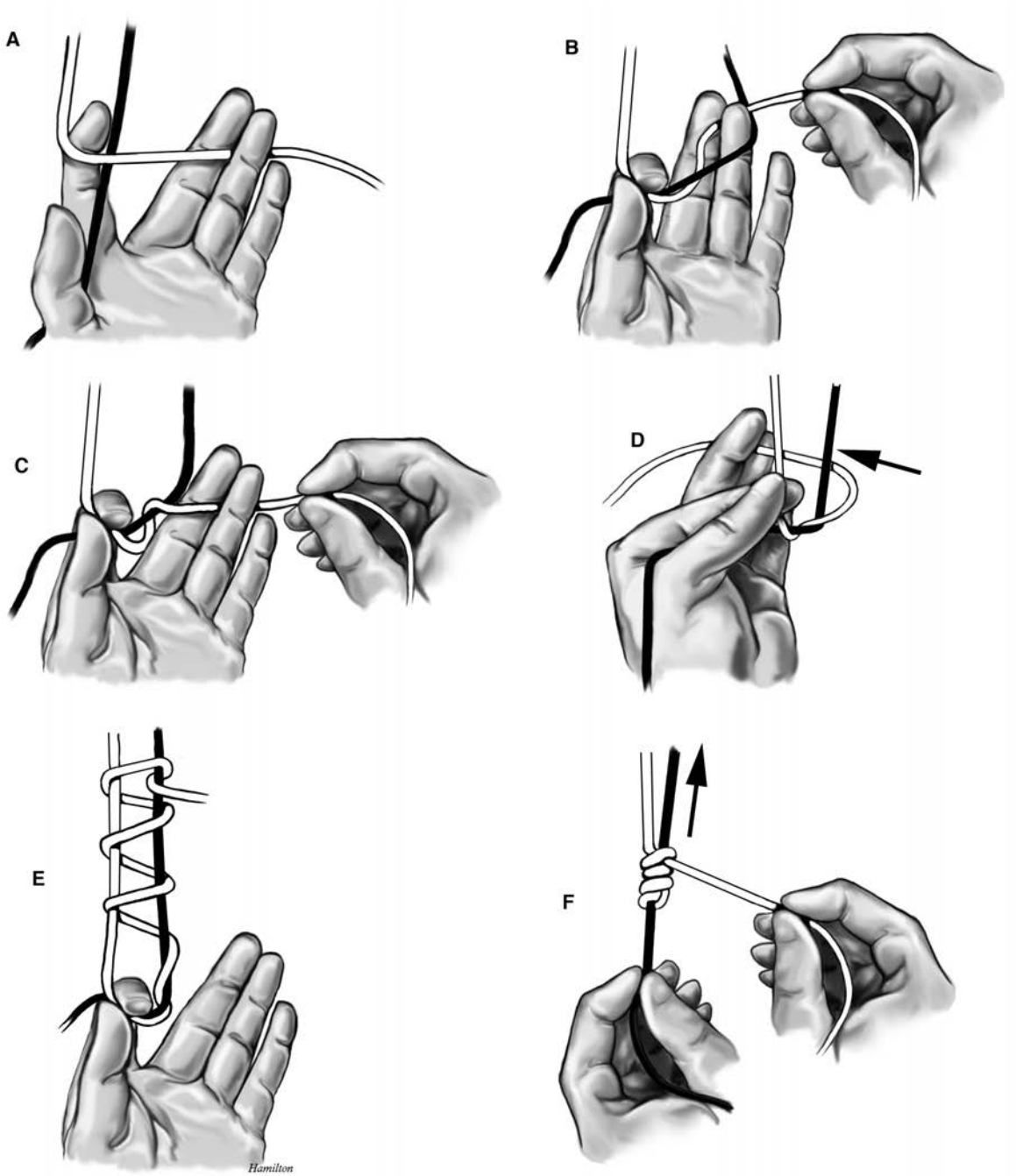


Figure 7-1. Extracorporeal Knot Tying. **A-C.** Produce a simple or surgeon's throw. **D-E.** Wrap the free end three times around both limbs of the loop. Then wrap the free end around the black limb once or twice. **F.** Tighten by pulling on the free end and advancing the knot with a knot pusher.

Pre-tied Loop (ENDOLOOP) Ligatures

Equipment

Pretied loop ligature (ENDOLOOP or SURGITIE)
One endoscopic needleholder and one endoscopic grasping forceps
Endoscopic scissors

Technique

Pretied loop ligatures are commercially available as ENDOLOOP or SURGITIE ligatures and require a free pedicle for proper use. The pre-tied loop ligature is passed through one port and a grasping forceps is passed through a second port. The grasper is passed through the loop to grasp and elevate the structure to be ligated. The knot is placed at the level of the intended ligation, and the loop is slowly closed with a knot pusher. The commercially available products have a nylon cannula with a conical tip that serves as the knot pusher. The cannula is scored near a red tab. After the grasper is positioned through the loop the tab is broken from the cannula at the score point. The tab is held with one hand while the cannula is advanced with the other. (Figures 7-2A-F) Endoscopic scissors are used to cut the suture tail (Figures 7-2G-I).

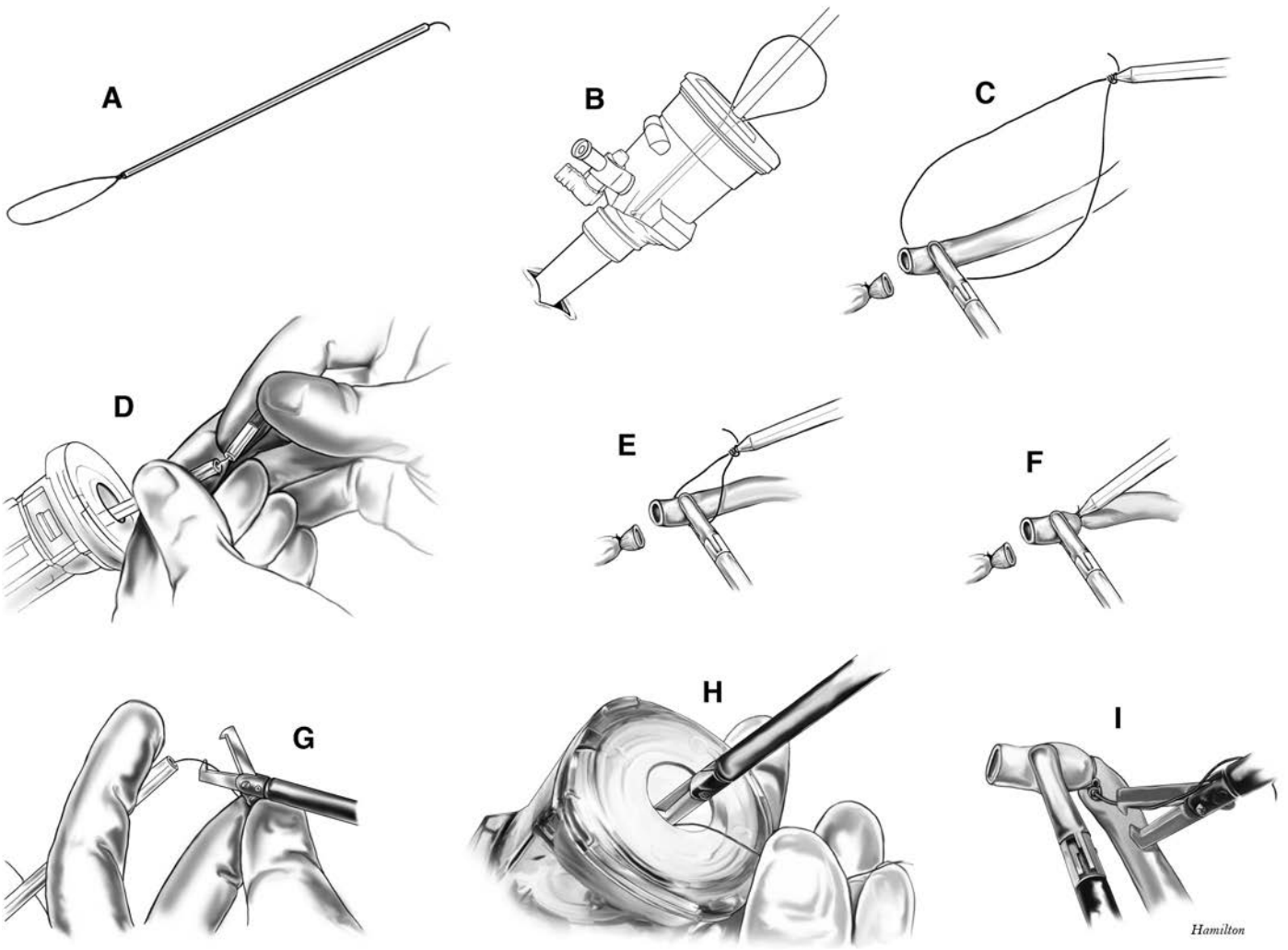


Figure 7-2. A. Pre-tied loop ligature. **B.** The loop folds backwards during insertion through the trocar. Using a trocar with clear housing allows visualization of the loop during insertion to ensure that it is not caught in the flapper valve mechanism of the trocar. **C.** The loop is introduced into the body cavity and a second grasping forceps elevates the desired tissue through the loop. The grasping forceps are passed to an assistant who holds the tissue firmly. **D.** Outside the trocar, the break point of the plastic cannula is identified by the red tab. The red tab is held with one hand while the plastic cannula is advanced with the other. **E.** As the cannula is advanced the knot is pushed distally, causing the loop to become smaller. **F.** The knot is positioned at the desired location and the cannula is firmly advanced while holding the suture taught to tighten the loop. **G.** The suture is cut and the tab is removed. The plastic cannula is removed. **H.** Laparoscopic scissors are introduced beside the suture. This maneuver avoids the need to place a third trocar for introduction of scissors. **I.** With the suture guiding the scissors, the suture is cut.

Intracorporeal Instrument Knot Tying

Equipment

Short ligature (10 to 15 cm) with a curved or half-curved (ski) needle
Two endoscopic needleholders or one needleholder and one grasping forceps
Endoscopic scissors

Technique

Endoscopic knot tying is an advanced technique that requires practice in an endoscopic training box for the surgeon to become proficient before attempting to perform the technqique on a patient. Proper suture placement requires proper trocar-cannula placement. The surgeon places two working cannulas and one cannula for the laparoscope. Ideally, the cannulas will be positioned in baseball diamond configuration with the laparoscope positioned at home plate, pointing towards the monitor. The two working ports are positioned at first and third base, with the incision at second base. The incision should be oriented nearly parallel to the shaft of the active needle holder. One simple intracorporeal suture technique is illustrated in (Figure 7-3A-H).

Intracorporeal Suturing

Equipment

ENDOSTITCH Suturing Device with ENDOSTITCH suture material available in sizes 0 to 4-0 (absorbable, silk, nylon, and polyester)
10 mm trocar

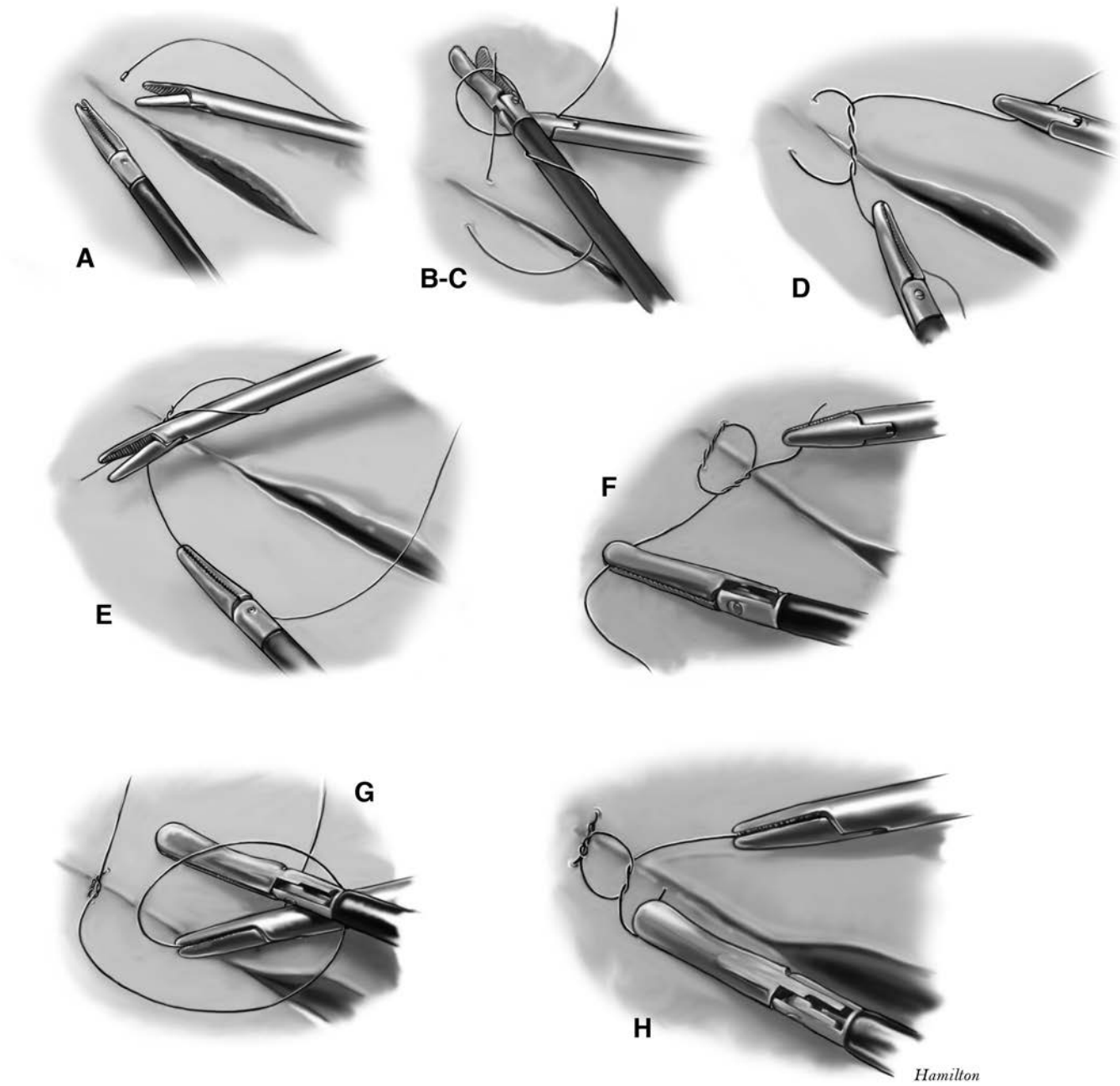


Figure 7-3. Intracorporeal Knot Tying. **A.** For optimal suturing, the incision is oriented at a 30 degree angle to the scope. The needle holder is held in the dominant (right) hand. Grasping forceps are used with the other hand. The needle is driven through tissue as pressure is applied to the tissue with grasping forceps. **B.** The needle tip is grasped and removed. A large C loop is made as the suture attached to the needle is brought to the right side of the incision. The suture is then wrapped about the grasping forceps, once for a simple throw and twice for a surgeon's throw. **C.** The suture tail is grasped with grasping forceps and brought through the loop. **D.** Even tension is applied to both the grasping forceps and the needle holder to complete the first throw of a square knot. **E.** A reverse C loop is then created with the grasping forceps holding the long end of suture. The needle holder is placed ventral to the free end of suture and the grasping forceps is used to wrap a single loop around the needle holder. The free end of suture is grasped and pulled through the loop. **F.** The square knot is tightened by moving the needle holder to the right and applying even tension with the needle holder and grasping forceps. **G.** A large C loop is made with the needle holder and the suture is wrapped around the grasping forceps. The free end of suture is grasped and pulled through the loop. **H.** The throw is tightened with even tension applied to the grasping forceps and needle holders.

Technique

The suture material is swaged to the center of a needle, oriented in a T-fashion. Each end of the needle is loaded into the jaws of the ENDOSTITCH suturing device. The needle can be toggled from one jaw to the other by flipping a switch on the suturing device handle. The needle is loaded on one side, the jaws of the device are closed on tissue, and the switch is flipped to transfer the needle to the other jaw of the instrument. Thus, the needle is held securely and passed through tissue easily, without the difficulty of loading the needle into the needle holder each time. After the tissue is apposed, it is possible to tie a knot by passing the needle around the suture material to create a loop and then passing the needle through the loop. Alternatively, barbed sutures, such as the V-LOC suture (Covidien) or STRATAFIX (Ethicon) can be utilized to avoid the need to tie an intracorporeal knot.

Laparoscopic Endosurgical Procedures

Patient Positioning

Equipment

Tilt table or other means of tilting the animal by elevating the head or feet and rotating the animal side to side

Technique

The animal may be placed in several different positions, depending on the procedure. In general, the laparoscope should be inserted to face the monitor with the target tissue placed between the trocar insertion site and the monitor. Usually, the target tissue will be elevated for optimal visualization. For procedures involving the cranial abdomen or thorax, position the monitor at the head of the table and elevate the head. For procedures involving the caudal abdomen or thorax, position the monitor at the foot of the table and elevate the tail. For ovariectomy procedures, the animal will need to be rotated to the right and to the left to identify the left and right ovaries, respectively.

Access

Equipment

Veress needle or Hasson trocar (blunt trocar with olive plug)

Technique

There are two methods used to create access to the abdominal cavity. A closed approach uses a Veress needle to insufflate CO_2 to create a space for primary trocar insertion. The body wall is grasped and lifted while the Veress needle is passed in the direction predicted to be devoid of viscera. Proper needle placement is confirmed by aspiration and hanging-drop techniques. The body cavity is insufflated with gas, and the needle is removed. The skin incision is made roughly equal to the diameter of the trocar being inserted, and the primary sharp trocar is then blindly placed in a similar fashion to the needle. In the dog, when the Veress needle is inserted at the umbilicus, it is not uncommon to injure the spleen. For this reason, many veterinarians use the open approach to gain entry to the abdominal cavity. The open approach, also known as the Hasson technique, uses a blunt trocar with an olive plug or a screw tipped trocar inserted under direct visualization. The skin incision is made and a midline incision is made through the linea alba. Sutures are placed on each side of the fascia and, after the trocar is inserted, are tied to the olive plug of the trocar (Figure 7-4A-F). Optical trocars, such as the OPTIVIEW, have a central channel for the laparoscope that allows continuous visualization of each tissue layer during insertion. They are used both with and without insufflation of the abdominal cavity. After the primary port is inserted, insufflation of the abdominal cavity with CO_2 is performed to provide a viewing cavity in which to work. Additional ports are placed as needed for each procedure.

Laparoscopic Liver, Intestinal and Pancreatic Biopsy Procedures

Indications

If abdominal exploratory and organ biopsy can be obtained with MIS, this method is preferred over other techniques. Laparoscopic liver biopsy enables the surgeon to obtain more tissue that is needed for heavy metal analysis than what can be obtained with ultrasound directed fine needle aspirates or ultrasound guided core biopsy procedures. Full thickness intestinal biopsy is preferred over obtaining endoscopic biopsy samples for accurate diagnosis of diseases of the intestinal tract. Finally, laparoscopy permits examination of internal organs and visual confirmation of hemostasis without the invasiveness of open surgery.

Equipment

5 mm trocars
5 mm blunt probe
5 mm endoscopic grasping forceps
5 mm endoscopic cup biopsy forceps
Hemostatic agent such as ENDO-AVITENE, SURGICEL, GELFOAM, or collagen sponge
Introducer sleeve and plastic push rod from a pre-tied loop ligature system (SURGITIE)

Technique

Liver Biopsy. When laparoscopic liver biopsy is the only technique being performed, positioning the animal in left lateral recumbency allows more of the liver surface to be exposed through the right lateral mid-abdominal approach. In addition, this position improves visualization because the falciform ligament moves out of the field. However, performing laparoscopic exploration is more difficult, so animals are usually positioned in dorsal recumbency if both techniques are to be performed.

If ascites is present, the open technique for primary port placement should be used to allow suctioning of the ascitic fluid before port placement. Pneumoperitoneum is created, the laparoscope is inserted, and the abdomen is inspected. The liver is inspected and any lesions are identified. A second 5 mm port is then placed in the right or left cranial abdominal quadrant, corresponding to the site of the lesion. A blunt probe is used to palpate and elevate each of the liver lobes prior to biopsy. Any remaining ascitic fluid is aspirated.

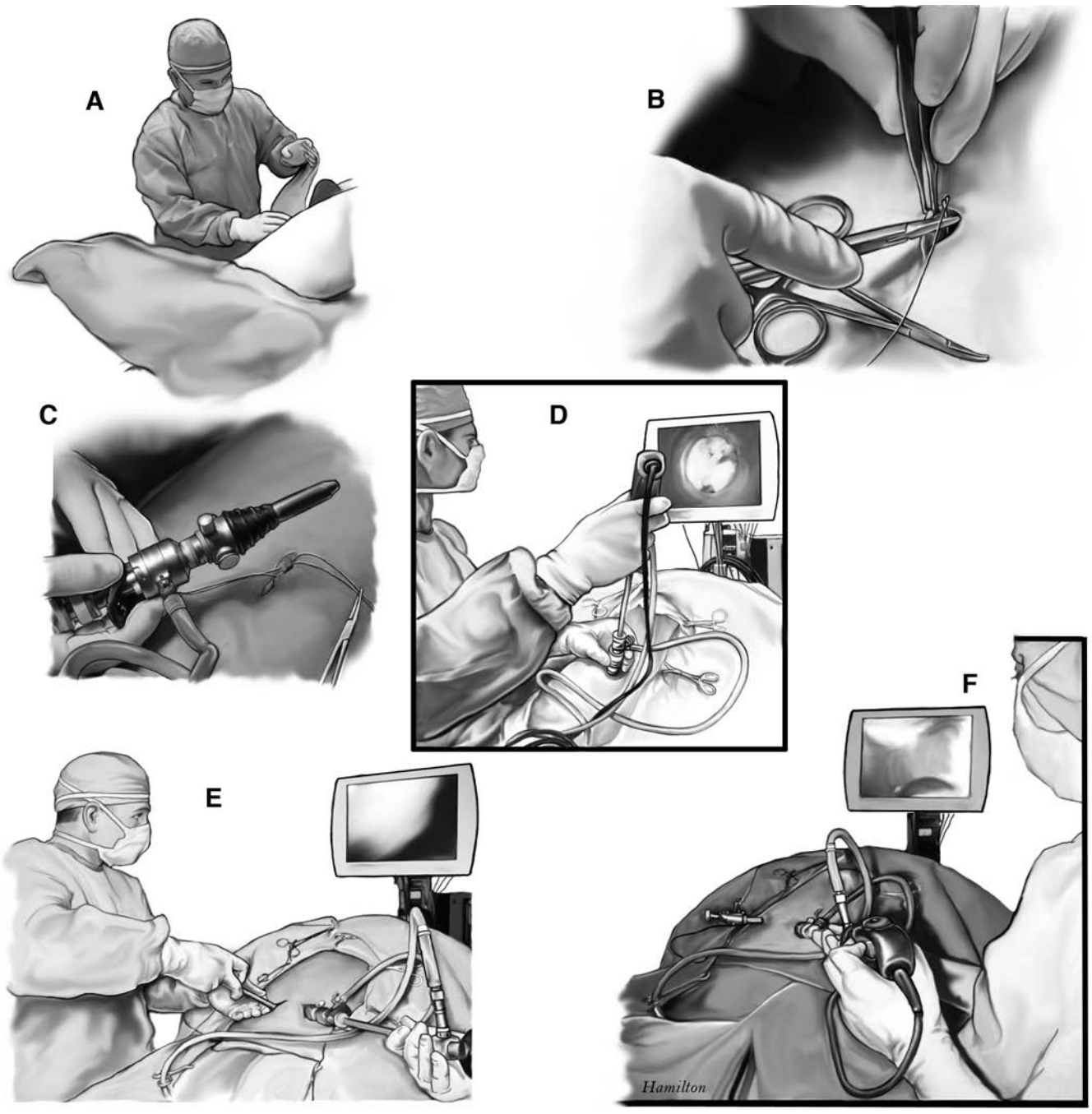


Figure 7-4. Laparoscopic Access. **A.** The abdomen is aseptically prepared for abdominal surgery with wide draping to facilitate ovarian suspension when laparoscopic ovariectomy is being performed. **B.** A small incision is made on midline near the umbilicus. The incision is extended into the abdominal cavity through the peritoneum. Two stay sutures are placed through the abdominal fascia. **C.** A reusable Hasson trocar has an olive plug that features a blunt obturator and tying posts to secure the sutures placed in the abdominal fascia. **D.** After the primary port is placed, the abdomen is insufflated with CO_2 to 12 mm Hg and the laparoscope is introduced. **E.** The working port is placed with direct visualization of its insertion provided by the laparoscope. **F.** A second port is placed in the cranial right abdominal quadrant to facilitate procedures in the cranial abdomen such as liver biopsy or laparoscopic-assisted gastropexy.

Liver biopsy is usually associated with minimal bleeding; however, placing small sections of Gelfoam into the abdominal cavity near the anticipated biopsy site assists in controlling bleeding if it does occur.[6] The Gelfoam sections are back-loaded into the introducer sleeve of the SURGITIE (pre-tied loop ligature) system, introduced through the trocar, and pushed into the abdominal cavity with the plastic rod. If generalized liver disease is present, marginal biopsy samples are obtained from the edge of the liver lobe (Figure 7-5A-C). The 5 mm biopsy forceps are passed through the port, opened, and positioned on tissue. Pressure is held for approximately 30 seconds and then the forceps are rocked or twisted until the tissue is detached. The Gelfoam samples are then nudged into the defect with the forceps to assist in hemostasis. A minimum of five samples are taken: one or two for histology, one for culture, and three to five for heavy metal analysis. If a discrete lesion is identified, the biopsy cup forceps can be used to obtain a sample as just described, or a needle aspirate or core biopsy can be performed

under direct visualization. For these biopsies, the needle is inserted through the abdominal wall, directly above and perpendicular to the lesion. Under direct observation, the needle is inserted into the core of the lesion and the syringe is aspirated or the barrel of a core biopsy needle is advanced to obtain the specimen. Suspending ventilation during this step helps avoid tearing the hepatic capsule. Aspirates of the gallbladder can be obtained using a spinal needle. To minimize bile leakage, the needle is introduced through hepatic parenchyma before entering the gallbladder.

Laparoscopic Intestinal and Pancreatic Biopsy. To reduce operative time and the potential for abdominal spillage, intestinal biopsy procedures begin with laparoscopic exploration for assessment of the liver and biliary tract and pancreatic biopsy. The procedure is then converted to a mini-laparotomy for obtaining multiple biopsy samples of the intestinal tract.

The initial 5 mm port is placed on midline just caudal to the umbilicus. A second 5 mm port is placed in the cranial right quadrant for insertion of biopsy and grasping forceps. Following liver biopsy and aspiration of the gallbladder, the biliary tree is examined. If there is dilation of the common bile duct and cystic duct, the region where the biliary and pancreatic secretions enter the duodenum must be seen. Visualization is obtained by elevating the duodenum and retracting it medially and caudally. If white, plaque-like discoloration of the pancreas is seen, a biopsy of that area should be obtained, as this can be an early sign of pancreatic adenocarcinoma. Biopsy samples can be obtained with the 5 mm cup forceps. Bleeding is minimal. The remainder of the left and right lobes of the pancreas can be visualized by applying traction to the duodenum and elevating

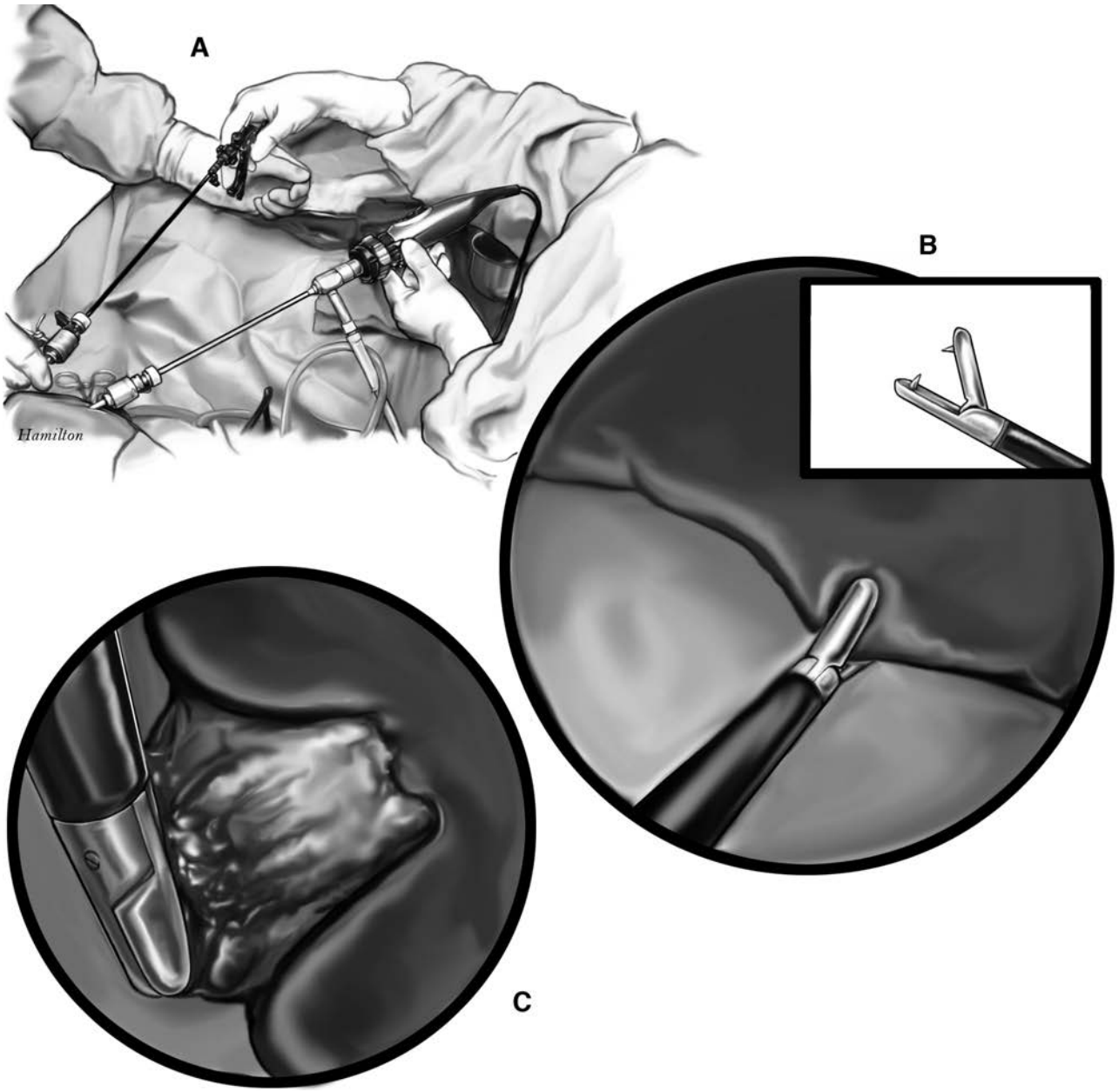


Figure 7-5. A. Laparoscopic Liver Biopsy. A 5 mm laparoscope is placed through the port at the umbilicus. Biopsy forceps are inserted through left lateral 5 mm port. **B.** Laparoscopic toothed biopsy forceps are used to obtain a sample from the liver margin. **C.** Gelfoam is placed in the biopsy site to assist with hemostasis.

the greater curvature of the stomach. To examine the bowel laparoscopically, a third port is placed for insertion of another pair of grasping forceps and a "hand-over-hand" technique is used to trace the bowel.

Usually, it is easier and quicker to visually examine the colon laparoscopically and then convert to a mini-laparotomy. To do so, the trocars are removed and the midline incision is extended cranially and caudally along the linea for a total length of ~ 5 cm. A loop of intestine is grasped and traced orally and aborally to completely examine and palpate the small intestine, mesentery, and mesenteric lymph nodes. Only a portion of the intestine is exposed and the remainder is returned to the abdominal cavity as the exploration proceeds. The entire intestinal tract is examined and full thickness biopsy samples of the stomach duodenum, jejunum, and ileum are obtained. The stomach may be difficult to expose, and if needed, the incision can be extended cranially.

Prior to closure, the abdomen should be inspected to ensure hemostasis. If the animal is hypotensive during surgery, bleeding can occur when the abdominal pressure is reduced and blood pressure returns to normal. If there is concern for active bleeding or contamination from the biopsy procedure, abdominal lavage and inspection should be performed prior to closure. The midline incision and trocar sites are closed in layers.

Laparoscopic Ovariectomy, Ovariohysterectomy

Indications

This procedure is indicated for elective sterilization or retrieval of ovarian remnants left from an incomplete ovariectomy. Studies have demonstrated that there is no increase in complications, such as weight gain, stump pyometra, urethral sphincter incompetence or uterine neoplasia associated with ovariectomy versus ovariohysterectomy. However, it is wise to be specific in discharge instructions for clients as to the procedure being performed to avoid potential future misunderstanding if the animal is seen by another veterinarian. Recently, randomized studies demonstrated that dogs undergoing laparoscopic ovariohysterectomy required less postoperative analgesia than those undergoing an open procedure.[7,12] Another study demonstrated less decrease in postoperative activity levels with laparoscopic approaches in small dogs, compared to open surgery.[1]

Equipment for dogs > 25 kg

10 mm blunt-tip trocar-cannula (with reducing cap to be compatible with 5 mm laparoscope)
5 mm sharp trocar-cannula
5 mm grasping forceps
Laparoscopic spay hook or large curved needle
5 mm LIGASURE device, ENSEAL or Harmonic scalpel

As a general guideline, in cats and very small dogs a 2.7 mm rigid scope is used; for dogs < 25 kg, a 5.0 mm laparoscope is used, and for dogs > 25 kg, a 10 mm laparoscope is used. The size dictates the size of the Hasson trocar, which is placed on midline, just caudal to the umbilicus.

Technique

The abdomen is insufflated to 12 mm Hg and the abdomen is explored. A second 5 mm port is placed on midline about halfway between the umbilicus and pubis. The grasping forceps are inserted and the animal is rotated to the right to expose the left uterine horn and ovary. Grasping forceps are used to grasp the proper ovarian ligament and elevate the ovary to a convenient location on the body wall (Figure 7-6A-F). The location must be inside the sterile field, hence a wide surgical clip and preparation are needed. A laparoscopic spay hook is inserted through the body wall and the ovary is draped over the hook as it is rotated to engage the tip in the body wall. If a needle and suture are used, the needle is rotated and removed from the body and forceps are attached to the suture and used to elevate the ovary and body wall. For secure and rapid hemostasis, an energy system such as the LIGASURE or Harmonic Scalpel is used. The jaws of the device are positioned across tissue, energy is applied, and the tissue is cut. The ovarian pedicle and suspensory ligament are cut first, followed by transection of the fallopian tube and proper ovarian ligament or the proximal portion of the uterine horn. Hemostasis is complete and the ovary is left suspended to the abdominal wall. The energy device is removed and the laparoscope is transferred to the caudal port. Grasping forceps are inserted through the subumbilical port to grasp the ovary as the needle or spay hook is released. The tissue is then removed with the trocar by detaching the sutures from the olive plug. Following inspection to ensure that the entire ovary was removed, the trocar is replaced and the procedure is repeated on the right side. Following final inspection to ensure hemostasis, the insufflation is relieved, and port sites are closed in 2 layers. A 5% lidocaine patch is applied to the skin around the port sites and postoperative analgesia is provided with nonsteroidal anti-inflammatory medication and injectable opioid pain medication.

Complications are rare, and the most common are inflammation of the port sites. Iatrogenic trauma to the spleen or other abdominal organs during insertion and removal of laparoscopic equipment, electrocautery injury to surrounding tissue, and subcutaneous emphysema may occur. Usually these complications are self-limiting and are treated conservatively with no serious consequence.

A laparoscopic ovariohysterectomy can be performed using a similar approach; however, with only one working port, it can be difficult to mobilize the ovary and keep it retracted to gain access to the broad ligament. If so, one can place an additional port so that caudo-medial retraction can be provided while the energy modality is used to coagulate and divide the broad ligament to the level of the uterine arteries and uterine bifurcation. Once both broad ligaments are transected, the uterine body is coagulated and cut or ligated. If the uterine body is small, the LIGASURE, ENSEAL, or Harmonic Scalpel can be used to coagulate and cut it. If very large, the uterine body may need to be ligated. The caudal midline trocar is removed and the incision enlarged so that the uterine body is exteriorized. An extracorporeal ligature can then be used to ligate the uterine body in the same fashion as in open surgery (technically performing a laparoscopic-assisted ovariohysterectomy). Another alternative is to use a pre-tied loop suture. The pre-tied loop is introduced and the ovaries and uterine horns are passed through it such that

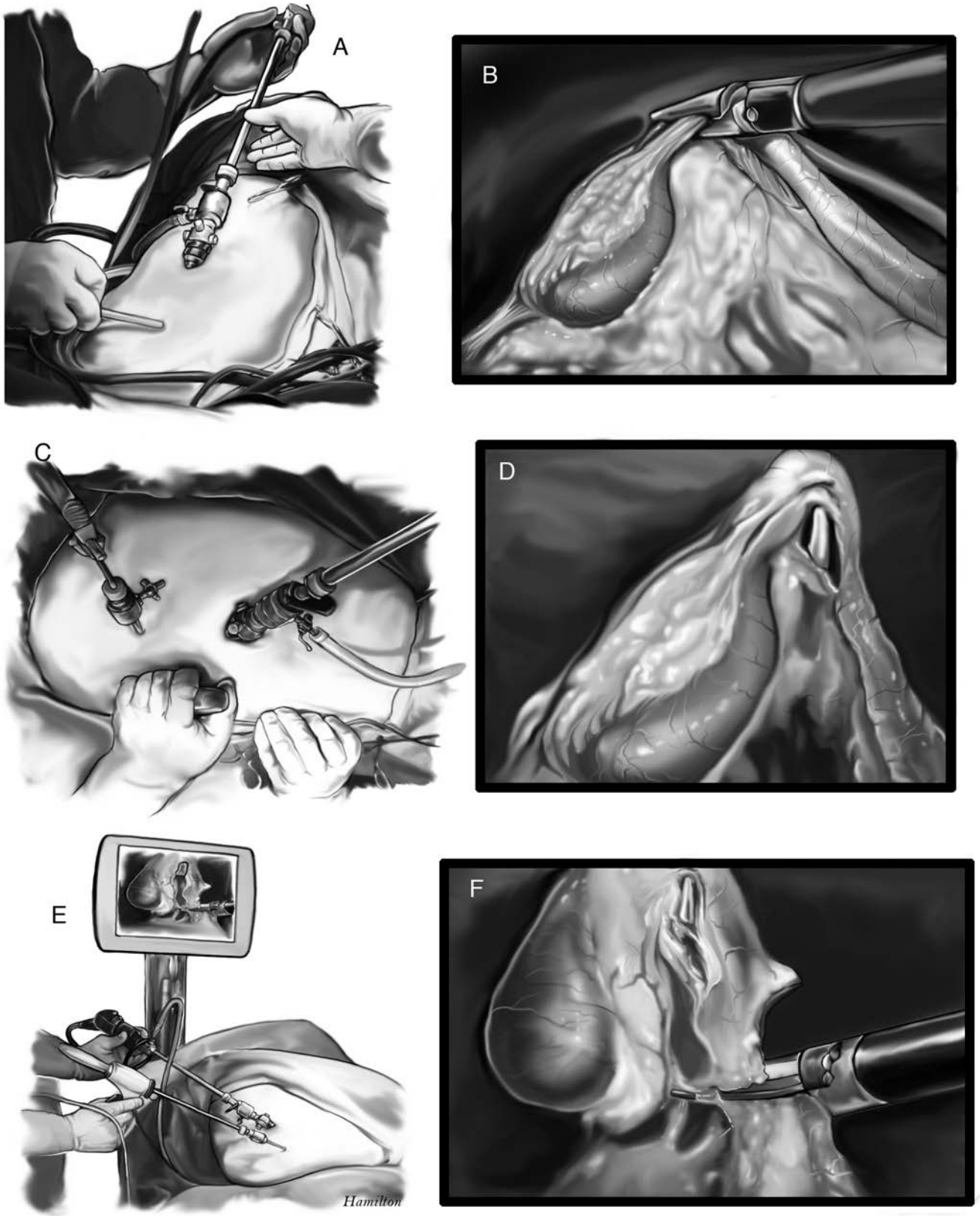


Figure 7-6. Laparoscopic Ovariectomy. **A.** A second 5 mm port is placed on midline midway between the umbilicus and pubis. **B.** The proper ligament of the left ovary is grasped and elevated to the body wall. **C.** External view showing the animal rotated to the right and the spay hook being introduced into the abdomen. **D.** The spay hook is introduced percutaneously and the proper ligament is draped over the hook and secured. **E.** External view showing the harmonic scalpel being used through the caudal midline port. Monitors are positioned at the head and foot of the table and the surgeon is observing the procedure on the monitor at the end of the table. **F.** The harmonic scalpel is used to transect the suspensory ligament, ovarian pedicle, and proximal portion of the uterine horn and the round ligament of the left ovary.

the loop can be positioned on the uterine body. A nylon cannula is broken and advanced to tighten the loop, taking care to avoid incorporation of other structures into it. When the loop is tight, the suture tail is cut with laparoscopic scissors. The uterus is then transected and removed from the sub-umbilical port.

If the tissue is suspected to be malignant or infected, a specimen retrieval bag can be utilized to protect the body wall from contamination. The bag is introduced through one of the ports, tissue is placed in it and the mouth of the bag is closed for withdrawal from the body. Final inspection is performed and the port sites are closed routinely.

Cryptorchid Castration

Indication

This procedure is indicated for animals that have intra-abdominal retained testicles, which are susceptible to torsion and neoplasia. A laparoscopic or laparoscopic-assisted technique can be performed, depending on available equipment. If an energy modality such as LIGASURE, ENSEAL, or Harmonic Scalpel is available, the laparoscopic approach is performed. If not, the laparoscopic-assisted technique is easiest and quickest.

Equipment

10 mm blunt-tip trocar-cannula (with reducing cap to be compatible with 5 mm laparoscope)
5 mm sharp trocar-cannula
5 mm grasping forceps
Laparoscopic spay hook or large curved needle
5 mm LIGASURE device, ENSEAL or Harmonic scalpel

Technique

With both techniques, the animal is positioned in dorsal recumbency and prepared for abdominal surgery. Following the guidelines described earlier, a Hasson port is placed on midline caudal to the umbilicus. The abdomen is insufflated and inspection is performed. Once the testis is identified, a second 5 mm or 10 mm port is placed under direct visualization in the caudal abdominal quadrant on the side opposite the location of the testicle if performing a totally laparoscopic procedure (Figure 7-7A-D). If the laparoscopic assisted technique will be utilized, the port is placed on the same side as the retained testicle. If both testicles are retained, they can usually be retrieved through the same port with the laparoscopic technique. The port is ideally placed just lateral to the lateral edge of the rectus abdominis muscle, taking care to avoid the caudal deep epigastric vessels.

If the laparoscopic assisted technique is used, the testicle is identified and elevated to the body wall. The trocar is removed and the testicle is exteriorized. It may be necessary to enlarge the incision, depending on the size of the laparoscopic port. Similar to open surgery, ligation of the gubernaculums, pampiniform plexus, and spermatic cord is performed. If both testicles are retained, it may be necessary to place a second working port in the opposite caudal abdominal quadrant for removal of the second testicle. Following final inspection to ensure hemostasis, the port sites are closed routinely.

When the 2-port laparoscopic technique is used for a totally laparoscopic procedure, the testicle is lifted suspended from the abdominal wall with a percutaneous suture, similar to the technique used for ovarian suspension in the laparoscopic ovariectomy. The LIGASURE, ENSEAL, or Harmonic Scalpel are used across the gubernaculums, pampiniform plexus, and spermatic cord. Alternatively, clips or sutures can be used. Once ligation and transection are complete, the testicle is removed. If a 10 mm port is placed on midline, the testicle can be removed from that port by transferring the laparoscope to the caudal port. Following final inspection, the port sites are closed routinely.

Gastropexy

Indications

Prophylactic gastropexy is performed to prevent gastric volvulus in large breeds of dogs that may be predisposed to developing gastric dilatation-volvulus syndrome. The procedure can be combined with laparoscopic ovariectomy in female dogs or castration in male dogs. In females, the laparoscopic-assisted procedure is performed; in males, an endoscopic-assisted procedure using a flexible endoscope avoids the need to use laparoscopic equipment. The technique is an incisional gastropexy procedure performed by suturing the seromuscular layer of the stomach to the internal fascia and transverse abdominis muscle at a site selected approximately 3 cm caudal to the costal margin on the right side. Biomechanical studies and clinical experience suggests that the resultant gastropexy adhesion is strong and reliable.[8]

Equipment

Laparoscopy equipment for the laparoscopic-assisted approach
10 mm blunt-tip trocar-cannula (with reducing cap to be compatible with 5 mm laparoscope)
10 mm sharp trocar-cannula
10 mm endoscopic Babcock forceps
Flexible endoscope for the endoscopic-assisted approach
76-mm long needle with size-2 polypropylene suture

Technique

Laparoscopic Approach. Following general anesthesia and positioning in dorsal recumbency, the abdomen is prepared for abdominal surgery. The monitor is placed at the animal's head and the surgeon stands on the animal's right side. A 10 mm Hasson port placed on midline, just caudal to the umbilicus serves as the camera port. The abdomen is insufflated to 12 mm Hg and inspected. Particular attention is paid to the location of the stomach, omentum, and spleen. The pylorus is identified beneath the right medial liver lobe and gallbladder. A second 10 mm port is placed 3 to 5 cm caudal to the ribs on the right side at the lateral edge of the rectus abdominis muscle. Babock forceps are introducted to elevate the liver lobes and fully expose the ventral aspect of the stomach (Figure 7-8A-H). Using the aperture of the Babcock forceps as a measuring tool, a site is selected in the antral region of the stomach approximately 5 cm orad to the pylorus and midway between the greater and lesser curvatures of the stomach. The gastric wall is grasped firmly and elevated to the body wall as the trocar cannula is withdrawn.

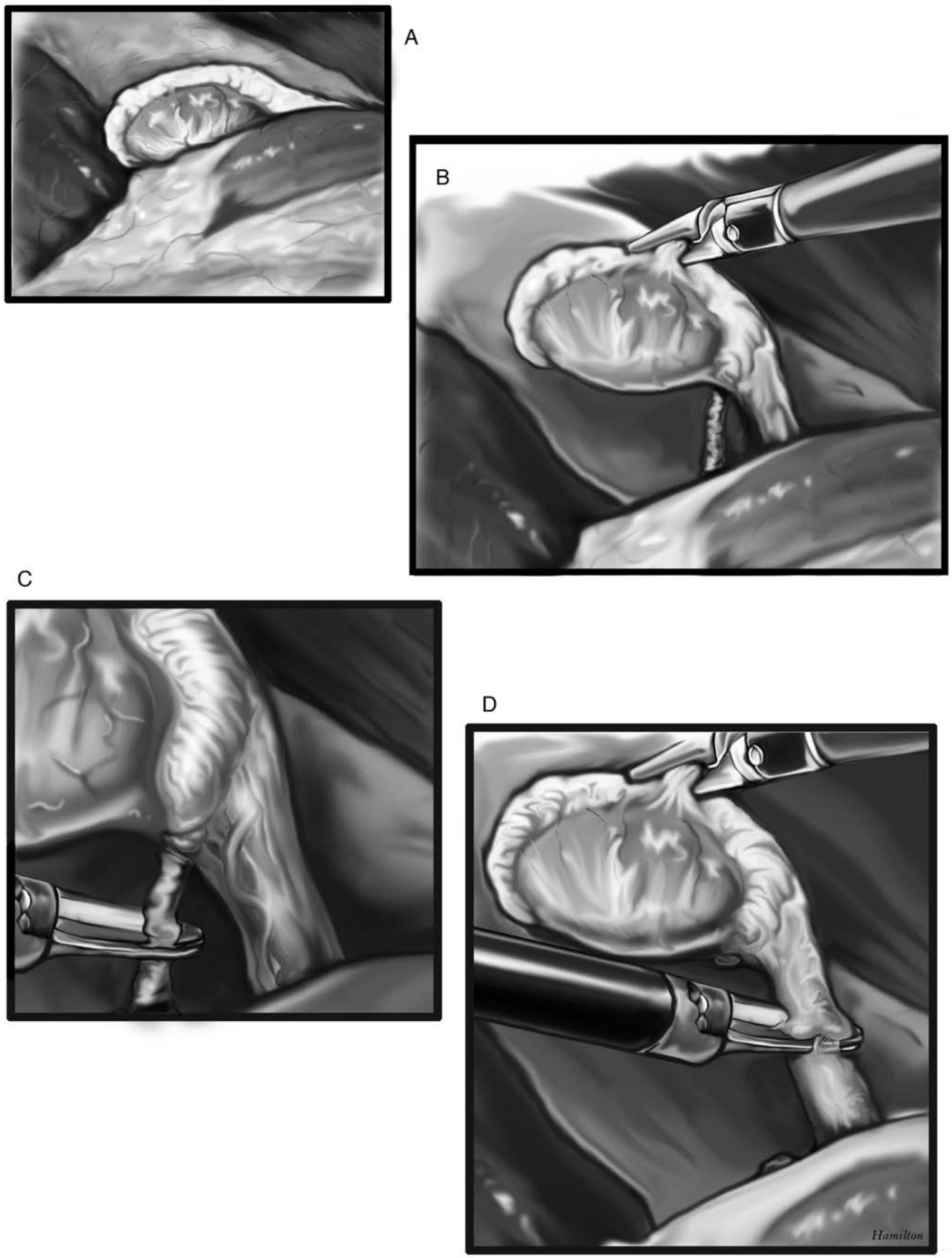


Figure 7-7. Laparoscopic Cryptorchid Castration. **A.** The retained testicle is identified on the right side, lateral to the urinary bladder (arrow). **B.** In this case, a port was placed in the right cranial quadrant to enable a gastropexy procedure. Grasping forceps are used to elevate the testicle. **C.** The vas deferens and pampiniformplexus are identified as the testicle is elevated. **D.** The harmonic scalpel is used for obtaining hemostasis and transection of the vascular structures. The testicle was then removed when the right cranial quadrant incision was enlarged prior to the gastropexy procedure.

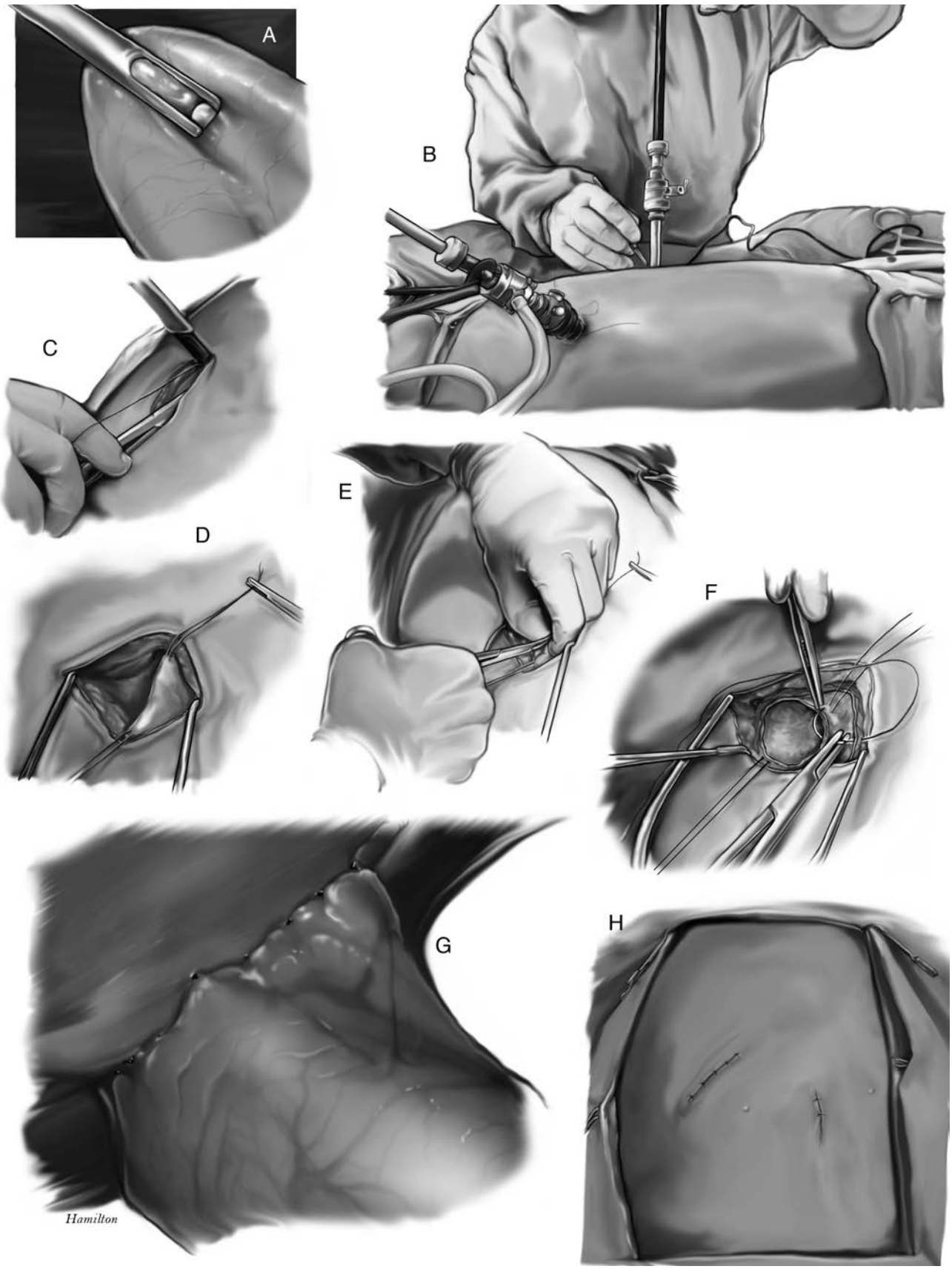


Figure 7-8. Laparoscopic-Assisted Gastropexy. **A.** The stomach is elevated to the base of the trocar with Babcock forceps. **B.** The skin and body wall incision is enlarged with a scalpel blade. **C.** With the forceps elevating the stomach, two stay sutures are placed about 5 cm apart in the gastric wall. **D.** A Gelpi retractor assists in providing clear visualization of the gastric surface. **E.** A seromuscular incision is made in the stomach wall. Pinching the surface of the stomach causes the mucosa to slip away, making the incision less likely to penetrate the mucosa. **F.** The seromuscular layer of the stomach is then sutured to the abdominal wall with a continuous pattern of absorbable sutures. **G.** Final inspection of the gastropexy site prior to closure. **H.** External view of the two incisions for laparoscopic-assisted gastropexy.

When the Babock forceps reach the abdominal wall, the skin and abdominal fascial incisions are extended to ~ 5 to 6 cm with a scalpel blade under laparoscopic visualization. Pneumoperitoneum is lost as the incision is extended and the insufflation gas is turned off. Bleeding is minor. Two stay sutures are placed in the gastric wall about 5 cm apart and the Babcock forceps are removed. Two Gelpi retractors or the Lone Star Veterinary Retractor system with multiple elastic stays can be helpful to aid in exposure and identification of the layers of the abdominal wall. The seromuscular layer of the stomach is then sutured to the abdominal wall with size 2-0 absorbable suture. The external fascia, subcutaneous tissue, and skin are closed routinely. Following inspection of the gastropexy site to ensure that there is no twisting of the gastric wall, the abdomen is desufflated, the umbilical port is removed, and the fascia, subcutaneous tissue and skin are closed. An alternative, totally laparoscopic, approach is direct laparoscopic suturing of the gastric seromuscular incision to an incision in the peritoneum and transversus abdominis muscle with traditional needleholders, barbed sutures, or using the ENDOSTITCH device.[9]

Endoscopic Approach. A flexible endoscope is passed to inspect and dilate the stomach with air. The animal is tilted to the left approximately 30 degrees to allow the distended stomach to be in contact with the right lateral body wall caudal to the costal margin. With gastric distention, identification of the pylorus, and indention from forceps applied to the body wall, the correct site for gastropexy is identified.[10] A large needle is passed percutaneously under direct vision with the endoscope into the stomach and back out through the abdominal wall. A second suture is placed under direct vision from the endoscope 4 to 5 cm from the first suture. Externally, an incision is made through the skin and abdominal wall between the 2 sutures. The gastric surface is identified and a 3 to 5 cm seromuscular gastric incision is made, avoiding the mucosa. Similar to the laparoscopic assisted gastropexy, the seromuscular layer of the stomach is sutured to the body wall and closure proceeds as described previously. The stay sutures are removed and final endoscopic inspection is performed. The surgeon should be alerted to the possibility of trapping of omentum or abdominal contents between the gastric and abdominal wall so careful identification and palpation should be performed prior to placing the percutaneous sutures.

Laparoscopic-assisted Cystoscopy

Indications

This procedure is performed when the surgeon desires to minimize the approach to bladder biopsy (Figure 7-9A-E) or management of urinary calculi that are too large or too numerous for other less invasive treatment modalities.[11] Most often, the procedure is performed in male dogs because stones are more easily retrieved from the urethra in female dogs. The benefit of this procedure is that the incisions are very small and there is less likelihood of urine contamination of the abdomen. Preoperative patient management practices and preparation are similar to open cystotomy.

Equipment

30 degree rigid cystoscope, 1.9 mm for small dogs and cats, 2.7 mm for most other dogs
Saline irrigation fluids with pressure bag and ingress/egress tubing
Stone Basket, compatible with insertion through the working channel of the cystoscope
Arthroscopy or alligator forceps
2 trocars, either 5 mm or 10 mm, depending on the laparoscope size
5 and/or 10 mm Babcock grasping forceps
5 mm disposable screw tipped trocar (optional)

Technique

The initial port is placed on midline near the umbilicus for insertion of the laparoscope. Following insufflation and inspection of the abdomen, a second 5 mm or 10 mm port is placed to exteriorize the bladder. In females, it is placed on midline; in males, the second port is placed lateral to the prepuce at the lateral edge of the rectus abdominis muscle. Through the second port, grasping forceps are introduced to grasp the apex of the bladder and elevate it to the body wall as the trocar is removed. Usually, a 10 mm incision is sufficient unless a very large stone is being removed, but a 5 mm port will need to be enlarged. Stay sutures are placed in the bladder wall and a stab incision is made into the bladder with a #11 scalpel blade. The bladder wall can be sutured to the skin to prevent abdominal contamination during the procedure or a 5 mm disposable screw tipped trocar can be positioned if repeated insertions of the cystoscope are anticipated. The insufflator is turned off and the laparoscope is disconnected from the camera and light guide cable. The camera and light cable, along with the ingress and egress fluid lines, are then attached to the cystoscope. The cystoscope is inserted into the bladder, the fluids are turned on, and thorough visual inspection of the bladder is performed. In male dogs, it can be helpful to pass a urinary catheter to assist in occluding the urethral lumen so that stones do not lodge in the urethra during cystoscopy. At the end of the procedure, the urethra can be flushed with the catheter to ensure that all stones are retrieved. A flexible endoscope can also be used to inspect and/or retrieve urethral calculi.

One of several methods may be used for stone retrieval, depending on the size and number of cystoliths present. The wire stone basket is efficient for removal of large numbers of small calculi that stick together with blood clot. The basket is passed through the working channel of the cystoscope and, under direct vision, passed past the calculi and opened. As the basket is closed, the stones are brought to the end of the cystoscope and the cystoscope is removed from the bladder to deliver the stones. If calculi are too large for the stone basket, they can be retrieved with forceps inserted beside the cystoscope. Numerous small calculi can be removed by using a suction device in the bladder and flushing the urethral catheter. At the end of the procedure, the urethral catheter is withdrawn and the cystoscope is positioned in the trigone region of the bladder. The urethral catheter is simultaneously flushed and passed, and any remaining stones are seen as they are flushed back into the bladder. Bladder polyps or biopsy can be performed with either cystoscopic technique using a biopsy forceps or externally, if full-thickness resection is needed.

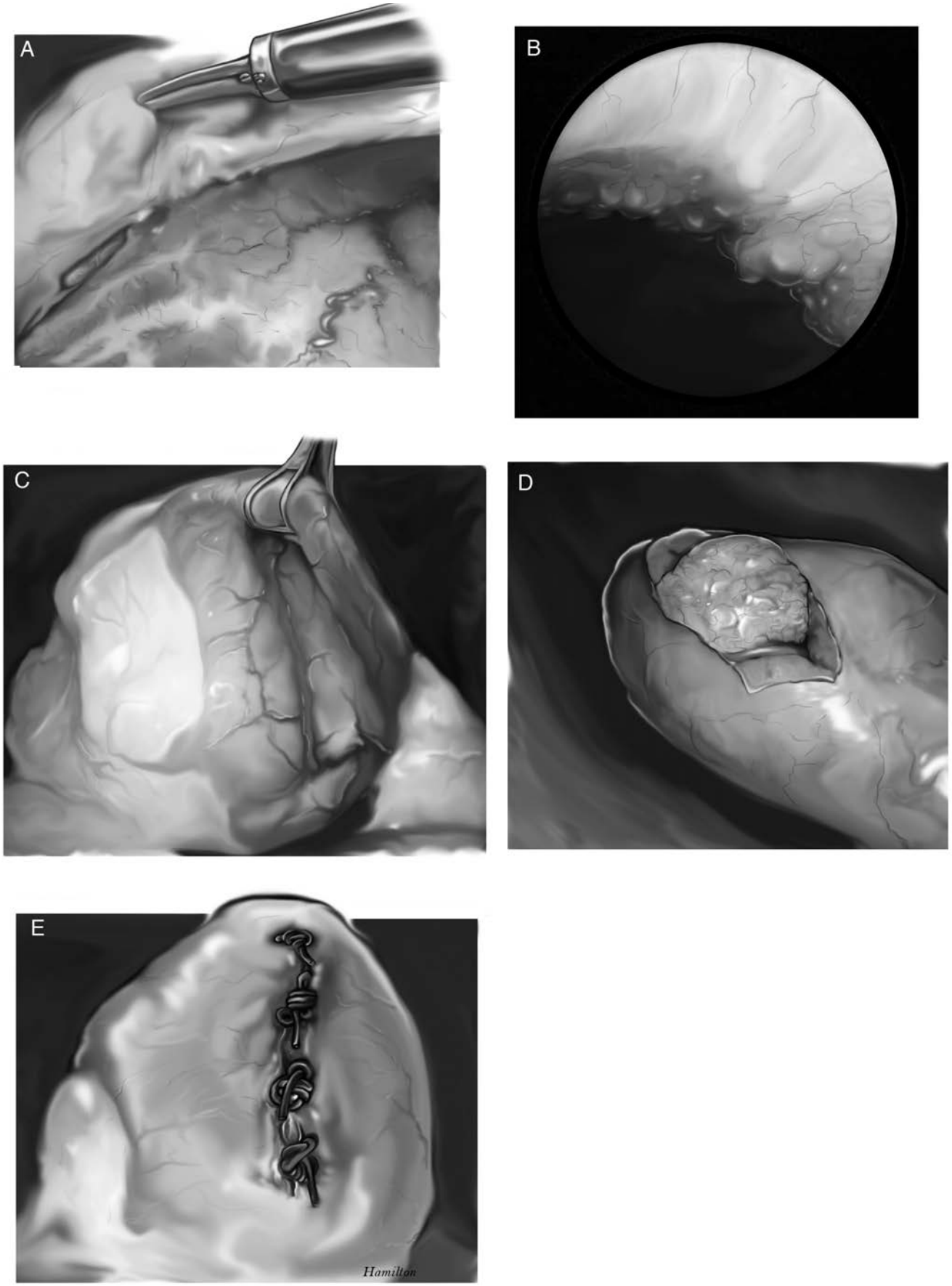


Figure 7-9. Laparoscopic Assisted Cystotomy. **A.** Visual inspection of the urinary bladder revealed scarring on the surface in this case of transitional cell carcinoma. **B.** Cystoscopyrevealed an irregular mucosal surface in the region of the trigone. **C.** Babcock forceps are being used to elevate the bladder to the abdominal wall. **D.** External view of the cystotomy showing bulging of the tissue from inside the bladder. **E.** Laparoscopic view of the bladder closure with simple interrupted sutures.

The cystotomy is then closed and the bladder is returned to the abdominal cavity. The caudal incision is closed, the laparoscope is re-attached to the camera and light guide cable, and the abdomen is re-insufflated. Following final inspection, the camera port is removed, the CO_2 is allowed to escape and the port site is closed routinely. Although always a concern, seeding of the abdominal wall with tumor cells following biopsy of transitional cell carcinoma has not occurred.

References

1. Culp WT, Mayhew PD, Brown DC. The effect of laparoscopic versus open ovariectomy on postsurgical activity in small dogs. Vet Surg 2009; 38:811-817.

2. Nadeau O, Kampmeier O. Endoscopy of the abdomen: abdominoscopy: a preliminary study, including a summary of the literature and a description of the technique. Surg Gynecol Obstet 1925; 41:259-271.

3. Bailey JE, Pablo LS. Anesthetic and physiologic considerations for veterinary endosurgery. In Freeman LJ (ed). Veterinary Endosurgery. St. Louis: Mosby, 1999.

4. Stoloff DR. Laparoscoic suturing and knot tying techniques. In Freeman LJ (ed). Veterinary Endosurgery. St. Louis: Mosby, 1999.

5. Freeman L, Rawlings CA, Stoloff DR. Endoscopic knot tying and suturing. In Tams TR and Rawlings CA (eds), Small Animal Endoscopy, 3rd edition. St. Louis: Elsevier-Mosby, 2011.

6. Freeman LJ. Laparoscopic liver biopsy. Clinician's Brief, May 2010.

7. Hancock RB, Lanz OI, Waldron DR, et al. Comparison of postoperative pain after ovariohysterectomy by harmonic-scalpel-assisted laparoscopy compared with median celiotomy and ligation in dogs. Vet Surg 2005; 34:273-282.

8. Rawlings CA, Foutz TL, Mahaffey MB, Howerth EW, Bement S, Canalis C. A rapid and strong laparoscopic-assisted gastropexy in dogs. Am J Vet Res 2001; 62:871-875.

9. Mayhew PD, Brown DC. Prospective evaluation of two intracorporeally sutured prophylactic laparoscopic gastropexy techniques compared with laparoscopic-assisted gastropexy in dogs. Vet Surg 2009; 38:738-746.

10. Dujowich M, Reimer SB. Evaluation of an endoscopically assisted gastropexy technique in dogs. Am J Vet Res 2008; 69:537-541.

11. Rawlings CA, Mahaffey MB, Barsanti JA, Canalis C. Use of laparoscopic-assisted cystoscopy for removal of urinary calculi in dogs. J Am Vet Med Assoc 2003; 222:759-761.

12. Devitt CM, Cox RE, Hailey JJ. Duration, complications, stress, and pain of open ovariohysterectomy versus a simple method of laparoscopic-assisted ovariohysterectomy in dogs. J Am Vet Med Assoc. 2005 Sep 15;227(6):921-7.

Thoracoscopy

Eric Monnet

Introduction

Thoracoscopy is a minimally invasive technique for viewing the internal structures of the thoracic cavity. The procedure uses a rigid telescope placed through a portal positioned in the thoracic wall in order to examine the contents of the pleural cavity. Once the telescope is in place, either biopsy forceps or an assortment of surgical instruments can be introduced into the thoracic cavity through adjacent portals in the thorax to perform various diagnostic or surgical procedures.

The minimal invasiveness of the procedure, the rapid patient recovery, and diagnostic accuracy make thoracoscopy an ideal technique for selected cases over more invasive procedures. Small animal thoracoscopy has not only developed into a diagnostic tool but more recently has progressed to become a means for performing minimally invasive surgical procedures.[1-4]

Despite the advent of newer laboratory tests, imaging techniques and ultrasound directed fine needle biopsy or aspiration, thoracoscopy remains a valuable tool when appropriately applied in a diagnostic plan. Thoracoscopy may also provide accurate and definitive diagnostic and staging information that would otherwise only be obtained through a surgical thoracotomy.[5-6]

Indications and Contraindications

The most common indication for thoracoscopy is to examine and biopsy thoracic organs or masses. Thoracoscopy is also a means of performing various surgical procedures. Thoracoscopy may not completely replace an exploratory thoracotomy but can provide a minimally invasive means of accomplishing a number of diagnostic and surgical procedures in small animals.

Diagnostic thoracoscopy is commonly used as a method for obtaining pleural biopsy, lung biopsy, cranial mediastinal and lymph node biopsy. Common surgical techniques currently being performed in small animals include partial pericardectomy or pericardial window, patent ductus arteriosus, lung lobectomy, resection of cranial mediastinal mass, correction of vascular ring anomalies, thoracic duct ligation, and debridement for the treatment of pyothorax. The advantages of surgical thoracoscopy over conventional open surgical exploratory thoracotomy include improved patient recovery because of smaller surgical sites, lower postoperative morbidity with lower infection rates and decreased postoperative pain.

Thoracoscopic Equipment

The basic equipment required for diagnostic thoracoscopy includes a telescope, corresponding trocar–cannula units, light source, and various forceps and ancillary instruments.[7-9] The telescope most commonly used by the author is a 5 mm diameter 0° field of view telescope for routine diagnostic thoracoscopy. The 0° designation means that the telescope views the visual field directly in front of the telescope. Angled viewing scopes, the most common being a 30° telescope, views in a 30° downward direction. The angled telescopes enable the operator to look over the top of organs and view in small areas which is very useful during thoracoscopy to look at hilar lymph nodes, around the base of the heart, the hilus of lungs during lobectomy, and the mediastinum.

The telescope is attached to a light source using a light guided cable. A Xenon light source with a high intensity is considered to give the truest colors of abdominal organs and is recommended. A high intensity light source provides enough light for deep chested dogs. The telescope is also attached to an endoscopic video camera which allows the image to be viewed on a monitor.

Open or closed cannulas can be used to perform thoracoscopy. With closed cannulas, a controlled pneumothorax can be induced and a ventilator is not required. With open cannulas, a ventilator is required because the pleural space is open to the environment. Open cannulas are recommended to perform thoracoscopy because they eliminate the risk of tension pneumothorax especially when advanced surgical procedures are performed. The open cannulas can be either soft or hard. Soft cannulas are less traumatic to the intercostal artery and nerve, and can be cut to a desired length therefore they do not protrude excessively into the thoracic cavity. Rigid cannulas are required for a transdiaphragmatic sub-xiphoid approach. Rigid cannulas protect the telescope better when an intercostal approach is performed. Ribs are very rigid and it is easy to bend or even break a scope if there is no cannula to move the ribs with. Closed or open cannulas are placed over a blunt trocar into the thoracic cavity. Cannulas exist in a wide variety of diameters. Diameter of the cannulas is determined by the instruments that will be used during the procedure. For example, the stapling equipment used for lung lobectomy comes in a 12 mm diameter. Therefore, a 12 mm cannula will have to be placed for the introducation of the stapling equipment. Thoracoscopy can be performed without cannulas. However, this technique increases the risk of damaging the intercostal nerve and artery. This approach is reserved for small size animals since cannulas take up excessive space in their thoracic cavity.

During diagnostic thoracoscopy, a number of accessory instruments are essential.[6,8,9] A palpation probe is required to move and palpate the thoracic organs. Most palpation probes have centimeter markings so one can estimate the relative size of organs or lesions. The palpation probe can also be used to apply pressure on a biopsy site that is bleeding excessively. Biopsy forceps are used for biopsy of lymph nodes, and pleura.

Surgical thoracoscopy often requires a vast array of instruments designed for specific indications. Common instruments include grasping forceps, scissors, aspiration tubes and clip applicators. Certain specialized instruments such as stapling devices are generally 10 to 12 mm in diameter. Many of the surgical instruments also have capabilities for monopolar electrosurgery at their distal tip. Retractors are very important during thoracoscopy because they allow retraction of lungs. With retractors, lung lobes can be removed without using one-lung ventilation.

Approaches

Since ribs are supporting the thoracic wall, the chest wall cannot be distended to create a working space. Different options are available to increase working space. First, lung tidal volume can be decreased on the ventilator and the frequency of ventilation increased. This will reduce the volume of the lungs without reducing ventilation. This will expand the surgical field enough to be able to perform diagnostic thoracoscopy. Second, one-lung ventilation can be instituted to completely collapse the lung on one side of the thoracic cavity.[10,11] One-lung ventilation induces a right to left shunt that results in desaturation of oxygen in arterial blood. To further assist patient ventilation, it is recommended to use positive end expiratory pressure since it does not reduce cardiac output but maintains open alveoli in the dependent ventilated lung. One-lung ventilation is mostly used with an intercostal approach when a lung lobectomy is performed. Different techniques have been described to achieve one-lung ventilation in dogs. Selective bronchial intubation with a long small diameter endotracheal tube can be used.[12] This technique works most effectively for selective ventilation of the left lung. Since the bronchus of the right cranial lung lobe is so cranial, it is difficult to perform selective intubation of the right lung. A double-lumen endotracheal tube can be used to intubate the left and right lung lobes. This approach allows one branch of the tube to be occluded so that the other lung can be selectively ventilated. Again, because of bronchial anatomy this technique is not very efficient in dogs. Introduction of an endobronchial occluder is commonly used in dogs to induce one-lung ventilation.[10,11,13] The occluder is advanced either through or along the endotracheal tube and is positioned under bronchoscopic guidance. After placement of the occluder in the desired position, the balloon at the end of the occluder is inflated to occlude the bronchi. It is important to induce one-lung ventilation with this technique, after the dog has been positioned for surgery. Manipulation of the patient can easily dislodge the ballon and cause complete occlusion of the trachea. When one-lung ventilation is used it is critical that a capnograph is used to monitor carbon dioxide production and patency of the airway. Third, carbon dioxide insufflation can be used to collapse the lung lobes.[14] This technique creates a pneumothorax and the amount of pressure in the pleural space will control the degree of the pneumothorax. This technique is not currently used in veterinary medicine. It can induce severe atelectasis and severe desaturation of oxygen in the arterial blood. This technique has been used to visualize specific areas of the pleural space.

Thoracoscopy can be performed using either a trans-diaphragmatic or an intercostal approach.[7,12,15] The trans-diaphragmatic approach allows visualization of both hemi-thoraces. A long axis view of the thorax is then obtained. This is the approach of choice for exploration of the thoracic cavity and biopsy. An intercostal approach is indicated for surgical thoracoscopy because it allows very good visualization of specific structures in the affected hemithorax.

Transdiaphragmatic Sub-xiphoid Approach

The patient is positioned in a dorsal recumbent position. First, a screw-in cannula is inserted from a sub-xiphoid position in a cranial direction. Before insertion of the screw in cannula, a small skin incision is performed caudal to the xiphoid. The cannula is screwed into the thoracic cavity under thoracoscopic visualization. After penetration of the thoracic cavity by the cannula, the thoracoscope is advanced into the thoracic cavity. After intial exploration of the thoracic cavity, two other cannulas are placed under thoracoscopic visualization to allow utilization of instruments. These cannulas are placed in intercostal spaces according to the location of the lesions, which require exploration or treatment. Cannulas need to be placed as ventral as possible to allow maximum mobility of the instruments. Metzenbaum scissors with electrocautery and grasping forceps are used to incise the mediastinum. This will allow exploration of both hemithoraces. A 0° telescope is used for initial exploration.

Intercostal Approach

Postioning of the patient is very important during an intercostal approach since it uses gravity to move lungs and heart within the thoracic cavity. Patients can be placed in ventral recumbency for exploration of the thoracic duct or in an oblique position to be able to visualize the hilus of the lungs during lung lobectomy.

During an intercostal approach, all the cannulas are placed in intercostal spaces in a triangular fashion around the organ or the lesion to be explored. Cannulas can be introduced from the third to the ninth intercostal space. The cannula used for the introduction of the telescope is usually placed as far as possible from the organ or the lesions to be biopsied or resected. After incising the skin with a #10 blade, a mosquito forceps is used to bluntly dissect through the intercostal space. The thoracoscopic cannula is then bluntly introduced into the intercostal space, and into the pleural space. Cannulas can be introduced at any level from dorsal to ventral in the intercostal space.

Surgical Procedures Performed with Thoracoscopy

Pericardial Window and Subtotal Pericardectomy

Creation of a window in the pericardium establishes permanent drainage for patients with pericardial effusion.[16-18] This procedure is performed effectively with minimally invasive technique and reduces operative trauma and postoperative pain. Indications for permanent pericardial drainage include neoplastic effusions, hemorrhage from neoplastic masses, inflammatory disease, and idiopathic effusion. This procedure prevents cardiac tamponade in the future by allowing drainage of pericardial fluid into the pleural space.

Approach

To create a pericardial window the patient is placed in dorsal recumbency and a para-xiphoid telescope portal is established.[12,15,16,19] There are two options for placing operative portals. The first places both portals on the right side and the second places one portal on the right side and one on the left side. Each has advantages and disadvantages with the choice between the two related mostly to surgeon preference. The first option places operative portals in the right 6th or 7th intercostal space and in the right 9th or 10th intercostal space. The second option places portals in the left and right 9th and 10th intercostal spaces. All portals are placed ventral to the costochondral junction in the area of the lateral margin of the transverse thoracic muscles. As an alternative, an intercostal approach can also be performed. The patient is placed in left lateral recumbency, and the camera portal is placed in the right ventral third of the 6th or 7th intercostal space. Two instrument portals are then placed in the right 4th intercostal and the 8th intercostal spaces. This approach allows a better visualization of the right atrial appendage and aortic root for diagnosis of neoplastic disease. A pericardial window will then be created on the right side of the pericardium. The phrenic nerve has to be indentified and avoided prior to incising the pericardium.

Surgical Technique

The surgeon stands on the right side of the patient for the paraxiphoid approach and on either side of the patient for the intercostal technique. The telescope operator stands at the foot of the patient or across the patient from the surgeon. Obliquing the patient slightly to the left (10° to 15°) can facilitate visualization and manipulation when both portals are placed on the right side. With all portals in place, the first step of the procedure is to incise the ventral mediastinum to move it from the visual and surgical field. Scissors are used to cut the mediastunum with electrosurgical assistance for control of bleeding. Inadequate control of bleeding from the mediastinal vessels interferes with the procedure by allowing blood to drip onto the telescope and obscure visualization. It is recommended to explore the cranial mediastinum for lymph node enlargement and biopsy. Biopsy of the medistinal lymph node may reveal the diagnosis of mesothelioma of the pericardium that might not be diagnosed on the pericardial window tissue submitted for biopsy.

A site is selected for the pericardial window on the cranial surface of the heart. When a pneumothorax is established and the patient is in dorsal recumbency, the apex of the heart falls dorsally presenting the cranial surface of the heart to the surgeon. Grasping forceps with teeth are used to pick up a fold of pericardium and Metzenbaum scissors are used to cut into this elevated fold of tissue for intitial penetration of the pericardium. This technique minimizes the potential for cardiac damage. The graspers are then repositioned to pick up a margin of the initial pericardial incision. Any excess pericardial fluid that has not been previously evacuated and that interferes with visualization is removed with suction. The pericardial incision is extended to remove a patch of pericardium taking care not to damage the phrenic nerves, heart, lungs or great vessels. There is no objective data to define how much pericardium to remove. The portion removed needs to be large enough to prevent closure of the defect by the healing process and small enough to preclude herniation of the heart though the window. A four centimeter by four centimeter portion of tissue is an acceptable size. The removed patch is extracted from the chest through one of the operative portals and is inspected for size and to define pathology. Samples are submitted for histopathology, and if indicated, for cultures.

Any residual pericardial and pleural fuid is removed with suction and the cavities are irrigated with saline. Operative portal cannulas are removed and the portals closed in layers to achieve an airtight closure. A thoracostomy drain is placed in a routine fashion through the chest wall. Placement of the tube can be controlled by visualization with the thoracoscope.

Partial Lung Lobectomy

Lung biopsy for chronic lung disease, excision of lung masses, lung abscesses, emphysematous bullae, or any other localized disease process in the peripheral portions of the lung lobes can be performed quickly and effectively with minimally invasive technique. Partial lung lobectomy can also be performed for diagnostic biopsy of generalized lung disease.

Approach

Portal placement for partial lung lobectomy is dictated by the location of the lung to be removed. Dorsal recumbency and the para-xiphoid telescope portal allows examination of both sides of the chest for cases where the side of the pathology cannot be determined preoperatively with radiographs or other diagnostic techniques. Lateral recumbency provides greater unilateral access and is the preferred position. The telescope and operative portals are inserted using appropriate triangulation to access the involved lung lobe lesion.

Surgical Technique

For small peripheral lesions and for lung biopsies the loop ligature technique can used.[12,15] The top of the lobe to be removed is positioned through a pretied loop ligature (Endoloop), which is tightened. The ligated portion of the lung is transected and removed. This technique is quick, easy, and safe. Larger or more central lesions require an endoscopic stapling device (Endo GIA) for occlusion and transaction of the portion of the lobe to be removed. When performing partial lung lobectomy with an endoscopic stapler the telescope and operative portals are placed, and the lung lobe lesion is defined and retracted or elevated as needed. The endoscopic stapler is placed through an additional portal to provide optimal alignment for application of the stapler. Following transection of the lung lobe the excised portion is removed from the chest by enlarging one of the portals to allow passage of the tissue. An endoscopic tissue pouch (Endopouch) can be used to facilitate tissue removal. The transected lung margin is observed for air leakage or bleeding with the telescope before exiting the chest. A thoracostomy drain is placed at a site away from all portals, operative and telescope cannulas are removed, and the portals are closed.

Lung Lobectomy

Complete lung lobectomy can be performed in dogs with minimally invasive technique.[15] It is the author's impression that lung lobes with small masses and that are away from the hilus of the lung can be removed with minimally invasive surgery. Large pulmonary masses impair visualization of the hilus of the lung and make manipulation of the affected lung lobe difficult.

Approach

Lateral recumbency with intercostal portal placement is the preferred technique for complete lung lobectomy. One-lung ventilation is recommended to increase the amount of space available in the thoracic cavity for manipulating the instruments and the lung mass. A telescope portal and two operative portals are placed with triangulation and the hilus of the lung lobe to be removed is prepared with sharp dissection.

Surigical Technique

For caudal lung lobes, the pulmonary ligament is incised to free the lung lobe from the diaphragm for manipulation into position for placement of the endoscopic stapling device. Individual structures of the hilus are not isolated for minimally invasive lung lobectomy and are separated from surrounding structures only enough to place the stapling device. A 45 mm to 65 mm long stapling cartridge with 3.5 mm staples is placed across the hilus of the lobe to be removed through its own additional portal that is placed ventrally and caudally at a location to allow the stapler to be placed perpendicular to the bronchus and blood vessels. The stapling cartridge must be long enough to include the entire hilus to be stapled. The resected lung lobe is removed from the thorax through a small intercostal thoracotomy. Enlarged hilar lymph nodes can be biopsied or removed with minimally invasive technique. If a lymph node is to be dissected and removed for biopsy, sharp and blunt dissection are used for lymph node removal with electrosurgical assistance and hemoclip application for hemostasis. An endoscopic tissue retrieval pouch facilitates removal of the lung lobe and decreases the potential of seeding neoplastic cells or infection to the chest wall. Prior to removal of the telescope the hilus is observed for air leakage or bleeding. A chest drain is placed at a site away from all portals, the operative and telescope cannulas are removed, and the portals are closed.

Thoracic Duct Ligation

Management of chylothorax by thoracic duct occlusion is possible with minimally invasive technique.[3] Magnification produced by the telescope and video system greatly enhances visualization of the thoracic ducts and instrumentation designed for minimally invasive surgery facilitates manipulation of structures deep in the chest. Occlusion can be achieved with vascular clips specifically designed for minimally invasive surgery (Endoclips).

Approach

Intercostal portals are placed with the patient in sternal recumbency. Intercostal portals are placed in the left chest wall with the patient in right lateral recumbency for cats. The telescope portal is placed in the seventh intercostal space at the dorso–ventral midpoint of the intercostal space. Operative portals are placed midway between the telescope portal and the dorsal end of the ribs in the sixth and ninth intercostal spaces.

Surgical Technique

The pleura is dissected to expose the thoracic ducts and multiple clips are applied to all visible branches of the duct. Injection of the popliteal lymph node or the cysterna chyli with methylene blue is recommended to improve visualization of the thoracic duct.

Peristent Right Aortic Arch Ligation

Minimally invasive transection of the ligamentum arteriosum in cases with persistent right aortic arch (PRAA) has been shown to be an effective alternative to the open surgical approach.[2,22]

Approach

To perform minimally invasive PRAA correction the patient is placed in right lateral recumbency, the telescope portal is placed in the left 4th or 5th intercostal space at the costochodral junction, and operative portals are placed in the 3rd and 6th or 7th intercostal space at the level of the costochondral junction and at the dorsal end of the 5th intercostal space.

Surgical Technique

A retractor is placed in the 6th or 7th intercostal portal to retract the cranial lung lobe caudally. A stomach tube is placed in the esophagus to improve visulazation of the ligamentum arteriosum. A palpation probe is used to further localize the ligamentum arteriosum. The ligamentum arteriosum is dissected with sharp and blunt dissection to isolate it from the pleura and esophagus. Endoscopic 5mm vascular clips are placed on the isolated ligamentum arteriosum and it is transected between the clips. An ultrasound dissector can be used to seal the edges of the ductus arteriosus and transect it. Any remaining fibers are dissected and divided and the esophagus is dilated by passage of a balloon dilation catheter or esophageal bougies. A chest tube is placed and the portals are closed. Postoperative dietary management is the same as for open surgical PRAA correction.

Mediastinal and Pleural Mass Excision

Selected neoplastic, (thymoma) and inflammatory masses can be removed effectively with minimally invasive technique.[15] Masses that are inoperable with minimally invasive technique can be evaluated for open surgical excision or biopsied and staged for appropriate non-surgical treatment. Patient position and portal placement are defined by location of the mass. Cranial mediastinal masses are visualized most effectively in dorsal recumbency with a para-xiphoid telescope portal. Operative portals can be placed with both portals on one side or with bilateral portals. Intercostal space selection for the operative portals again depends on the location and size of the cranial mediastinal mass. Portals are placed as ventrally in the appropriate intercostal spaces as possible without traumatizing the internal thoracic artery. Masses are dissected with sharp and blunt dissection as indicated with ligatures, vascular clip, and electrosurgical assistance for hemostasis.

Thoracoscopy is in its infancy in veterinary medicine and surgery. The major advantage of thoracoscopy seems to be the reduced morbidity and pain when compared to thoracotomy.

References

1. Borenstein N, Behr L, Chetboul V, et al. Minimally invasive patent ductus ateriosus occlusion in 5 dogs. Vet Surg 2004; 33:309-313.

2. MacPhail CM, Monnet E, Twedt DC. Thoracoscopic correction of persistent right aortic arch in a dog. J Am Anim Hosp Assoc 2001;37:577-581.

3. Radlinsky MG, Mason DE, Biller DS, et al. Thoracoscopic visualization and ligation of the thoracic duct in dogs. Vet Surge 2002;31:138-146.

4. Dupré GP, Corlouer JP, Bouvy B. Thoracoscopic pericardiectomy performed without pulmonary exclusion in 9 dogs. Vet Surge 2001;30:21-27.

5. Kovak JR, Ludwig LL, Bergman PJ, et al. Use of thoacoscopy to determine the etiology of pleural effusion in dogs and cats: 18 cases (1998-2001). J Am Vet Med Assoc 2002;221:990-994.

6. McCarthy T. Diagnostic thoracoscopy. Clinical Techniques in Small Animal Practice 1999;14:213-219.

7. Remedios AM, Ferguson J. Minimally invasive surgery: Laparoscopy and thoracoscopy in small animals. Compend Cont Ed Pract Vet 1996;18:1191-1199.

8. Freeman LJ. Veterinary Endosurgery. 1st ed. St. Louis: Mosby 1999.

9. McCarthy TC. Veterinary endoscopy. 2005:606.

10. Kudnig ST, Monnet E, Riquelme M, et al. Cardiopulmonary effect of thoracoscopy in anesthetized normal dogs. Vet Anest Analg 2004;31:121-128.

11. Kudnig ST, Monnet E, Riquelme M, et al. Effect of one-lung ventilation on oxygen delivery in anesthetized dogs with and open thoracic cavity. Am J Vet Res 2003;64:443-448.

12. Potter L, Hendrickson DA. Therapeutic video assisted thoracic surgery. 1998;169-191.

13. Cantwell SI, Duke T, Walsh PJ, et al. One-lung versus two-lung ventilation in the closed-chest anesthetized dog: A comparison of cardiopulmonary parameters. Vet Surg 2000;29:365-373.

14. Daly CM, Swalec-Tobias K, Tobias AH, et al. Cardiopulmonary effects of intrathoracic insufflation in dogs. J Am Anim Hosp Assoc 2002;38:515-520.

15. McCarthy TC, Monnet E. Diagnostic and Operative Thoracoscopy in: McCarthy TC, ed. Veterinary Endoscopy. St. Louis: Elsvier Saunders, 2005;229-278.

16. Dupré GP, Corlouer JP, Bouvy B. Thoracoscopic pericardiectomy performed without pulmonary exclusion in 9 dogs. Vet Surg 2001;30:21-27.

17. Jackson J, Richter KP, Launer DP. Thoracoscopic partial pericardiectomy in 13 dogs. J Vet Intern Med 1999;13:529-533.

18. Walsh PJ, Remedios AM, Ferguson JF, et al. Thoracoscopic versus open partial pericardiectomy in dogs: comparison of postoperative pain and morbidity. Vet Surg 1999;28:472-479.

19. Jackson J, Richter KP, Launer DP. Thoracoscopic partial pericardiectomy in 13 dogs. J Vet Intern Med 1999;13:529-533.

20. Brissot HN, Dupré GP, Bouvy BM, et al. Thoracoscopic treatment of bullous emphysema in 3 dogs. Vet Surg 2003;32:524-529.

21. Enwiller TM, Radlinsky MG, Mason DE, et al. Popliteal and mesenteric lymph node injection with methylene blue for coloration of the thoracic duct in dogs. Vet Surg 2003;32:359-364.

22. Isakow K, Fowler D, Walsh P. Video-assisted thoracoscopic division of the ligamentum arteriosum in two dogs with persistent right aortic arch. J Am Vet Med Assoc 2000;217:1333-1336.

Small Animal Arthroscopy

Kurt S. Schultz

This topic is written based on the available literature through 2010 and does not cover the most current literature on this topic.

Introduction

Arthroscopy is the technique of endoscopic examination of a joint. The use of arthroscopy is growing rapidly in small animal orthopedic practice for several reasons. Arthroscopy is significantly less invasive than a traditional arthrotomy and both veterinarians and pet owners are seeking to minimize pain associated with surgical trauma. The excellent visualization provided by arthroscopy has led to the discovery of new joint diseases and for certain diseases such as ligamentous instability of the shoulder or medial compartmental disease of the elbow it may be the only practical method of diagnosis. Arthroscopy provides increased magnification and visualization of joint structures and this may be its greatest advantage over traditional surgical techniques.

Magnification has provided new understanding of the development of osteoarthritis in small animals. For example, it is now known that osteoarthritis of the canine elbow affects the medial compartment much more severely than the lateral compartment (medial compartment disease). Arthroscopy has also demonstrated that osteoarthritic lesions may occur in sites identical to that of osteochondritis dissecans (OCD) in the shoulder or stifle without diagnostic radiographic findings. Finally, arthroscopy has the ability to diagnose and grade osteoarthritis much earlier and with greater accuracy than radiography in virtually all joints (Table 7-1).

Other advantages of arthroscopy include the ability to perform procedures that are not possible with arthrotomy. The use of radiofrequency therapy for joint stabilization is only possible through arthroscopy. Topical osteoarthritis treatment using microfracture or abrasion techniques can be performed more precisely with arthroscopy due to the magnification that arthroscopy provides. A contributing factor to the increased use of arthroscopy in small animals has been the development of smaller but high quality instrumentation. Arthroscopes of 1.9 to 2.7 mm in diameter are routinely used in small animals and in the near future diagnostic arthroscopes as small as 1.1 mm in diameter will be available for outpatient diagnosis and follow up procedures (second look arthroscopy). Client demand has also stimulated the increased use of arthroscopy. Many pet owners are knowledgeable regarding arthroscopy and understand the benefits of minimally invasive surgical technique. The ability to provide arthroscopy in small animals allows veterinarians to provide advanced orthopedic diagnosis and therapy. Although increased expense is associated with arthroscopy, I have found most clients willing to incur the increased cost due to the previously mentioned advantages of the procedure (Table 7-2).

Arthroscopy presents challenges but has few disadvantages. Arthroscopic equipment is expensive and requires specialized care and handling. The cost for an arthroscopy system varies considerably with equipment selected. In addition, becoming proficient in arthroscopy both diagnostically and therapeutically can be difficult and requires considerable time. The skills involved in arthroscopy are considerably different from those of traditional surgery although some principles remain the same. Continuing education courses are available for training in small animal arthroscopy and veterinarians interested in becoming proficient are encouraged to gain experience in the teaching laboratory. Iatrogenic damage to the joint and the equipment is common during the learning process. Initially, performing an arthroscopic procedure will require more time than traditional surgery but with increasing experience arthroscopic procedures become faster than open surgery. Arthroscopy seems likely to become the standard of care for many diagnostic and therapeutic procedures involving the joints of companion animals.

Basic Terminology

Arthroscopy is the technique of endoscopy of a joint. **Instrumentation** refers to the insertion of an arthroscope or other instruments into the joint. **Triangulation** refers to successful visualization of the hand instruments through the arthroscope in a manner that is conducive to performing biopsies or therapeutic procedures within the joint. All equipment inserted into the joint is done through **portals** or holes established through the skin and soft tissues. **Cannulas** are metal tubes that maintain the portals and protect the instruments during the procedure. Arthroscopes are always used through specifically designed cannulas. Other instruments and fluid outflow devices may be used with or without cannulas. Fluid flowing into the joint is referred to as **in-flow or ingress** while fluid flowing out of the joint is referred to as **out-flow or egress**. Portals are defined by their use. The arthroscope is inserted through a scope or camera portal and power and hand tools are inserted through an instrument portal. Repeat arthroscopic examination of a joint that has been previously scoped is referred to as **second-look arthroscopy**.

Instrumentation Arthroscopes differ in diameter (1.9, 2.3, 2.7 mm and larger), length (short, long) and angle. Arthroscopes in common use in small animal arthroscopy include any of the diameters and lengths described and most scopes have a 30° angle. The diameter designates the telescope diameter alone and does not include the diameter of the arthroscope cannula, which is necessary for use. The selection of diameter is based on the size of the joint and surgeon preference with larger scopes providing more rigidity and greater field of view and smaller scopes causing less iatrogenic damage and having greater mobility.

Table 7-1. Common Diagnoses with Arthroscopy

Shoulder	Elbow	Carpus	Hip	Knee	Tarsus
OCD	FCP	osteoarthritis	osteoarthritis	OCD	OCD
Osteoarthritis	OCD	Chip fractures	Labral tearing and avulsion	Cruciate disease	Chip fractures
Biceps disease	UAP		Tearing of the ligament of the femoral head	osteoarthritis	
Medial collateral tearing	Osteoarthritis of the medial compartment				
Lateral collateral tearing					

Table 7-2. Common Arthroscopic Procedures

Shoulder	Elbow	Carpus	Hip	Knee	Tarsus
Fragment removal – OCD	Fragment removal – OCD, FCP	Fragment removal – chip fractures	Osteoarthritis assessment	Fragment removal – OCD	Fragment removal OCD
Osteoarthritis treatment – microfracture, abrasion	Osteoarthritis treatment – microfracture, abrasion	Osteoarthritis treatment – microfracture, abrasion		Osteoarthritis treatment – microfracture, abrasion	Osteoarthritis treatment – microfracture, abrasion
Biceps tenotomy				Meniscal treatment	
Soft tissue shrinkage for instability				Cruciate excision	

The camera head attaches to the arthroscope eyepiece. Cameras are digital and available as 1 or 3 chip and must be used with a specific camera box that processes the image for the video monitor. For general use, 1-chip cameras provide excellent resolution and recording capabilities and 3 chip cameras are only necessary for video or still image work that is to be published. Medical grade video monitors are recommended to provide a bright, clear, and accurate image. Most new light sources use xenon lamps, which provide increased light intensity and higher color temperature than halogen and therefore provide higher visual clarity and truer color. Xenon light sources are more expensive than halogen but are recommended for superior image quality.

Fluid flow during arthroscopy helps maintain joint distention, aids in clearing blood and other debris from the joint, and decreases the risk of joint contamination. Fluid may be delivered to the joint by gravity or from an arthroscopic pump. The use of lactated ringers solution as lavage fluid is preferred over saline as the former is thought to be less destructive to articular cartilage. Fluid outflow is provided by either a disposable needle or a specific outflow cannula.

The majority of arthroscopic therapy is performed with hand instrumentation. Both hand instruments and power tools are inserted into the joint through an instrument portal that may be used with or without a cannula. Hand instruments include probes, knives, curettes, and forceps. The most commonly used probes are right angled and may have calibration marks for measurement of lesions. Numerous styles of knives and curettes are available for manipulations of soft tissue. The most common forceps used in small animal arthroscopy are graspers for removal of hard or soft tissues and biters for debridement of soft tissues.

Power instruments are not necessary for basic small animal arthroscopy but increase the surgeon's efficiency and capabilities. The most common power instrument used is a shaver. These motorized hand tools have numerous tip designs including burrs, sharp cutters, and aggressive cutters. Additional power instruments include electrocautery and radiofrequency. Electrocautery tips specific for use in arthroscopy are available for some electrocautery generators. Alternatively, cautery may be performed by use of a radiofrequency unit. These units, which are available in both bipolar, and monopolar designs have also been advocated for soft tissue ablation and collagen shrinkage.

Arthroscopy of the Shoulder

Knowledge of diseases of the shoulder and their treatment has grown recently due to increased experience with shoulder ultrasound, arthroscopy, and MRI of the shoulder. The differential diagnosis for shoulder diseases has been expanded, as have the potential methods of treatment. Arthroscopy of the canine shoulder should be performed with a 2.7 mm arthroscope. A cranio-lateral or caudo-lateral arthroscope portal is generally used (Figure 7-10). Recently described portals include a medial portal using an in to out technique. Arthroscopy on the shoulder requires less equipment than other joints but can be the most difficult to instrument for beginning arthroscopists. The shoulder is also the least forgiving when mistakes in technique lead to substantial fluid leakage. Regardless, complications associated with arthroscopy of the shoulder are uncommon.

Thorough examination of the shoulder joint with the arthroscope includes assessment of the cartilage of the humeral head and glenoid cavity, evaluation of the origin of the biceps tendon and the remainder of the proximal tendon, evaluation of the subscapularis tendon, and evaluation of the medial glenohumeral ligaments. Lesions of the cartilage of the shoulder joint include OCD, focal or localized osteoarthritis, and generalized osteoarthritis. OCD is the most commonly treated disease of the shoulder joint. Arthroscopic treatment of OCD is usually rapid and highly successful. Although similar clinical results can be obtained

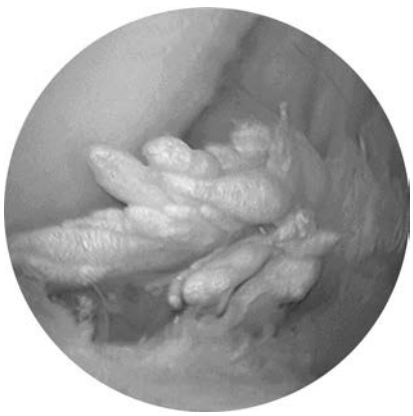


Figure 7-10. Arthroscopy of the canine shoulder with a 2.7 mm arthroscope and a craniolateral or caudo-lateral arthroscopic portal.

with arthrotomy, arthroscopy can aid in retrieving fragments that have migrated and allows easier inspection of the entire lesion. Focal osteoarthritis can occur in a site identical to that of OCD. The specific cause of the lesion is unknown and it may not be apparent on radiographs. Treatment may include topical arthroscopic techniques such as microfracture or abrasion arthroplasty although the primary treatement is medical. Generalized osteoarthritis may be identified with or without other injuries to the shoulder such as tearing of the biceps tendon or collateral ligaments.

Diseases of the biceps tendon are easily diagnosed with arthroscopy since it provides outstanding visualization of this structure. Tendon tears and synovitis are readily apparent. Tears can be rapidly treated by tenotomy through a cranial portal but synovitis should not be treated with tenotomy since it may be an indication of other joint disease.

Arthroscopy has demonstrated that many dogs suffer from damage to the supportive structures of the shoulder including the medial and lateral collateral ligaments and the subscapularis tendon. Other supportive structures with the exception of the biceps tendon cannot be visualized through an arthroscope. If damage to these structures is identified they may be treated by arthrotomy and ligament reconstruction or through arthroscopy by the use or radiofrequency that shrinks collagen thereby eliminating instability.

Arthroscopy of the Elbow

Elbow dysplasia is the most common cause of forelimb lameness in dogs. The ability to diagnose and treat this widespread disease has improved through the use of arthroscopy. The single greatest lesson learned from elbow arthroscopy is "for a forelimb lameness of unknown origin, arthroscopy of the elbow should be part of the diagnostic plan." Justification for this philosophy is the high prevalence of elbow osteoarthritis found during arthroscopic examination in spite of normal radiographic findings.

The two primary indications for elbow arthroscopy are for diagnosis of suspected elbow joint disease and for treatment of elbow dysplasia. It is well recognized that osteoarthritis and fragmented coronoid process (FCP) can be present with minimal radiographic changes (Figure 7-11). Correct diagnosis of these cases may be impossible without arthroscopic examination due to minor radiographic changes. Arthroscopic examination permits thorough exploration of the joint with a minimally invasive technique and enables increased visualization of all important regions of the joint. Fragmentation of the medial coronoid process is easily visible with arthroscopy as is cartilage damage.

Once disease of the elbow joint is confirmed, arthroscopy permits treatment of most of these diseases with methods that may be more effective and are less invasive than arthrotomy. Arthroscopy permits rapid and easy removal of loose fragments due to OCD or FCP. Areas of cartilage damage may be treated with topical management such as microfracture or abrasion arthroplasty. These two techniques produce bleeding at the site of cartilage disease which encourages the formation of fibrocartilage.

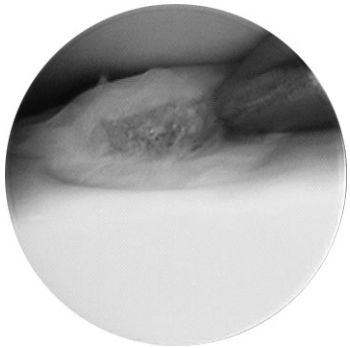


Figure 7-11. A fragmented coronoid process on arthroscopic examination.

Abrasion arthroplasty is performed with a hand burr or preferentially a power shaver burr. A thin layer of subchondral bone over the area of the lesion is removed until bleeding is observed in the area of cartilage loss. Microfracture is performed with an appropriately angled micropick. The pick is placed against the surface of the diseased cartilage or subchondral bone and then impacted to create microfractures into the bone marrow. These cracks allow bleeding into the diseased area, the formation of a clot, and subsequent fibrocartilage formation. Although the efficacy of these procedures is controversial, they are recommended in the management of elbow arthritis.

Less commonly, elbow arthroscopy has been used to treat humeral condylar fractures and ununited anconeal process. In both cases, arthroscopy is used primarily to visualize joint surfaces and assure congruency during screw insertion for stabilization of the condylar fracture or ununited anconeal process. Arthroscopy is also useful for diagnosis of incomplete fusion of the humeral condyle which is difficult to diagnose radiographically.

Arthroscopy of the Carpus

Arthroscopy of the carpus is uncommonly performed as there are few clinical applications. Diseases diagnosed and treated with arthroscopy have included joint infection, chip fracture removal, and cartilage assessment in association with osteoarthritis.

Arthroscopy of the Hip

The technique of arthroscopy of the canine hip was described in the early 1990's but its use has been limited until recently. The ability to visualize the, articular cartilage, femoral capital ligament, and acetabular labrum by arthroscopy allows accurate grading of intrarticular disease. Grading of hip disease has been employed primarily in clinical research involving the use of triple pelvic osteotomy (TPO) used for treatment of juvenile hip dysplasia. Other potential clincial applications include evaluation of fractures of the femoral head and septic arthritis of the hip. Arthroscopy of the hip is potentially simpler than in other joints such as the shoulder, elbow, and stifle.The coxofemoral joint is easily entered and complete examination of the joint can be achieved quickly. Special instrumentation is not necessary for arthroscopy of the hip joint although long versions of arthroscopes (2.7 mm, 30E, long) and hand instruments are needed.

Arthroscopy of the Stifle

Arthroscopy of the stifle provides a minimally invasive method for evaluation of all structures of the stifle joint. Stifle arthroscopy is a rapid and minimally invasive method for the treatment of OCD. For the experienced arthroscopist, an OCD lesion can be quickly removed through a very small incision. The cartilage lesion may then be treated with abrasion arthroplasty or microfracture to encourage cartilage healing. Arthroscopy is also commonly used in the diagnosis and management of cruciate disease and meniscal injury (Figure 7-12). In cases where early cruciate ligament injury has occurred, diagnosis may be difficult due to the lack of palpable instability or other obvious clinical changes. Arthroscopy provides excellent visualization of the cruciate ligament and meniscus. Small tears in the meniscus are more easily seen and treated through an arthroscope than by arthrotomy. The use of arthroscopy in the management of known cruciate injury eliminates the need to incise the joint capsule which is thought by some surgeons to be the primary cause of pain following conventional arthrotomy.

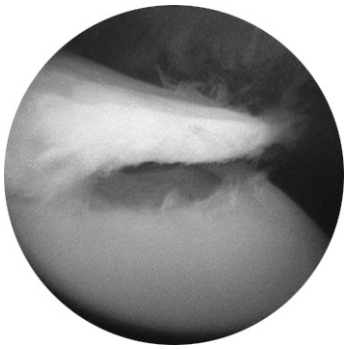


Figure 7-12. Arthroscopic appearance of cruciate disease and meniscal injury.

The stifle joint is often difficult to visualize for inexperienced arthroscopists because there are numerous cavities within the joint and the fat pad and synovium can obscure anatomic structures. I remove a portion of the fat pad with either a power shaver or radiofrequency probe to enhance visualization of the joint. Once the fat pad has been ablated there should be a clear view of the cruciate ligaments, femoral condyles, patella, trochlear groove, long digital extensor tendon, and the medial and lateral meniscus. Arthroscopy of the stifle is also used for treatment of articular fractures and techniques are being developed for the mangement of patella luxation.

Placement of a large cannulas in the stifle joint for fluid lavage and the use of shavers for synovectomy are useful techniques employed in treating septic stifle joints. These techniques are easily mastered with experience in arthroscopy.

Arthroscopy of the Tarsus

Arthroscopy of the hock is regarded as difficult. Entry into joints with significant effusion is generally easy but entry into joints with minimal effusion is much more difficult. Hock arthroscopy is primarily used for treatment of OCD and evaluation of cartilage damage.

Chapter 8

Microvascular Surgical Instrumentation and Application

Otto I. Lanz and Daniel A. Degner

Introduction

Microvascular surgery in veterinary medicine is indicated for free tissue transfer such as skin and muscular flaps and in kidney transplantation. Microvascular instrumentation development began in the 1930s and progressed further in 1952 with the creation of the Microsurgical Instrumentation Research Association.[1] Thanks to the work of Acland, Buncke, Tamai, and others, many instruments have been designed specifically for varying microsurgical needs. This wide variety of microvascular instruments includes both basic and sophisticated instrumentation that is necessary for correct tissue handling during surgery.[1,2]

Microsurgical instruments have fine tips like ophthalmic instruments, but they differ in that they are a more standard length, whereas ophthalmic instruments are generally shorter than conventional surgical instrumentation. Plastic and reconstructive surgery usually involves a superficial operative field and the average length of the instruments is 14 to 16 cm.[2] The majority of instruments are spring loaded to reduce cramping of the hand muscles during long procedures that can lead to shaking and tremors. The handles are generally rounded to facilitate maneuvering the instruments in the fingers and allowing them to be rolled in the fingers, as necessary for suture placement and tissue manipulation. Many microsurgical instruments are grooved near the head to make them conform to the notch created between the surgeons' thumb and index finger. This groove allows the instrument to rest in the notch without being actively held, to minimize muscle fatigue from grasping the instrument, which can result in tremors. Additionally, many instruments are counterbalanced with a weight at the head of the instrument to minimize finger fatigue caused by prolonged gripping of the instrument (Figure 8-1).

Instruments for microvascular surgery are generally made of stainless steel with the tips of the instruments containing chromium to increase their strength. Some surgeons advocate the use of titanium instruments, which are lighter, stronger, and more importantly have antimagnetic properties that prevent the fine microneedles used in suturing from sticking to the instrument. Microsurgery is performed with the surgeon in a sitting position to minimize fatigue and muscle tremors. The surgeons' antebrachium rests on the table, with the heels of the hands resting comfortably on the table as well. The instruments are held as one holds a pen or pencil, with most operative maneuvers carried out by the fingers while the wrists remain motionless on the table.



Figure 8-1. These microsurgical tying forceps are of standard length with miniaturized tips, rounded shanks; this instrument is contoured to fit in the notch between the base of the thumb and the index figure and is counterbalanced.

This chapter describes instrumentation and suture materials that are most commonly used when performing veterinary microsurgery. In addition, descriptions of free skin transfer, free muscle tissue transfer and their indications are presented.

Jeweler's Forceps

Jeweler's forceps consist of two flat, narrow legs connected at the head that narrow to form the jaws of the instruments.[1-3] The contact surface at the tips is referred to as the bit and the distance between the jaws is approximately 8 mm. Jeweler's forceps are numbered according to the width of the bit and legs and their overall shape. Five basic jeweler's forceps are used in microvascular surgery: Nos, 2,3,4,5, and 7 (Figure 8-2A,B,C). The No. 2 forceps have the largest contact surface and are advocated for use as needle holders. The No. 3 forceps are used for testing vessel patency. The Nos. 4 and 5 forceps are useful for delicate tissue handling; the No. 4 forceps have a slightly larger bit. The No. 7 forceps have the unique feature of having curved tips, which are useful to access obstructed areas or to prepare small vessels for anastomosis (Figure 8-2C).

Special care must be taken to avoid bending the tips of jeweler's forceps. The tips should be examined under a microscope before the beginning of a surgical procedure to assess the alignment of the tips because bent tips may catch on adventitia, tear vessel walls, and inhibit proper handling of the microneedle. The tips of some jeweler's forceps are pointed or rough, leading to tissue or vessel damage and inadvertent cutting of suture material. For these reasons, it is recommended to gently file the tips of jeweler's forceps with an emery board or Arkansas stone before their first use.

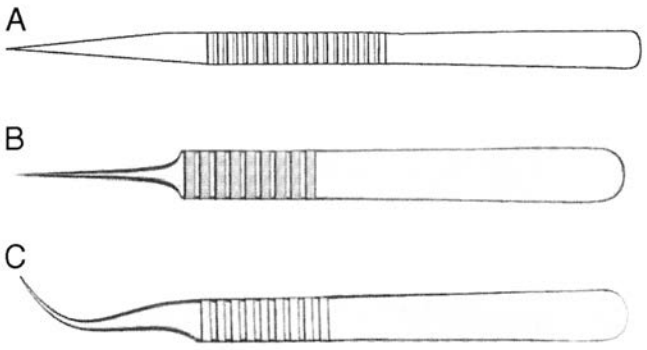


Figure 8-2. Jeweler's forceps are available in different sizes and configurations. **A.** No. 3 jeweler's forceps are used to test the patency of small vessels by occluding the flow with the forceps and allowing the vessel to refill after the forceps are removed. **B.** No. 5 jeweler's forceps have fine, delicate tips for microsurgical applications. **C**. No. 7 jeweler's forceps have a curve enabling the surgeon to gain access to remote areas of the surgical field.

Jeweler's forceps are inexpensive and have a wide range of styles and usefulness during microvascular surgery; however, they do not have round handles, are not counterbalanced, and are of short length. In contrast, microvascular forceps are available in a variety of styles and designs but are considerably more expensive than jeweler's forceps. Microvascular DeBakey forceps, microring tipped forceps, and a variety of curved or straight microforceps are available. These forceps are appropriate in length, have round handles, and are counterbalanced.

Needle Holders

Number 2 jeweler's forceps are used as needle holders for their simplicity, ease of knot tying, lack of concern about entrapment of the suture material in the lock mechanism, and low cost. The major disadvantage of jeweler's forceps is that the needle is not held securely and may slip at an inopportune moment. Additionally these forceps do not have rounded handles, lack a grooved head, and are not counterbalanced. Rounded shanks are particularly important in needle holders because passage of the microneedle through the vessel wall requires that the instrument be rolled in the fingers.

The three basic parts of the needle holder are the jaws, the lock, and the shank. The jaws are usually flat and not grooved. Generally, curved needle holders are used because they have less of a tendency to obstruct the surgeon's view of the operating field. Ratchetless needle holders are used exclusively in microsurgery because of the delicate nature of the microneedles. Additionally, the locking and unlocking of the ratchet causes motion in the tips that can damage the vessel.

Scissors

Microvascular scissors are among the more expensive instruments in the microvascular surgical pack. They should have rounded shanks, be spring loaded, and have fine, delicate tips. They are used for delicate dissection, for cutting suture, and for trimming adventitia during vessel preparation.

Scissors are composed of blades, lock, and shanks. The blade tips are pointed or slightly rounded, and the blades are only sharp along their inner surface. The blades may be straight, curved, or angled at 45°. The shanks are spring loaded so the blades are open at rest, and when the shanks are compressed, they come together with a cutting action. These instruments are used for blunt dissection by closing the blades, inserting them into the fascial plane, and allowing the spring action to open the blades within the tissue plane. Scissors must be thoroughly cleaned, well protected when not in use, and their sharpness constantly maintained.

Vessel Dilators

Vessel dilators are modified jeweler's forceps with a narrower, smoother, nontapering tip (Figure 8-3). The tips of this instrument are inserted into the vessel lumen and are opened slightly to dilate the vessel gently as part of vessel preparation. Dilators may also be used as a counterpressor when suturing vessels. They should be inspected under high magnification to ensure alignment of the tips. The tips must be smooth and unbent to prevent injury to the vascular intima when they are inserted into the vessel lumen.

Microvascular Clamps

Microvascular clamps are used to occlude the vessel and prevent intraoperative hemorrhage. These clamps must be atraumatic yet have adequate closing pressure to prevent hemorrhage from the vessel. The blades should be flat to disperse the pressure evenly across the vessel, and they should have a rough surface to hold the vessel securely. Clamps should be easy to apply with finger pressure or applicator forceps (Figure 8-4). Most clamps are small enough to fit in the operative field but large enough to be easily manipulated. Clamps are available in various sizes with varying closing pressure to accommodate variation in vessel size. The closing pressure of the clamps should be less than 30 gm/mm to avoid endothelial damage. The surfaces of the clamps are usually dull, to minimize light reflection.

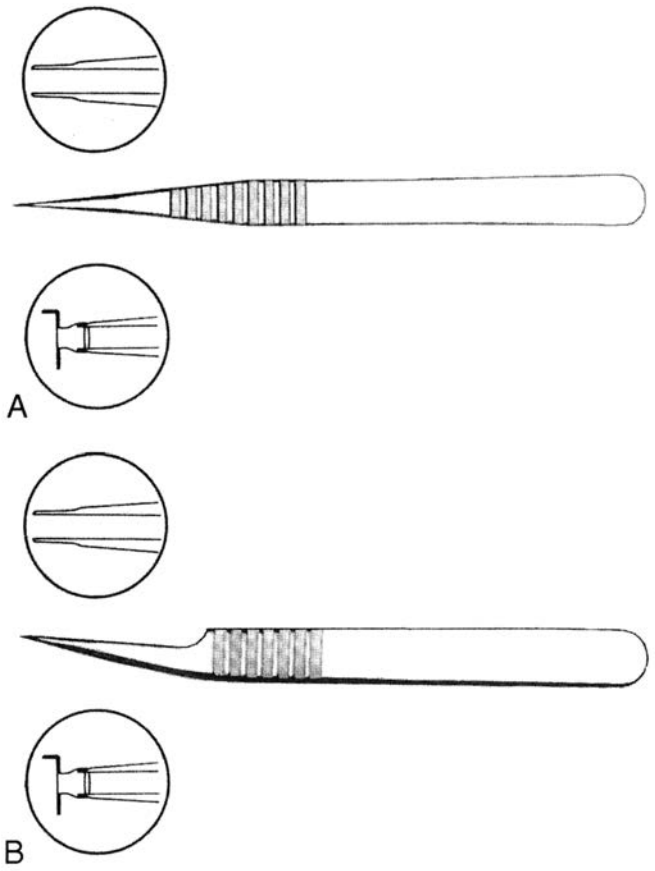


Figure 8-3. Vessel dilators have smooth, nontapered tips that are inserted into the vessel lumen and are opened gently to dilate the vessel. **A.** No. 3 jeweler's forceps modified for use as a vessel dilator. **B.** Another vessel dilator with angled tips.

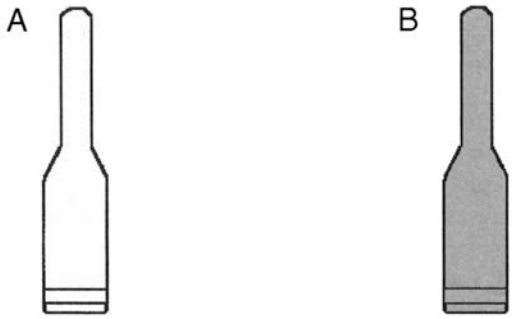


Figure 8-4A and **B**. Vessel clamps are precisely manufactured to provide adequate pressure to occlude blood flow without damaging the vessel.

The approximating clamp facilitates retraction and reapproximation of vessels for suturing. The purpose of the approximator clamps is to decrease the amount of tension between two vessels being anastomosed, thereby allowing for atraumatic vascular anastomosis. An approximating clamp is composed of two microvascular clamps joined by a connecting bar. The clamps may be movable along the connecting bar to allow for the distance between vessels to be adjusted (Figure 8-5) or fixed in position to the connecting bar, a position requiring that the clamps be placed at the appropriate distance along the vessels because the interclamp distance cannot be adjusted. The entire clamp should fit in the operating field, yet be large enough to be easily maneuvered and turned over for suturing both sides of the vessels. The Acland framed nonmovable approximator clamps have two cleats on the frame that facilitate vessel anastomosis, especially when a surgical assistant is not available (Figure 8-6). Because they are expensive microvascular instruments, extreme care should be taken when cleaning and storing microvascular clamps and approximator clamps to prevent damaging them.

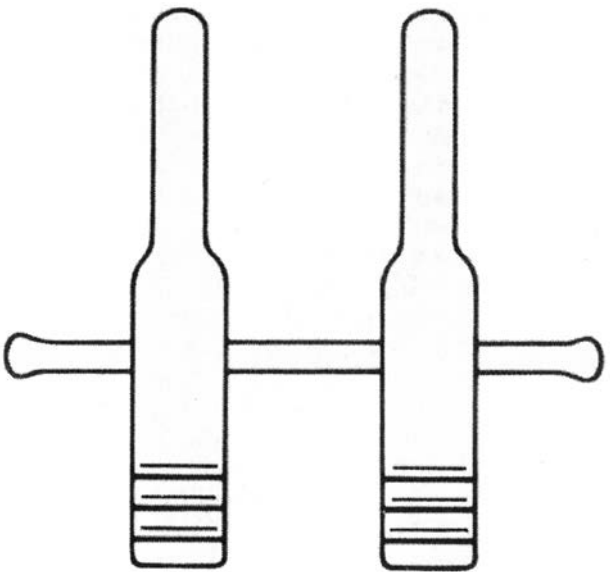


Figure 8-5. This vessel approximator clamp consists of two vessel clamps that are movable along the bar. Vessels to be anastomosed are placed one in each clamp; then the distance between the vessel ends can be adjusted.

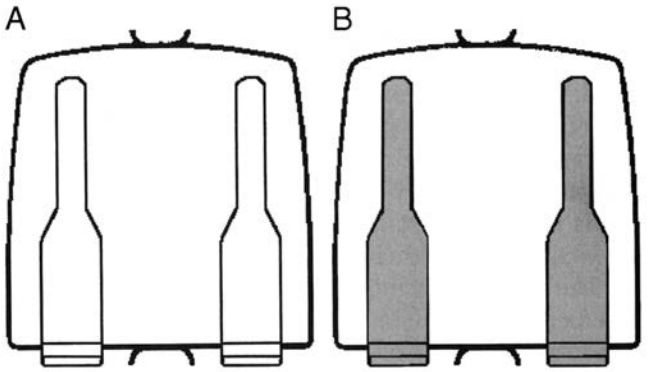


Figure 8-6A and **B**. Another vessel approximator clamp in which the clamps do not move along the bar. With this type of clamp, the vessels must be positioned precisely to allow the ends of the vessels to be sutured because the distance between them cannot be adjusted.

Coagulators

Hemostasis is essential for creating a clear field for microvascular surgery. Because of the magnification required to perform surgery, even small amounts of blood can obscure the operating field making surgery virtually impossible. Unipolar coagulators damage surrounding tissue because the current passes from the cautery tip, through surrounding tissues, into the patient, and out to the ground plate. This dissipation of current and associated heat generation can damage the parent vessel of interest. Bipolar cautery has the advantage that both current and heat are only produced in the small space between the tips of the coagulating forceps. This restricts the amount of tissue damage, yet it provides for accurate hemostasis. A thin layer of sterile petrolatum applied to the tips of bipolar cautery forceps helps to prevent charred tissue from adhering to the tips of the forceps. If bipolar coagulation is not available, jeweler's forceps can serve as cautery forceps. Although this application is monopolar, it is more precise and minimizes the amount of lateral heat and damage to adjacent tissues compared with the standard cautery pencil.

The amount of cautery used in microsurgery should be kept to a minimum, to avoid damage to vessels or other important structures that may be in the vicinity of the operating field. For vessels larger than 1.5 mm in diameter, hemostatic clips are effective in achieving hemostasis without damaging adjacent structures. Clips are used judiciously because too many hemostatic clips can interfere with the surgical procedure.

Suction

Vacuum suction is an optional tool in microvascular surgery. If mechanical suction is used, care must be taken to avoid contact with vessels or nerves. Endothelial damage from suction can lead to complete thrombosis of the vessel and surgical failure. Standard suction tips are generally too large for microsurgical application. A 20-gauge catheter may be connected to appropriately sized Silastic tubing and connected to the suction unit to create a fine tipped suction device. A small fenestration created in the Silastic tubing allows the surgeon some control over the strength of the vacuum. The surgeons' finger is placed over the hole to occlude the fenestration partially or completely, thereby adjusting the amount of suction at the catheter tip. This control over the strength of suction aids in minimizing vascular injury. Sterile applicators can also be used for fluid absorption, but care must be taken to avoid damaging vessels or nerves.

Irrigators

Irrigation of the wound is essential in microvascular surgery to decrease the amount of desiccation caused by the intense light source of the operating microscope. Irrigation is also used to remove clots and to float the vessel edges apart. Standard irrigation syringes are too bulky and flood the microsurgical field. A simple irrigator can be made for microsurgery using a 10-ml syringe attached to a 20-gauge needle or catheter using either saline or heparinized saline. Irrigation is applied in a gentle stream. The catheter tip is not inserted into the vessel, to avoid damaging the vascular endothelium.

The Bishop-Harmon anterior chamber irrigator is used extensively in ophthalmic surgery and is applicable to microvascular surgery. Many cannulas are available and the advantage of this system is that it is easier to operate and to control the flow of the fluid with the small bulb than with a syringe.

Background Material

When performing microvascular surgery, a background is used to set the vessels out from surrounding structures. Background material is placed behind the structures of interest to improve their visualization through the operating microscope. Various colors are advocated to maximize visualization of the structures of interest. Use of dark colors, such as green or blue, enhances visualization of the artery and the vein, as well as the suture material. Background materials are commercially available, but a rectangular section of a balloon can be sterilized and used as an inexpensive background.

Counterpressor

Counterpressors are used to avoid suturing the opposite wall of a vessel during a vessel anastomosis. When the surgeon passes the needle through the vessel wall, counterpressure must be applied, or the wall is pushed away. The counterpressor provides resistance for passing the microneedle. The instrument must be sturdy, small enough to fit in a vessel, and easily maneuverable. The counterpressor has either a circular or a double-pronged tip, so the microneedle can be passed through the circle or between the tips. A counterpressor can be constructed by twisting 34-gauge wire onto itself, creating a tiny loop at the end. The free end is connected to a disposable tuberculin syringe or a metal bar to serve as a handle.

Maintenance of Instruments

Microvascular instruments are delicate and easily damaged. Extreme care is exercised when cleaning and storing instruments. After use, instruments are soaked in warm water containing a commercially available enzymatic cleaner, rinsed in distilled water, and air dried. Ultrasonic instrument cleaners offer the best way of cleaning microinstruments. Care should be taken when instruments are dried with a cloth, because

the delicate tips of the microinstruments bend easily. After the instruments are thoroughly cleaned and dried, tipped instruments should be covered with rubber tubing to protect them from bending. Because of the amount of electrical instrumentation in the operating room, microinstruments become magnetized, causing the microneedle to become attracted to clamps and other instruments during surgery. This problem is prevented by subjecting the instruments to a demagnetizer coil before packing and autoclaving takes place.

Storage boxes should contain specially shaped, trough like receptacles made of foam to prevent damage to instruments. Instruments must not be stored where they are in direct contact with metal or other instruments. Gas is the preferred method of sterilizing micoinstruments because steam damages the instruments over time.[1-3]

Microvascular Suture

The creation of microsuture enabled surgeons to anastomose vessels with a diameter of 1.0 to 2.0 mm. The microvascular needle consists of a point, blade, and body, and swage. The needle may be straight or curved, and the curve may be one-half, three-eights, one-fourth circle, or progressive. A 3-4 mm length needle is used most commonly. The diameter of the needle is important because it is directly related to the amount of trauma the needle inflicts on the vessel. Most microneedles contain a tapered point, which is the least traumatic to tissue. Currently, flat needles are used almost exclusively because the flat needle is more secure in the needle holder than a round needle, which can roll between the microneedle holder jaws. The needle may be made from carbon steel, stainless steel, or other metal alloys, with carbon steel being the strongest and least malleable.

Nylon is the most commonly used suture material in microvascular surgery.[1,2] It is smooth; allowing it to glide easily through tissue, and it has a high tensile strength while causing minimal tissue reaction. The major disadvantage of nylon is that additional throws may be needed to ensure knot security. The most commonly used suture in microvascular surgery is 10-0 nylon on a tapered needle.[4]

Vessel Preparation and Anastomosis

In veterinary medicine the long-term patency of microsurgically anastomosed vessels in the dog is approximately 93 to 95%.[5-7] Performing a microsurgical anastomosis of an artery or a vein has three steps: 1) vessel preparation; 2) vessel anastomosis; and 3) evaluation of vessel patency.

Vessel Preparation

Vessel preparation is one of the most critical steps in performing a microvascular anastomosis. Vessel preparation includes proper alignment of the vessel in the approximator clamp, vessel irrigation, trimming the adventitia from the end of the vessel, and vessel dilation. The ends of the vessels must be properly oriented in the approximator clamp to ensure that the vessels are not twisted following completion of the anastomosis (Figure 8-7). Blood should be flushed from the vessel lumen flushed, using



Figure 8-7. Vessel ends placed in an approximator clamp.

heparinized saline delivered with a #22 angiocath. This procedure prevents blood located at the ends of the vessels from developing into a thrombus (Figure 8-8). To prepare the vessels, 2-3 mm of adventitia is removed from the end of each vessel. Adventitia is removed with jeweler's forceps or microsurgical forceps and microscissors under 10-16x magnification. Once the adventitia is draped over the vessel end, a small hole is made in the adventitia with microsurgical scissors, and one blade of the scissors is placed into this hole (Figure 8-9). The scissor blade is moved adjacent to the attachment of the adventia on the vessel, and the adventitia is excised around the circumference of the vessel wall. This prevents adventitia from being caught in the lumen during anastomoses. The framed approximator clamp is then applied, bringing the two ends of the vessels close enough so that there is little tension during the anastomosis. It is important to remember that the clamps will be flipped after the near side of the anastomosis is complete. Vessel spasm can be reversed with topical lidocaine or gentle dilation. Vessel dilation results in temporary paralysis of the smooth muscle in the vessel, thereby preventing vasospasm at the anastomotic site (Figure 8-10). Dilating the vessel also helps to increase the overall diameter of the lumen and helps delineate the near and far wall of the vessel.

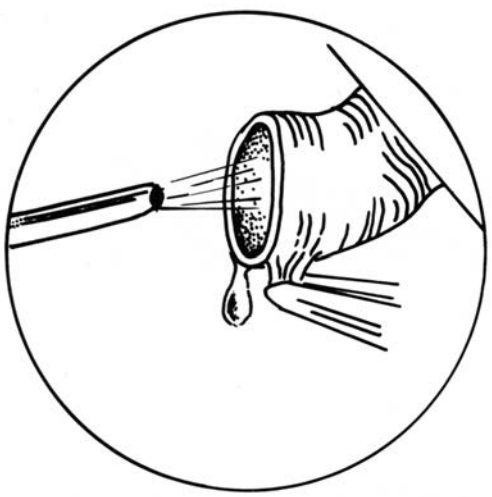


Figure 8-8. Irrigation of vessel ends to remove intraluminal blood.

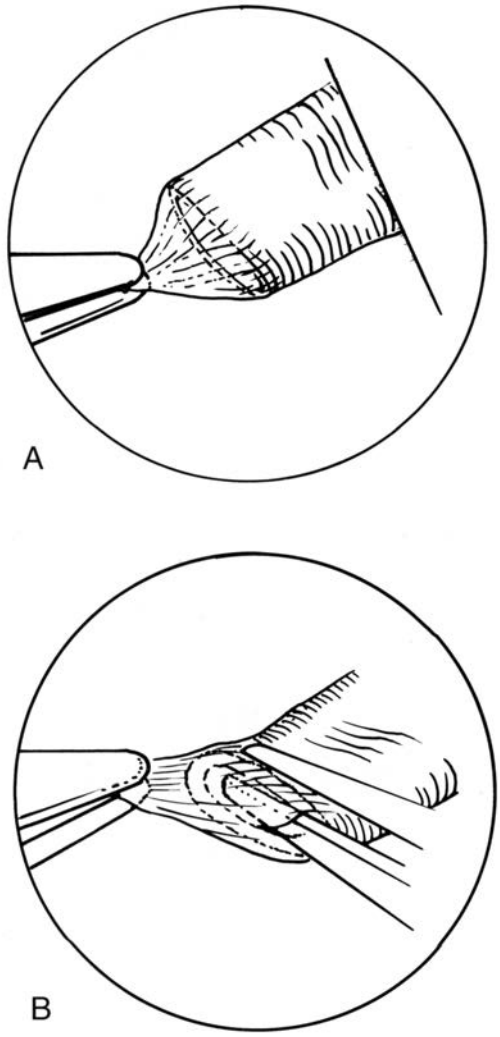


Figure 8-9. A. The adventitial skirt is drawn over the vessel end with a pair of forceps. **B.** The adventitia is then excised.

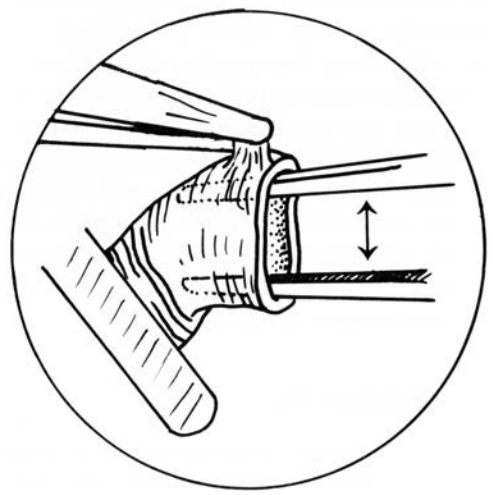


Figure 8-10. Vessel dilation is performed to prevent vasospasms and to improve definition of the vessel lumen.

Preparation of veins is technically much more difficult than arteries due to the relative thinness of the venous wall. Special care must be taken when removing the adventitia of a vein because inadvertent damage to the tunica media may result, thus weakening the vessel. Irrigating the end of a vein with a 22-gauge catheter will help in identifying the lumen of the vessel and the adventitia. Thin-walled veins may be prepared by submerging the vessel in a pool of saline to improve visualization of the vessel lumen.[3]

End-to-End Vessel Anastomosis

The end-to-end vascular anastomosis is usually performed by using a full thickness simple interrupted pattern with 10-0 nylon on a 100 µm flat-bodied needle. The ends of the vessels are aligned in the approximator clamp to create a 1 to 2 mm gap between the vessel ends. A background may be placed behind the approximating clamps to improve visualization of the vessels and suture material. The needle is grasped using a two-handed technique by grasping the suture with one hand and the needle with the other. The needle is held just beyond its midpoint, 1-2 mm back from the end of the needle holder. Three guide sutures are placed 120° apart, two on the near vessel wall, and one in the far vessel wall (Figure 8-11). The suture tags are left long to help manipulate the vessels with minimal trauma during the anastomosis procedure. It is imperative that the guide sutures be accurately placed, as sutures not exactly 120° will result in twisting at the anastomotic site. With the guides in place, equal numbers of interrupted sutures are placed between each guide suture. Counterpressure may be applied adjacent to the intended exit site of the needle to aid in passage of the needle through the vessel wall (Figure 8-12). Enough sutures are placed so that there is no anastomotic leak. Usually a total of 9 sutures are necessary for the average size artery. Needle placement must be accurate and symmetric. The needle entry point should be twice the thickness of the vessel wall away from the edge and symmetrical entry should be taken on the opposite edge. Uneven placement leads to vessels overlapping and thrombus formation. Needle placement should utilize a two-handed action under 20x to 30x magnification. The needle lumen is cannulated with micro-forceps or in larger vessels the adventitia is grasped to provide

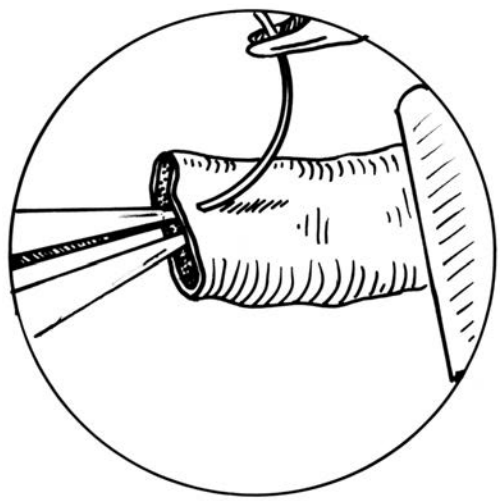


Figure 8-11. Atraumatic manipulation of the vessel wall is performed by inserting the tips of a pair of forceps into the vessel lumen.

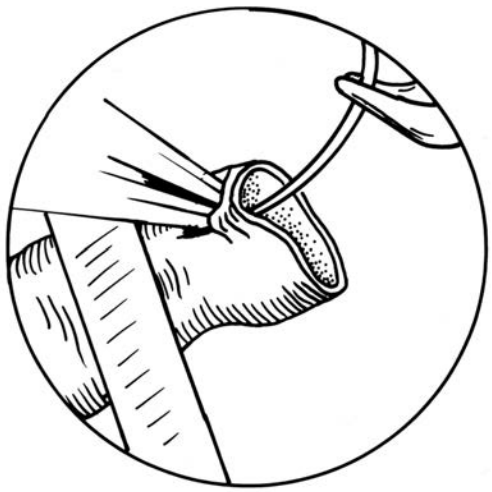


Figure 8-12. Counterpressure is applied adjacent to the site of exit of the needle to facilitate passage of the needle through the vessel wall.

counter pressure as the needle is advanced through the vessel wall. After the needle penetrates the wall, the needle is pulled along its arch. A two-pass technique is used, unless the vessel edges are approximated. Tying the suture correctly also impacts on the likelihood of vascular patency. Knots need to lie flat and the proper amount of tension must be applied each time. Excessive tension damages the vascular intima while inadequate tension hampers proper vessel approximation. Surgeon's knots are thrown first, followed by a simple square knot. After the near vessel wall is sutured, the clamp is flipped, and the process is repeated on the far vessel wall. Veins are anastomosed in a similar fashion but extreme care must be taken since the walls of veins are delicate and easily torn by suture material. A continuous suture pattern provides the same accuracy and versatility as a simple interrupted suture pattern[8-10] and is significantly faster and associated with less anastomotic leakage.[9] However, a continuous pattern significantly narrows the vessel lumen. As a result, a continuous suture pattern should be avoided in arteries with a vessel diameter greater than 0.7 mm in diameter and in veins with a diameter greater than 1.0 mm in diameter.[9] The main application of the continuous suture pattern is for end to side anastomoses performed on large arteries and veins.

Release and removal of the microvascular clamps should be completed in the same order each time. Once both anastomoses are completed the anastomoses are irrigated with a 1% lidocaine solution and the clamp release is started. The arterial clamp is released first, then the venous clamp. This eliminates misinterpreting venous backflow for adequate arterial inflow. Some leakage may occur at the anastomosis, and usually stops with direct pressure. Continued bleeding will occasionally occur and requires additional suture placement.

End-to-Side Anastomosis

Careful placement of sutures can accommodate disparities in vessel luminal diameters of up to 2:1.[11] The technique involves placing interrupted sutures farther apart on the larger vessel. When vessel diameter differences of 2:1 or 3:1 occur, beveling or spatulation of the vessel with the smaller luminal diameter is advisable.[3,12] When beveling an edge, the oblique cut should not be more than 30° in order to avoid turbulence. Spatulation is performed by creating a longitudinal incision in the cut end of the smaller vessel. When vessel discrepancy exceeds 3:1, end to side anastomosis is required.

End-to-side anastomosis is performed when there is a large vessel diameter mismatch. In order to minimize turbulent flow at the anastomosis site, the angle between the donor and recipient vessel should be as small as possible. Angles less than 60° are preferred. The angle of anastomosis can be decreased by spatulating or beveling the vessel with the smaller diameter. To prepare the recipient vessel, an approximator is placed on the isolated side of the recipient vessel and the adventitia is removed from the proposed arteriotomy site. A properly sized arteriotomy forcep is placed on the recipient vessel and a Dennis blade is used to gently cut the portion of artery held by the arteriotomy forcep or a stay suture technique can be used to create the arteriotomy (Figure 8-13). A single clamp is placed on the donor vessel and the adventitia is removed. Intraluminal blood from both the donor and recipient vessel is flushed with heparinized saline to prevent thrombus formation. Unlike the end to end technique, there are only two guide sutures, each placed 180° apart. The intervening sutures are placed as usual using a continuous or interrupted suture pattern.

Evaluation of Patency

Patency of a vascular anastomosis can be tested in a variety of ways. Venous patency is easily assessed when the vessel is translucent. Direct observation of expansive arterial pulsation is a reliable indicator of patency, whereas longitudinal pulsation usually signifies partial or complete obstruction. In free tissue transfer, examination of the arterial bed of the transplanted tissue flap for pulsation and evaluation of the cut surface of the flap for capillary bleeding can document arterial patency.

The chance of vessel thrombosis is greatest at the site of anastomosis 15 to 20 minutes following completion of the anastomosis. It is therefore advisable to observe the anastomosis and test vessel patency during this period of time. If partial obstruction occurs, gently squeezing the vessel with forceps, or massaging the vessel may break up the thrombus. A complete thrombosis necessitates resection of the damaged area, and repeating the anastomosis. Vascular thrombosis is most commonly due to technical error in suture placement, or the use of a vessel with a damaged intima. Venous rather than arterial thrombosis is the most common cause of flap failure. The thinner venous wall makes the anastomosis more fragile, more compressible, and more likely to twist and kink. After the first 20 minutes, postoperative days 1-3 are also critical for anastomotic patency. In most cases, a flap that is viable at day 5, will likely survive.

Anastomotic Devices

Anastomotic coupling devices may be used in place of hand suturing for microvascular anastomosis. Anastomotic devices reduce anastomotic time by 50%-75%, and have patency rates similar to hand suture techniques.[13,14] The device performs well on thin-walled vessels of similar size, but can cause vessel intimal

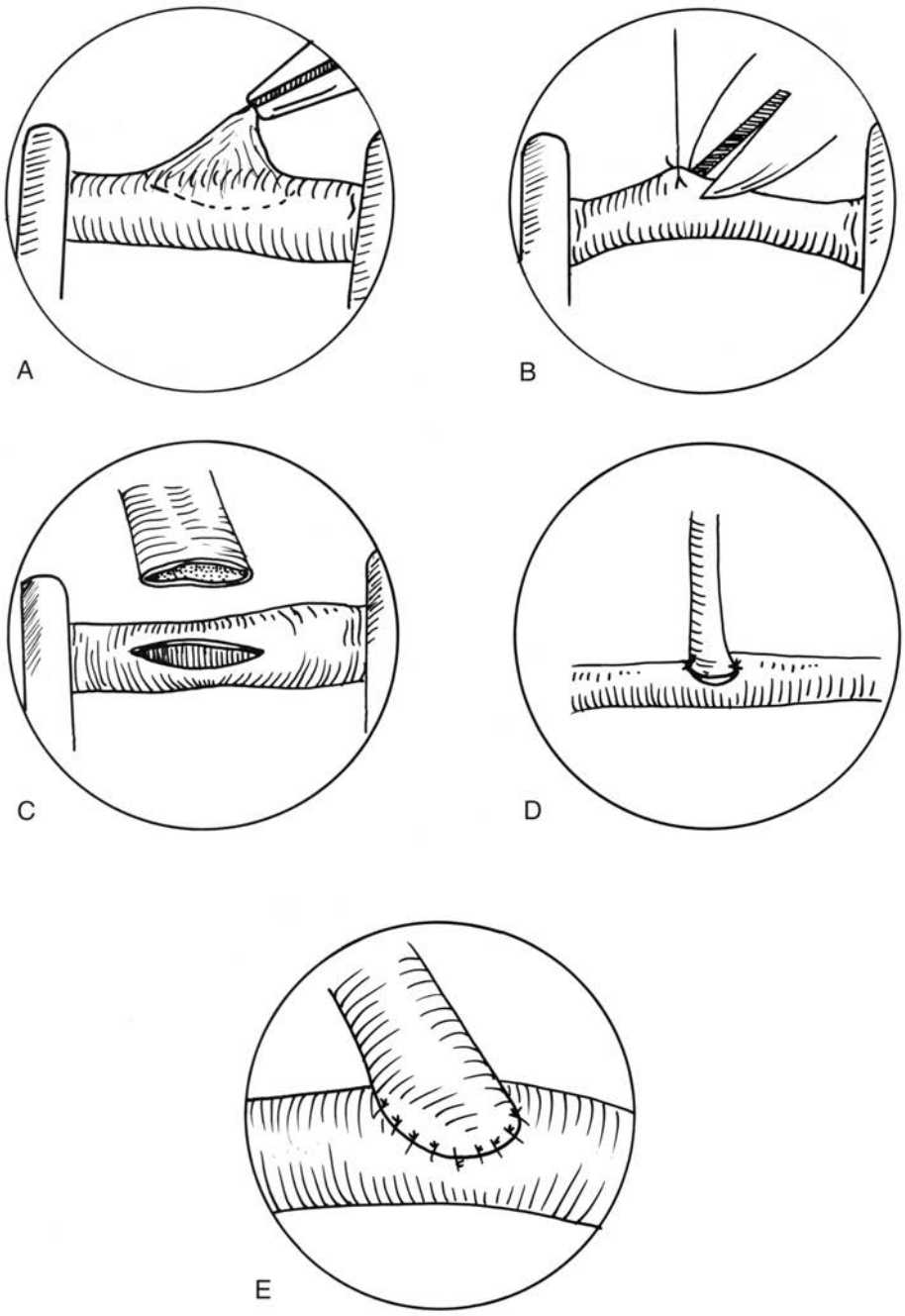


Figure 8-13. End-to-side anastomosis. **A.** The adventitia is removed from the vessel. **B.** A stay suture is placed in the wall of the vessel, and the arteriotomy is performed. **C.** The diameter of the arteriotomy site should approximate the diameter of the "end" vessel. **D.** The first two sutures are placed 180° apart to position the vessels for the anastomosis. **E.** The sutures are placed perpendicular to the anastomotic line in a radiating fashion.

damage on thick-walled arteries. Because of the increased risk of technical errors associated with performing a suture microvascular venous anastomosis a coupling device is routinely used and recommended when performing the venous anastomosis. Some familiarity with the device is necessary for success, but the technique can be quickly learned. The coupling device consists of a pair of polyethylene rings with six small pins on one side of each ring. The anastomosis is performed by pulling the end of the vessel through the ring and impaling the wall of the vessel over the six pins. The other end of the vessel is also impaled on the pins of the second ring, and the two rings are precisely joined together with an anastomotic instrument. This device provides a secure anastomosis with intima-to-intima contact which in turn improves patency and reduces the chance of thrombosis (Figure 8-14). A second major advantage to using a coupling device is shortened overall procedure time which decreases the overall ischemia time of tissue when compared to hand suturing.[13-15] Anastomotic couplers come in sizes of 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, and 3.0 mm diameter.

Free Skin Flaps

Microvascular free skin flaps can be used to reconstruct wounds in almost any location on the body. Some of the described axial pattern skin flaps can be used for this purpose.[16] The requirements for an axial pattern tissue flap to be used as a free flap include a

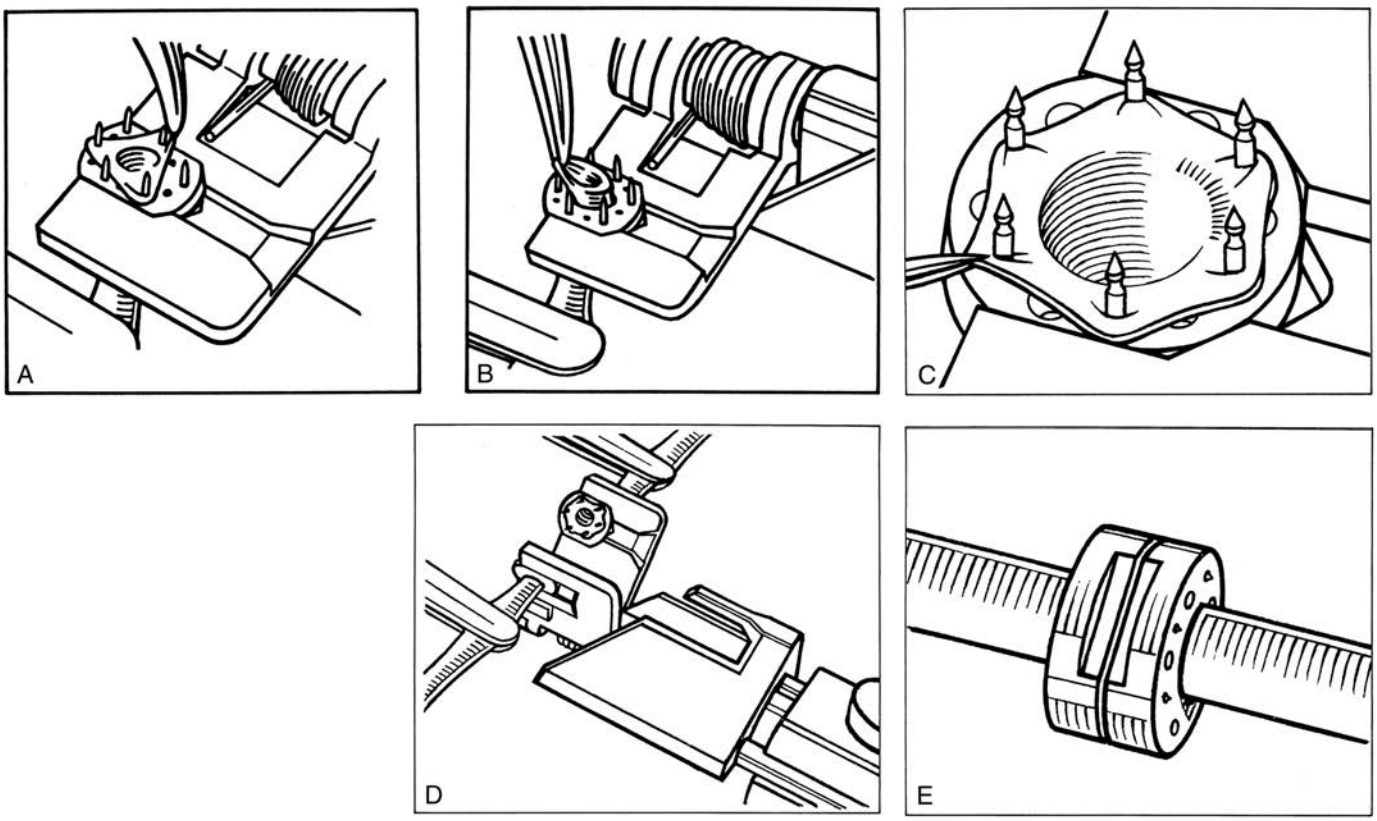


Figure 8-14. Anastomotic coupling devices can be used to anastomose vessels instead of hand suturing. **A-C.** The vessel is drawn through the lumen of the anastomotic ring device, and the vessel wall is implanted on alternate pins of the ring. **D** and **E.** The ends of the vessels are approximated by precisely mating the anastomotic rings together with the anastomotic instrument.

1 mm pedicle vessel diameter and a 2 to 4 cm vascular pedicle length. Generally, the longer the vascular pedicle, the easier it is to perform the vascular anastomosis. As a result, the omocervical, thoracodorsal, deep circumflex iliac, caudal superficial epigastric, and the medial saphenous fasciocutaneous flaps could be used in free tissue transfer. The skin flaps that are most commonly used for this purpose are the medial saphenous fasciocutaneous and omocervical cutaneous free flaps.[5-7,17-21]

Blood Supply Patterns

The skin has two sources of blood supply. In dogs and cats the predominant blood supply is from direct cutaneous arteries. These arteries typically perfuse a very large section of skin. Over the torso they exit the body wall and lie in the well-developed panniculus carnosus muscle known as the cutaneous trunci muscle. In other areas of the body where the panniculus is absent (extremities), the cutaneous arteries run in the subcutaneous fascial layer.[22]

The direct cutaneous artery divides into a network of branches, similar to a tree trunk and its numerous branches. All of the tissues that are supplied by this single artery are called the primary angiosome. Other angiosomes called secondary angiosomes are connected to the primary angiosome by choke vessels (Figure 8-15). The skin within the primary angiosome will consistently survive; likewise a large portion of the secondary angiosome usually will survive. Extending the flap into the tertiary angiosome leads to inconsistent survival.[22] Since vessels cannot be visualized on the surface of the skin either mapping of the vasculature with Doppler or the use of deep anatomic landmarks are used to define the angiosome of a skin flap. One precautionary note is that the skin of dogs and cats is loose over the torso and may shift during positioning of the patient on the operating table; this will shift the angiosome relative to deep anatomical landmarks. In order to correct for this problem, the skin should be grasped, pulled upward, and then allowed to relax back in position. This should reposition the skin relative to deep anatomical landmarks.

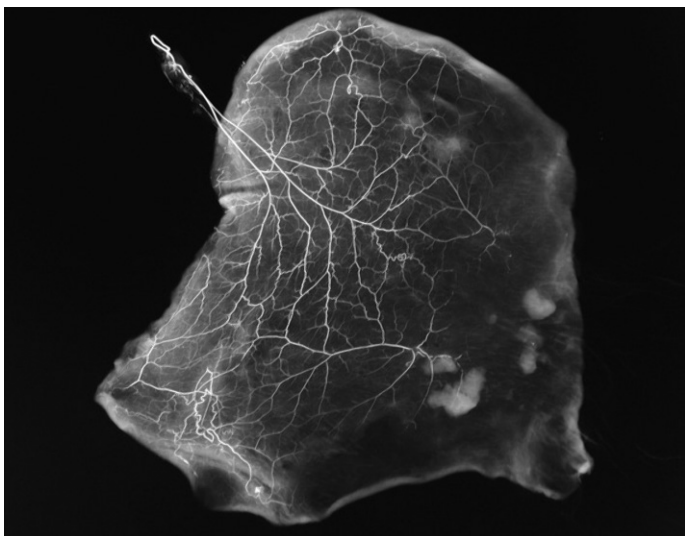


Figure 8-15. Angiogram of a deep circumflex iliac flap from a cat demonstrating a primary (1), secondary (2) and tertiary (3) angiosome.

Another useful technique to identify the angiosome when elevating a skin flap is to use a transillumination technique. As the skin is dissected off the underlying muscle, it is elevated and illuminated with an operating lamp on the epithelial side of the flap and inspected from the subcutaneous side. The vessels can be easily visualized through the skin. Use of this technique will aid in preventing damage to the perforatoring vessels of the skin.

Omocervical Free Skin Flap[7,18-21]

The flap tends to have a substantial amount of subcutaneous fat associated with the skin. As a result, it is best suited for wounds located at the level of or proximal to the stifle; it can also be used for wounds in the forelimb that are located at the level of or proximal to the antebrachial region. If the dog is very lean, the flap likewise will be very thin and can be used in any location on the body. The flap has a thick coat of hair which makes it suitable for reconstruction of a highly visible region.

Flap Designs

- Simple skin flap
- Myocutaneous - skin flap and the cervical portion of the trapezius muscle
- Osteomyocutaneous - skin flap, the cervical portion of the trapezius muscle, and the spine of the scapula

Blood Supply

The blood supply of the omocervical free skin flap arises from the cutaneous branch of the superficial cervical artery and vein. These vessels penetrate the fascia between the omotransversarius and the cervical portion of the trapezius muscles. The superficial cervical artery and vein have 7 named branches, most of which supply the adjacent muscles. The prescapular lymph nodes are intimately associated with the vessels as they traverse medial to the aforementioned muscles. This is in the region of the cranial shoulder depression, which is easily palpated cranial to the scapula. In a large breed dog, the vascular pedicle of the flap is about 5 cm long and the diameters of the artery and vein are about 1.5 mm and 4 to 5 mm, respectively. The vein is very thin walled which can make it more challenging to work with during microvascular anastomosis to a recipient vein. One should be aware that the vascular pedicle does not always course under the omotransversarius, but may travel superficial to it (Figure 8-16). This variant was reported in 1 dog and described in another 2 dogs.[17]

Anatomic Boundaries

The cutaneous anatomical boundaries of the angiosome of the superficial cervical artery include the wing of the atlas cranially, dorsal midline, spine of the scapula caudally, and the acromion of the scapula ventrally. The axis of the cutaneous vessels is oriented in a caudoventral to craniodorsal direction, therefore the outline of the flap should be oriented in this direction (Figure 8-17).

Procedure

The cervical region in some dogs can be laden with fat. This makes the dissection of this flap very difficult. In order to prevent damage to the vascular supply during the dissection of the flap,

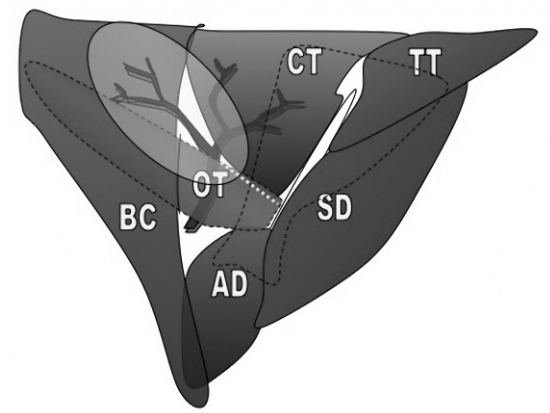


Figure 8-16. Lateral view of left shoulder. Take note of the typical pathway (left figure) of the superficial cervical vessels (deep to omotransversarius) versus the anomalous (right figure) path of the vessels (superficial to the omotransversarius muscle). Abbreviation key: *CT*=cervical part of trapezius muscle; *TT*= thoracic part of trapezius muscle; *SD*=spinous head of deltoid muscle; *OT*=omotransersarius muscle; *BC*=brachiocephalicus muscle; *AD*=acromial head of deltoid muscle.

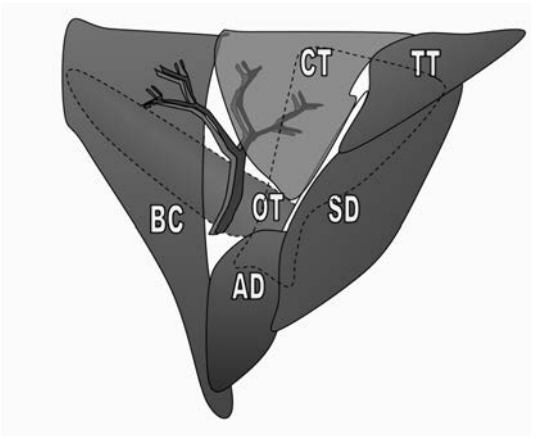


Figure 8-17. Lateral view of left shoulder depicting the location of the omocervical free flap. Abbreviation key: *CT*=cervical part of trapezius muscle; *TT*= thoracic part of trapezius muscle; *SD*=spinous head of deltoid muscle; *OT*=omotransversarius muscle; *BC*=brachiocephalicus muscle; *AD*=acromial head of deltoid muscle.

the underlying fat should be elevated with the skin. After the skin has been incised around the entire circumference of the proposed flap, the caudal border of the flap is dissected until the intermuscular septum between the cervical portion of the trapezius and the omocervical muscle is identified. The dissection then continues along the dorsal border in a ventral direction.

The fascia between the cranial border of the cervical part of the trapezius and omotransversarius is incised to the level of the acromion, which exposes the superficial cervical artery and vein. The cutaneous branches are visualized and the remaining portion of the skin flap is dissected free from the muscles. The muscular branches of the superficial cervical vessels are ligated and divided. The fat surrounding the vessels is carefully removed (skeletonized) in order to decrease pedicle bulk of the pedicle.

Careful removal of adventitia at the proposed site of vein transection when it is distended with blood can make this

process more easily performed, than after the vessel has been transected and deflated. After the vessels have been isolated as far down the pedicle as possible, they are occluded with microvascular clamps, ligated distal to the clamps, and transected.

The wound is closed in layers in order to minimize dead space. It is advisable to place a closed suction drain in the wound for 3 to 5 days, as seroma formation is a common complication in this highly mobile region. The recipient site is protected with a soft padded bandage. The bandage is changed daily as abundant serosanquinous discharge is expected.

The flap is transferred to the recipient wound. Care is taken to ensure that the vascular pedicle is not twisted. The skin flap is then tacked in place with a few sutures in order to ensure proper orientation of the hair (if possible) and vascular pedicle. Microvascular anastomosis of the artery and vein of the flap to recipient vessels is performed.

Medial Saphenous Fasciocutaneous Free Flap[5,6]

Uses

This flap is relatively thin therefore it is useful for reconstruction of wounds located on the distal extremities and face. The flap is somewhat sparsely haired in some dogs and the client must be informed about the potential for less hair at the recipient site.

Flap Designs

- Simple skin flap
- Myocutaneous - skin flap and the distal half of the caudal head of the sartorius
- Osteomyocutaneous - skin flap and distal half of the caudal head of sartorius and medial tibial cortex
- Osteocutaneous - skin flap and medial tibial cortex

Blood Supply

The blood supply to this flap comes from the saphenous artery and medial saphenous vein (Figure 8-18). Proximally, these vessels lie under the caudal aspect of the caudal head of the sartorius, then enter the superficial fascia at the level of the distal femur.

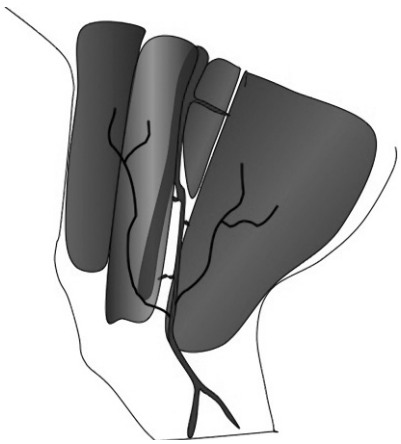


Figure 8-18. Medial view of vessels of the right hindlimb. Take note of the two muscular branches that penetrate the caudal head of the sartorius and one branch that enters the cranial aspect of the gracilis.

There are two cutaneous perforators that perfuse the medial saphenous fasciocutaneous flap: a cranial branch and a caudal branch (Figure 8-19). Cadavaric studies have confirmed that the skin on the entire medial aspect of the femorotibial region from the level of the inguinal ligament to the distal tibia is perfused by segmental fascial perforators of the saphenous artery. Two muscular branches are found proximal to the cutaneous branches: one to the distal gracilis muscle and the other to the distal sartorius muscle. The distal 1/2 of the caudal head of the sartorius is consistently perfused by the saphenous artery. The gracilis muscle is not well perfused by the saphenous vessels, as its dominant blood supply is based on the proximal caudal femoral artery and vein.

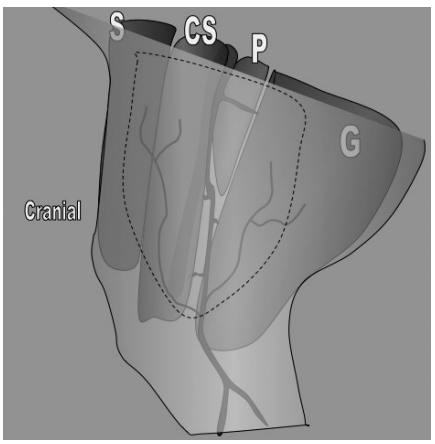


Figure 8-19. Medial view of right thigh. Take note of the two cutaneous perforators that perfuse the medial saphenous fasciocutaneous free flap. Abbreviation key: *Cr*=cutaneous perforator of the medial saphenous flap; *Ca*=caudal perforator of the medial saphenous flap; *S*=cranial head of sartorius muscle; *CS*=caudal head of sartorius muscle; *P*=pectineus muscle; *G*=gracilis muscle.

Anatomic Boundaries

The medial saphenous fasciocutaneous free flap generally is based on the proximal two cutaneous branches. If a smaller flap is needed, it can be based on either the cranial or caudal cutaneous branch. The most proximal cutaneous branch supplies the caudal half of the flap and the second cutaneous branch supplies the cranial half of the flap. There may be some variation of the location where the first two cutaneous branches originate off the medial saphenous vessels, thus care must be taken when elevating the flap. The flap generally is centered over the thigh region with the proximal most aspect of the flap being at the junction of the thigh and abdomen. The flap should not be centered over the stifle as this may increase the risk for incisional dehiscence.

Procedure

The proximal, cranial and caudal borders of the flap are incised and the flap is elevated. A transillumination technique is used to identify the cutaneous perforators of the flap. The distal border of the flap should be incised last, as the cutaneous vessels may extend off the parent vessels in a more distal location than expected. Next, the saphenous artery and medial saphenous vein distal to the cutaneous perforators are isolated, ligated and divided. The saphenous vessels are dissected from their fascial

attachments between the gracilis and the sartorius muscles. The gracilis muscular branch of the saphenous vessels is ligated and divided. Two muscular branches of the saphenous vessels entering the caudal head of the sartorius muscle are ligated and divided. The pedicle is then completely isolated to the level of the femoral vessels.

The vessels are ligated at the level of the femoral vessels, occluded with microvascular clamps just distal to this region, and sharply divided. The medial saphenous nerve, which is sacrificed at the time of the vessel dissection, is injected with bupivacaine (Figure 8-20). The donor site is closed in two layers: subcutaneous fascia and the skin. A drain is usually not placed in the donor site.

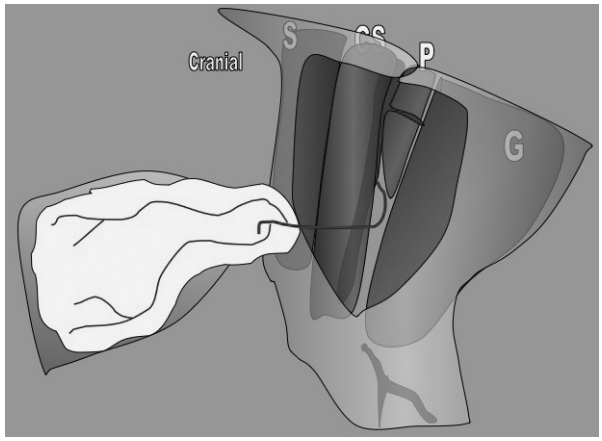


Figure 8-20. Medial view of right thigh. The saphenous artery and medial saphenous vein have been ligated and divided distal to the cutaneous perforators of the medial saphenous fasciocutaneous flap. Abbreviation key: *S*=cranial head of sartorius muscle; *CS*=caudal head of sartorius muscle; *P*=pectineus muscle; *G*=gracilis muscle.

A number of precautions should be taken in order to decrease the risk of donor site wound dehiscence:

- The maximum width of the flap should not be greater then 6 cm in a large breed dog; if the flap needs to be wider, harvest a much longer flap as the length of the flap will translate into greater flap width.
- Attempt to keep the location of the flap as proximal as possible.
- Flex and extend the stifle to determine the isometric points of tension and temporarily appose the skin edges with towel clamps at the time of wound closure.
- Close the fascia that is attached to the underlying skin edges with a simple interrupted pattern and close the skin with an interrupted intradermal pattern.
- Protect donor site with a modified Robert-Jones bandage for 10 days after surgery.

Table 8-1 summarizes important differences between the medial saphenous fasciocutaneous and omocervical free flaps.

Free Muscle Flaps

Muscle flaps have a number of characteristics which make them ideal for reconstructive surgery. A muscle flap will revascularize a wound bed rapidly and improve the delivery of antibiotics, antibodies, and components of cell mediated immunity to the area. Oxygen tension in the wound bed is increased which inhibits anaerobic infection and promotes healing. A muscle flap can prevent, and potentially help to eliminate osteomyelitis in open fractures. In humans, open tibial fracture osteomyelitis has almost been eliminated as a postoperative complication, with the use of free muscle transfer. Muscle flaps provide a healthy, well vascularized surface for immediate free skin grafting. Muscle flaps conform well to any shape wound bed and they will atrophy to 40% of their original thickness within two months after surgery.

Table 8-1. Free Flap Charactaristics

Flap	Medial saphenous free flap	Omocervical free flap
Thickness of flap	Thin	Thick
Appearance in wound bed	Conforms well	Bulges due to fat
Hair orientation	Good match to distal extremity, at times flap will have incorrect hair orientation	Poor match to distal extremity
Coat thickness	Frequently thinner than native coat of distal limb	Frequently thicker and longer than native coat of distal limb
Muscle within angiosome	Caudal head of sartorius	Cervical part of trapezius
Bone within angiosome	Medial tibial cortex - will survive based on periosteal blood supply	Spine of scapula has questionable survivability
Vascular pedicle length	7 to 10 cm	4 to 5 cm
Vein of pedicle	Thick and easy to work with	Thin and more challenging to work with
Vessel diameters	Adequate for anastomosis	Adequate for anastomosis
Identification of vascular pedicle	Easy	More difficult
Ease of flap elevation	Easy	More difficult
Size of flap	Limited width	Less limitation

The advantage of using a muscle flap over a free skin flap is that the angiosome is contained within the specific muscle; therefore there is no "guess work" as to the location of the blood supply. If the skin is shifted or skewed off important deep landmarks, the flap may not be within the primary angiosome.

Selection of the appropriate muscle for wound reconstruction is important in the preoperative planning. A muscle that is expendable with little functional or cosmetic detriment to donor site function should be used. The muscle should fit the size and shape of the wound. The rectus abdominis muscle is ideal for distal extremity wounds. Due to its length, the blood supply of the rectus can be anastomosed to recipient vessels that are well outside the zone of the wound. The cervical part of the trapezius is also acceptable for distal limb extremity. Its vascular leash is relatively long, however, if trauma to the extremity is extensive and recipient vessel integrity is questionable, it should not be considered as a first choice. The latissiumus dorsi myocutaneous flap is useful for very large wounds that require bulk, but is infrequently used in veterinary medicine in free tissue transfer.

All muscle flaps need a cutaneous covering. There are two options: free skin grafting or creation of a composite flap (myocutaneous). One of the primary disadvantages of using a myocutaneous flap to reconstruct a wound on the distal extremity is that the resultant flap tends to be rather bulky, thus it is cosmetically less acceptable. If the patient gains a significant amount of weight, the flap usually will become bulkier due to deposition of adipose tissue. The second disadvantage of a myocutaneous flap based on the perforator system in dogs is that survival of the skin portion is inconsistent. The survival of the skin pedicle when developed on the axial pattern blood supply is consistent. Skin grafting over the muscle flap is more successful in veterinary patients.

Trapezius Free Muscle Flap[23,24]

Uses

The cervical portion of the trapezius can be used for reconstruction of distal extremity and facial wounds. It is a fairly sizeable muscle flap and can therefore be used to reconstruct moderately large wounds. The muscle may be harvested with the omocervical skin flap to form a myocutaneous flap. This composite myocutaneous flap, however, tends to be very bulky when used for reconstruction of distal extremity wounds.

Blood Supply

The cervical portion of the trapezius muscle is a relatively thin and broad muscle with the superficial cervical artery and vein serving as the dominant pedicle. This muscle is useful for reconstruction of distal extremity and facial wounds.

The cervical part of the trapezius muscle has a type II blood supply. The dominant pedicle consists of the superficial cervical artery and vein which enters the cranial aspect of the muscle. The blood supply within the muscle can be visualized on the under side of the muscle. The vascular pedicle is about 5 cm long and the artery and vein diameters are approximately 1.5 mm and 4 to 5 mm, respectively. Numerous side branches arising from the superficial cervical artery and vein enter the omotransversarius, deltoid, supraspinatus and brachiocephalicus muscles and need to be ligated and divided during the dissection. The pedicle has a relatively thick cuff of fat that can be safely removed in order to skeletonize the vascular pedicles.

Procedure

A skin incision is made 5 cm cranial and parallel to the full length of the spine of the scapula. Next the fascial attachment between the cervical trapezius muscle and the omotransversarius muscle is incised with a pair of scissors (Figure 8-21).

The omotransversarius is retracted ventrally to expose the superficial cervical artery and vein (Figure 8-22). Branches of the superficial cervical artery and vein extending into the omotransversarius, acromial deltoid, supraspinatus and the brachiocephalicus muscles are ligated and divided to free the pedicle. If a skin paddle is not included in the flap design, the direct cutaneous artery and vein are ligated and divided. At this

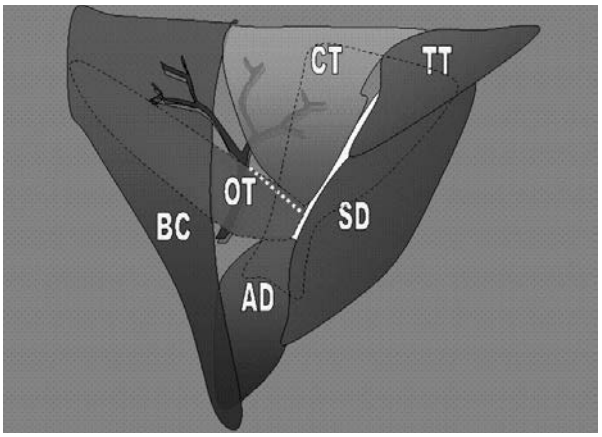


Figure 8-21. Lateral view of the left shoulder region. The dashed line indicates the initial incision that is made between the omotransversarius and the cervical part of the trapezius. Abbreviation key: *CT*=cervical part of trapezius muscle; *TT*= thoracic part of trapezius muscle; *SD*=spinous head of deltoid muscle; *OT*=omotransversarius muscle; *BC*=brachiocephalicus muscle; *AD*=acromial head of deltoid muscle.

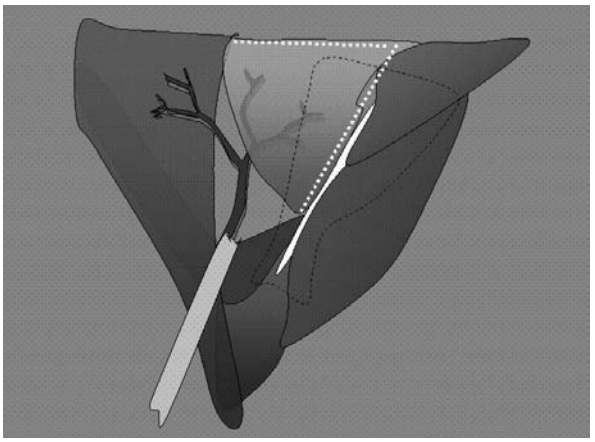


Figure 8-22. Lateral view of the left shoulder region. The omotransversarius muscle is retraced ventrally to expose the superficial cervical artery and vein. The dashed line demonstrates the incision in the origin and insertion of the cervical part of the trapezius muscle.

point the fat and prescapular lymph nodes can be removed from the pedicle using very gentle dissection and ligation of any side branches. The attachment of the trapezius muscle to the dorsal spinous processes and the spine of the scapula are incised. The trapezius muscle is flipped over which will expose the blood supply from the superficial cervical artery and vein (Figure 8-23).

A prominent dorsal venous extension from the superficial vein, beyond the branch that enters the trapezius, is ligated and divided. At this point the entire trapezius should be completely free other than being attached to its vascular pedicle.

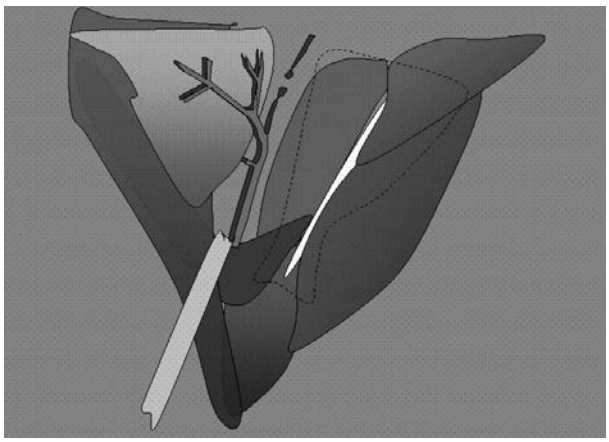


Figure 8-23. Lateral view of the left shoulder region. Following detachment of the origin and insertion of the muscle, the flap is flipped over to expose the blood supply entering the flap.

Rectus Abdominis Free Muscle Flap[25,26]

Uses

The rectus abdominis muscle is very useful for distal extremity, facial, and intraoral reconstruction. Because the flap is long, it can be revascularized to recipient vessels that are distant to the primary wound bed.

Blood Supply

The rectus abdominis muscle is thin and flat and extends from the first rib to the brim of the pelvis. The abdominal portion of the rectus abdominis can be used as a free flap. The muscle has multiple tendinous intersections located along its length. The rectus muscle has a type 3 blood supply. The blood supply to the rectus abdominis is from three sources: the cranial epigastric, caudal epigastric, and segmental lateral perforator arteries and veins. The caudal epigastric vessels join the caudal superficial epigastric vessels from the mammary chain to form the pudendoepigastric vessels. In some dogs the pudendoepigastric vessels are absent, leaving the caudal superficial epigastric and the caudal epigastric vessels to originate directly from the deep femoral artery and the external iliac vein.

The caudal two-thirds of the abdominal part of the muscle is perfused by the caudal epigastric artery and vein. The primary angiosome based on the caudal vascular pedicle extends approximately to the third tendinous intersection. Based on the fact that the caudal pedicle is perfusing a much larger portion of the muscle, a free rectus muscle flap should be based on this set of vessels.

The caudal epigastric artery and vein enter the caudolateral aspect of the rectus abdominis muscle near the inguinal ring. The pedicle is about 2 to 3 cm long, and the artery and vein diameters are 1 mm and 2.5 mm, respectively; by harvesting the pudendal artery and vein, the diameters of the vessels are greatly increased.

Surgical Procedure

A ventral midline skin incision is made from the xiphoid process to the cranial border of the pubis. In male dogs a parapreputial incision is made. The initial skin incision is deepened to the level of the linea alba. Subcutaneous tissues are then dissected off the superficial rectus sheath.

The superficial rectus sheath is incised starting at the external inguinal ring and extended cranially over mid portion of the muscle. The muscle is dissected out of its sheath with a combination of blunt and sharp dissection. Dorsally, the deep rectus sheath, which is less adherent to the muscle is bluntly dissected. Perforators entering the lateral aspect of the muscle are ligated and divided. The flap is transected at the cranial border and is reflected caudally.

The caudal epigastric artery and vein are ligated just proximal to the caudal superficial epigastric vessels and divided. The superficial rectus sheath is closed with 0 PDS in a simple continuous suture pattern. Subcutaneous tissues and skin are closed routinely.

Table 8-2 summarizes important characteristics of the trapezius and the rectus abdominis muscle flaps.

References

1. Daniel RK, Terzis, J.K.: Reconstructive microsurgery Boston: Little, Brown, 1977.

2. Zhong-wei C, Dong-yue, Y., De-sheng, C.: Microsurgery. New York, Shanghai Scientific and Technical Publisher, 1982.

3. Acland RD: Practice manual for microvascular surgery (ed 2). St. Louis, CV Mosby, 1989.

4. Urbaniak JR, Soucacos PN, Adelaar RS, et al: Experimental evaluation of microsurgical techniques in small artery anastomoses. Orthop Clin North Am 8:249-263, 1977.

5. Degner DA, Walshaw R: Medial saphenous fasciocutaneous and myocutaneous free flap transfer in eight dogs. Vet Surg 26:20-25, 1997.

6. Degner DA, Walshaw R, Lanz O, et al: The medial saphenous fasciocutaneous free flap in dogs. Vet Surg 25:105-113, 1996.

7. Fowler JD, Degner DA, Walshaw R, et al: Microvascular free tissue transfer: results in 57 consecutive cases. Vet Surg 27:406-412, 1998.

8. Blair WF, Pedersen DR, Joos K, et al: Interrupted and continuous microarteriorrhaphy techniques: a hemodynamic comparison. J Orthop Res 2:419-424, 1984.

9. Chen YX, Chen LE, Seaber AV, et al: Comparison of continuous and interrupted suture techniques in microvascular anastomosis. J Hand Surg [Am] 26:530-539, 2001.

10. Cordeiro PG, Santamaria E: Experience with the continuous suture microvascular anastomosis in 200 consecutive free flaps. Ann Plast Surg 40:1-6, 1998.

Table 8-2. Muscle Flap Charactaristics

Flap	Trapezius	Rectus abdominis
Thickness of flap	Thin	Thin
Shape of flap	Triangular	Long and rectangular
Bone within angiosome	Spine of scapula has questionable survivability	None
Cutaneous paddle	Omocervical skin flap	Caudal superficial epigastric skin flap
Vascular pedicle length	5 cm	2 to 3 cm
Vein of pedicle	Very thin walled	Very thin walled
Vessel diameters	Adequate for anastomosis	Adequate for anastomosis
Identification and isolation of vascular pedicle	More difficult	Easy
Ease of flap elevation	More difficult	Easy

11. Lopez-Monjardin H, de la Pena-Salcedo JA: Techniques for management of size discrepancies in microvascular anastomosis. Microsurgery 20:162-166, 2000.

12. Adams WP, Jr., Ansari MS, Hay MT, et al: Patency of different arterial and venous end-to-side microanastomosis techniques in a rat model. Plast Reconstr Surg 105:156-161, 2000.

13. Ahn CY, Shaw WW, Berns S, et al: Clinical experience with the 3M microvascular coupling anastomotic device in 100 free-tissue transfers. Plast Reconstr Surg 93:1481-1484, 1994.

14. Zdolsek J, Ledin H, Lidman D: Are mechanical microvascular anastomoses easier to learn than suture anastomoses? Microsurgery 25:596-598, 2005.

15. Falconer DP, Lewis TW, Lamprecht EG, et al: Evaluation of the Unilink microvascular anastomotic device in the dog. J Reconstr Microsurg 6:215-222, 1990.

16. Pavletic MM: Skin flaps in reconstructive surgery. Vet Clin North Am Small Anim Pract 20:81-103, 1990.

17. Degner DA, Walshaw, R., Kerstetter K.K.: Vascular anomaly of the prescapular branch of the superficial cervical artery and vein of an omocervical free skin flap in a dog. Vet Comp Orthop Traumatol 8:102-106, 1995.

18. Fowler JD, Miller CW, Bowen V, et al: Transfer of free vascular cutaneous flaps by microvascular anastomosis. Results in six dogs. Vet Surg 16:446-450, 1987.

19. Miller CC, Fowler JD, Bowen CV, et al: Experimental and clinical free cutaneous transfers in the dog. Microsurgery 12:113-117, 1991.

20. Miller CW: Free skin flap transfer by microvascular anastomosis. Vet Clin North Am Small Anim Pract 20:189-199, 1990.

21. Miller CW, Bowen V, Chang P: Microvascular distant transfer of a cervical axial-pattern skin flap in a dog. J Am Vet Med Assoc 190:203-204, 1987.

22. Pavletic MM: Anatomy and circulation of the canine skin. Microsurgery 12:103-112, 1991.

23. Philibert D, Fowler JD: The trapezius osteomusculocutaneous flap in dogs. Vet Surg 22:444-450, 1993.

24. Philibert D, Fowler JD, Clapson JB: Free microvascular transplantation of the trapezius musculocutaneous flap in dogs. Vet Surg 21:435-440, 1992.

25. Calfee EF, 3rd, Lanz OI, Degner DA, et al: Microvascular free tissue transfer of the rectus abdominis muscle in dogs. Vet Surg 31:32-43, 2002.

26. Lanz OI: Free tissue transfer of the rectus abdominis myoperitoneal flap for oral reconstruction in a dog. J Vet Dent 18:187-192, 2001.

Chapter 9

Pain Management in the Surgical Patient

Pain Management in the Small Animal Patient

Stephanie H. Berry and Richard V. Broadstone

In spite of increased emphasis on pain management in small animals recently, veterinarians can be reluctant to administer appropriate analgesic agents to their patients. This reluctance appears to be based on the perception that pain free animals may damage surgical repairs, exhibit undesirable side effects from analgesic drugs, or that analgesic drugs may mask clinical signs of disease. It is known that untreated pain can produce detrimental physiologic effects that adversely affect the response to therapy. Transmission of painful stimuli to the central nervous system results in a marked neuroendocrine stress response. Increased levels of circulating catecholamines and catabolic hormones can lead to decreased immune system function, impaired wound healing, hypercoagulability, increased myocardial oxygen consumption, gastrointestinal stasis, and decreased pulmonary function.[1] By designing and implementing appropriate analgesic protocols, veterinarians can decrease the neuroendocrine stress response and improve the postoperative recovery of surgical patients.

The Pain Pathway

In simple form, the pain pathway consists of three neurons. Specialized free nerve endings, or nociceptors, transduce mechanical, chemical, or thermal stimuli from the environment into electrical signals. These electrical signals are then transmitted by afferent sensory fibers to the dorsal horn of the spinal cord where modulation of the painful stimulus can occur. The signal ascends the spinal cord, and is then projected to the cerebral cortex where perception of pain occurs.[2]

Untreated pain can result in sensitization of both the central nervous system and peripheral receptor sites. Tissue damage and inflammation at the site of injury cause release of chemical mediators such as Substance P, prostaglandins, leukotrienes, and bradykinin. These mediators excite and increase the sensitivity of peripheral nociceptors to painful stimuli.[3] The mechanism of central sensitization is complex and occurs at the level of the spinal cord and brain. Glutamate, appears to be the primary mediator and activator of *N*-methyl-D-aspartate (NMDA) receptors, which results in an increased responsiveness of spinal neurons to stimuli.[4]

The exact mechanisms responsible for the generation and maintenance of pain in animals are still being investigated. It is clear, however, that modulation and inhibition of painful stimuli serves to avoid or decrease the adverse consequences of the neuroendocrine response to untreated pain.

Recognition and Assessment of Pain

Recognition of pain in the small animal patient can be difficult. Several scoring systems have been developed or adapted from human medicine and general guidelines for recognizing painful behaviors in animals have been published. Traditionally, methods for scoring the intensity of pain in animals have included the visual analogue scale (VAS), the simple descriptive scale (SDS), and the numerical rating scale (NRS).[5] However, a gold standard for pain recognition and assessment has not been established in veterinary medicine.

The *visual analogue scale* consists of a 10 cm line with the ends relating to extremes of pain intensity. The left end of the line is labeled as "no pain" while the right end of the line is labeled as "worst pain possible for this procedure". An observer places a mark on this line that best corresponds with the intensity of the animal's pain. The distance from the left end of the line to the intersecting mark is then measured and this number is the VAS pain score. The VAS has been used in several clinical studies to assess pain and although the VAS is easy to use, it does have limitations.[6-8] First, this technique simply assigns a number to a subjective judgment, making the assessment one-dimensional. Significant observer variability has also been demonstrated, even when trained individuals view the same animal at the same time.[8] These limitations must be recognized when using the VAS as a basis for designing analgesic protocols.

The *simple descriptive scale* is the most basic method for assessing pain in animals. The scale consists of four to five degrees of severity such as no pain, mild, moderate, and severe pain. An observer assigns the patient to a category based on their observations of that patient. The SDS is a broad classification and does not allow for small changes in pain response to be identified.[5]

Holton et al have shown that physiologic factors such as heart rate, respiratory rate, and pupil size are not useful indicators of pain in hospitalized dogs, however other investigators have shown that a combination of several physiologic and behavioral parameters considered together can be useful in assessing pain.[9,10] The *numerical rating scale,* combines both physiologic and behavioral categories with numeric scores assigned to each category. The scores are then summed to yield an overall pain score and used as the basis for analgesic therapy (Table 9-1).

Recognizing Painful Behaviors

Characteristic changes in behavior have been associated with pain in both dogs and cats. It is important to observe the animal's posture, temperament, locomotion, and vocalization for changes that may indicate untreated pain. In dogs, postural changes such as holding the tail between the legs, arching of the back, or drooping of the head have been associated with untreated pain. Additionally, a reluctance to move, nonweight-bearing lameness, attacking, biting, barking, and whimpering are also behaviors that have been associated with pain.[11] Cats exhibit more subtle behavioral changes associated with pain such as escaping or avoidance, hiding, squinting of the eyes, reluctance to move, hissing or lack of interest in food or grooming.[12] Assessments of

Table 9-1. An Example of a Numerical Rating Scale for Assessment of Analgesia.

Numerical scores are given in each category. The values are then summed to yield a total pain score. Treatment is based on the total pain score. Modified from Hellyer & Gaynor (1990).

Observation	Score	Description
Heart Rate	0	0-15%increase from baseline
	1	16-30% increase from baseline
	2	31-45% increase from baseline
Respiratory Rate	0	0-15% increase from baseline
	1	16-30% increase from baseline
	2	31-45% increase from baseline
Vocalization	0	No vocalization
	1	Vocalization that responds to a calm voice
	2	Vocalization that does not respond to a calm voice
Interactive Behavior	0	Normal
	1	Not interactive when approached, looks at affected limb
	2	Not interactive when approached, not mobile, vocalizes when affected limb touched
	3	Aggressive when approached, extremely restless
Lameness	0	No lameness evident
	1	Lameness evident in affected limb
	2	Moderate lameness evident in affected limb, patient occasionally only toe-touches
	3	Patient will not bear weight on affected limb
Range of Motion	0	0-20% decrease from baseline
	1	21-40% decrease from baseline
	2	41-60% decrease from baseline
	3	Patient will not tolerate movement
Tolerance to pressure	0	0-20% decrease from baseline
	1	21-40% decrease from baseline
	2	41-60% decrease from baseline
	3	Patient will not tolerate touching of affected limb
	Total Score (0-18)	

animals for pain should occur frequently, at regular intervals, and be documented in the medical record. Especially important times for assessment are if there is onset of new pain, when previously identified pain changes in frequency or pattern, or when there has been a major therapeutic intervention. Changes in the analgesic plan should be made in response to these assessments.

The Analgesic Plan

Proactive planning and design of analgesic protocols should be performed for all small animals undergoing surgery. These plans should be individualized and should consider such factors as the type of surgery or procedure to be performed, the expected severity of pain, any underlying medical conditions, the risk/benefit ratio of available analgesic techniques, and any previous clinical experiences with the animal. After considering these factors, a complete history should be gathered from the owner and a plan including preoperative, intraoperative, and postoperative analgesics should be constructed. Once the plan is enacted, the animal's pain level and behavior should be assessed frequently and refinements in the treatment protocol should be made.

Preemptive and Multimodal Plans

Preemptive analgesia refers to the practice of administering analgesics to a patient before a painful stimulus occurs such as surgery. The preemptive administration of analgesics has been shown to decrease the intensity and duration of postoperative pain.[13] Additionally, preemptive analgesics have been shown to decrease both peripheral and central nervous system sensitization.[14,15] It is important to remember, however, that administration of analgesic drugs preemptively will not eliminate postoperative pain, but can reduce the severity and duration of that pain.

A simplified explanation of the pain pathway is described here however, it is important to recognize that clinical pain is the result of signals transmitted along a multitude of pathways throughout the peripheral and central nervous systems. These pathways involve many mechanisms and neurotransmitters so, it is unlikely that a single analgesic agent or technique will alleviate all pain. Construction of a multimodal analgesic plan that uses drugs of different classes, each acting at different sites along the pain pathway (e.g. NSAIDS, opioids, local anesthetics), will result in more effective pain relief. Additionally, the co-administration of drugs in various classes has additive or synergistic effects and individual drug doses can often be reduced.

Analgesic Drugs

The drugs commonly used to treat perioperative pain in companion animals consist of nonsteroidal anti-inflammatory drugs (NSAIDs), opioids, alpha-2 agonists, local anesthetics, and adjunctive medications.

NSAIDs

These are commonly used in the canine and less frequently in the cat for analgesia (Table 9-2). These drugs are used to treat pain in a variety of cases ranging from acute surgical pain to chronic pain. Analgesia, anti-inflammatory, and antipyretic effects are brought about by inhibition of the cyclooxygenase (COX) enzymes resulting in a decrease in the release of prostanoids and prostaglandin.[16] It is known that NSAIDs act at the tissue injury site and there is evidence that NSAIDs also produce analgesia at the level of the central nervous system.[17] NSAIDs are well absorbed after oral administration, or when given parenterally.[18] Most are metabolized in the liver and the metabolites are then excreted in the urine and feces.[19] NSAIDs are effective, relatively inexpensive, and long lasting analgesics, however side effects may occur. Gastrointestinal irritation ranging from mild gastritis and vomiting to intestinal ulceration, hemorrhage and death have been reported.[20] Nephrotoxicity can also occur after NSAID administration due to decreases in renal blood flow.[21] Hepatotoxicity has been reported (with Labrador Retrievers over represented) and is generally believed to be idiosyncratic.[22] Serious complications have been associated with the use in dogs of NSAIDs intended for humans. NSAIDs should not be used in animals with existing renal or hepatic insufficiency, gastric ulceration, dehydration, hypotension, shock, or coagulopathies. Additionally, NSAIDs should not be administered concurrently with other nephrotoxic drugs, corticosteroids, or other NSAIDs. Careful monitoring for gastrointestinal, renal, or hepatic toxicity is required when using NSAIDs, especially in animal's at high risk. Renal and hepatic function should be evaluated before instituting NSAID therapy in dogs at risk for complications and during chronic NSAID therapy.

Opioids

Opioids are the most consistently effective drugs used for the treatment of moderate to severe pain (Table 9-3). This class of drugs produces analgesia by acting on opioid receptors without the loss of proprioception or consciousness. Three opioid receptors (mu, kappa, and delta) have been identified and are found in varying numbers within the brain, dorsal horn of the spinal cord, and the periphery.[23,24] Activation of opioid receptors results in inhibition of adenylate cyclase, a decrease in the opening of voltage-sensitive calcium channels, inhibition of the release of excitatory neurotransmitters, and activation of potassium channels resulting in membrane hyperpolarization.[25] The overall effect of opioid receptor activation is a decrease in neurotransmission.[26]

Opioid analgesics are classified by their receptor selectivity and may be active at one or more receptors. Mu agonists include morphine, oxymorphone, hydromorphone, fentanyl, and meperidine. These agonists induce a maximal response, and can produce increasing levels of analgesia with increasing dosages. This is in contrast to the partial mu agonist, buprenorphine, which binds tightly to the mu receptor but does not induce a maximal response.[27] Butorphanol has agonist activity at the kappa receptor and antagonist activity at the mu receptor.[28] Increasing doses of butorphanol are associated with a ceiling effect, such that no improvement of analgesia occurs with increasing doses.

In addition to producing analgesia, the opioids also affect other organ systems. Opioid administration can result in respiratory depression due to a decrease in the respiratory center's response

Table 9-2. Nonsteroidal Anti-inflammatory Drugs used in the Treatment of Peri-operative Pain.

Drug	Dosage	Frequency	Notes
Carprofen	Dog: 4.4 mg/kg IV, SQ, IM 2.2 mg/kg PO	Once at induction Every 12 hours	Acute hepatoxicity reported, does not appear to affect platelet function
	Cat: 4.0 mg/kg SQ, IV (67)	Once at induction	
Deracoxib	Dog: 3-4 mg/kg PO	Every 24 hours	COX – 2 inhibition, GI upset can occur
Etodolac	Dog: 10-15 mg/kg PO	Every 24 hours	Enterohepatic circulation maintains serum concentrations for extended period
Ketoprofen	Dog: 2.0 mg/kg IV, IM, SQ, PO 1.0 mg/kg IV, IM, SQ, PO	Once Every 24 hours	Preoperative administration can result in hemorrhage due to antithromboxane activity, not recommended for more than five days, renal damage reported
	Cat: 2.0 mg/kg SQ 1.0 mg/kg PO	Once Every 24 hours	
Meloxicam	Dog: 0.2 mg/kg IV, SQ 0.1 mg/kg IV, SQ, PO	Once Every 24 hours	
	Cat: 0.2 mg/kg SQ 0.05 mg/kg PO	Once Every 24 hours for 3-4 days	
Firocoxib	Dog: 5 mg/kg PO	Every 24 hours	Use of doses more than 5 mg/kg in puppies less than 7 months of age can result in severe adverse reactions, including death.
Tepoxalin	Dog: 10 - 20 mg/kg PO 10 mg/kg PO	Once Every 24 hours	Preoperative administration is not recommended
Ketorolac	Dog: 0.5 mg/kg IV, IM	Every 12 hours for 1 to 2 treatments	1 to 2 treatments only to reduce risk of gastric ulceration
Acetaminophen	Dog: 10 - 15 mg/kg PO	Every 8 hours	Can be combined with opioid for synergistic effect
	Cats: **Do not administer to cats**		**Do not administer to cats.**
Aspirin	Dog: 10 - 25 mg/kg PO	Every 12 hours	Ulcers and renal damage at higher doses
	Cat: 1 - 25 mg/kg PO[67]	Every 72 hours	
Tolfenamic acid	Dog: 4.0 mg/kg IM, SQ, PO	Every 24 hours	Give for four days, then off for three days
	Cat: 4.0 mg/kg SQ, PO[67]	Every 24 hours	Use for 3 days in cats
Piroxicam (Feldene)	Dog: 0.3 mg/kg PO	Every 48 hours	Use with gastroprotectant
Robenacoxib (Onsior)	Dog: 2 mg/kg SQ 1 mg/kg PO	Once perioperatively Every 24 hours	

Table 9-3. Opioids used in the Treatment of Peri-operative Pain.

Drug	Dosage	Duration	Notes
Morphine	Dog: 0.1-0.5 mg/kg IV 0.5-1.0 mg/kg IM, SC Cat: 0.05-0.1 mg/kg IV 0.1-0.2 mg/kg IM, SC	1 hour 3-5 hours 1 hour 3-4 hours	Dysphoria in cats with higher doses. Histamine release when given IV rapidly.
Morphine (Oral)	Dog: 0.5-4.0 mg/kg PO Cat: 0.25-1.0 mg/kg PO	4 hours; 8-12 hours if sustained release 4 hours	
Hydromorphone	Dog: 0.05-0.1 mg/kg IV 0.1-0.2 mg/kg IM, SC Cat: 0.05-0.1 mg/kg IV 0.1-0.2 mg/kg IM, SC	1 hour 3-4 hours 1 hour 3-4 hours	Associated with occasional hyperthermia in cats, no histamine release, less vomiting
Oxymorphone	Dog: 0.05-0.1 mg/kg IV, IM, SC Cat: 0.05-0.1 mg/kg IV, IM, SC	4 hours 4 hours	Less vomiting.
Fentanyl	Dog: 2-10 mcg/kg IM, SC Cat: 1-5 mcg/kg IM, SC	0.5 hour 0.5 hour	
Meperidine	Dog: 3-5 mg/kg IM, SC Cat: 3-5 mg/kg IM, SC	1-2 hours 1-2 hours	Significant histamine release if given IV.
Buprenorphine	Dog: 10-20 mcg/kg IV, IM, SC Cat: 10-20 mcg/kg IV, IM, SC, Buccal	6-8 hours 6-8 hours	Onset of action may be 30 minutes or more.
Butorphanol	Dog: 0.2-0.4 mg/kg IV, IM, SC Cat: 0.2-0.4 mg/kg IV, IM, SC	1 hour 1 hour	Only use for minor pain
Butorphanol (Oral)	Dog: 1.0-4.0 mg/kg PO Cat: 0.5-2.0 mg/kg PO	1-4 hours 1-4 hours	
Methadone	Dog: 0.3-1 mg/kg SC, IM, IV (slowly) Cat: 0.1-0.5 IV, IM	1-4 hours 1-4 hours	
Remifentanil	Dog: 4-10 mcg/kg/hr Can be increased to 20-60 mcg/kg/hr intraoperatively Cat: 15-60 mcg/kg/hr		Should be used as a constant rate infusion
Opioid Antagonist Naloxone	Dog: 0.01 mg/kg IV 0.04 mg/kg IM Cat: Same as dog	20-40 minutes 40-70 minutes	Animal should be observed for renarcotization or resedation due to short duration of action.

to increasing levels of CO_2.[29] The respiratory rate and rhythm may also be altered. Some animals pant due to the drug's effect on the thermoregulatory system. Respiratory depression is often cited as a reason for withholding opioid therapy but is rarely of clinical significance when proper dosing regimens are used.

The cardiovascular system may be affected by opioid administration. Bradycardia may result from inhibition of sympathetic tone to the heart.[30] Opioid induced bradycardia is not life threatening and usually does not require treatment. Opioids have little effect on cardiac contractility. Some opioids, particularly morphine and meperidine, can produce hypotension due to histamine release.[31,32] The degree of histamine release appears to be related to the overall dose and rate of administration, therefore small doses administered slowly should minimize this potential problem.

The propulsive activity of the gastrointestinal tract is decreased after opioid administration, which may result in constipation. Smooth muscle and sphincter tone tend to be increased, but intestinal peristalsis is decreased.[33] Vomiting may occur after direct stimulation of the chemoreceptor trigger zone.[34] Tone of the biliary sphincter is increased, which will increase biliary pressure. Contraction of the smooth muscle of the pancreatic ducts can increase plasma concentrations of lipase and amylase.

Alterations in mood and locomotion have been documented after opioid administration. Paradoxic excitement or dysphoria is possible in any species, although it appears that cats are more susceptible especially if excessive doses are given.[37] Opioid induced dysphoria may be treated with sedatives such as acepromazine, or in severe cases an opioid antagonist such as naloxone. Antagonism of opioids should be performed cautiously in animals experiencing pain since the analgesic effect of the opioid will be reversed.

Opioids can produce additive or synergistic effects when used in combination with other analgesics such as NSAIDs, alpha-2 agonists, and local anesthetics. Commonly, the dosage of each drug can be reduced, thereby potentially reducing the severity of adverse effects of each class of drugs.

Local Anesthetics

Local anesthetic drugs are tertiary amines connected to an aromatic ring by either an ester (procaine, tetracaine) or amide (lidocaine, mepivacaine, bupivacaine, ropivacaine) linkage (Table 9-4).[18] Local anesthetics bind to voltage gated sodium channels within nerve membranes, preventing the influx of sodium ions.[38] This prevents the conduction and propagation of nerve impulses and can produce complete analgesia. Local anesthetics with an ester linkage are hydrolyzed by pseudocholinesterases, while those with an amide linkage are metabolized by the liver.[18]

The use of local anesthetic drugs is relatively safe when administered correctly. However, if local anesthetic is injected intravenously or used in excessive doses, central nervous system and cardiotoxicty may occur. In the central nervous system, toxicity manifests as sedation, nausea, ataxia, nystagmus, and tremors, which can progress to convulsions, unconsciousness, coma, and eventually respiratory arrest.[39] Blockade of sodium channels within the myocardium will depress the electrical conduction pathways and the mechanical function of the heart. This can result in sinus bradycardia and sinus arrest.[40,41] The peripheral vasculature can also be affected by the administration of local anesthetics resulting in peripheral vasodilation and hypotension.[42] Finally, local anesthetics can cause direct damage to the tissues injected, allergic reactions, and methemoglobinemia.[43,44]

Local anesthetics when used epidurally in conjunction with opioids will produce a more profound and longer lasting analgesia than either drug used individually.[45] The use of local anesthetics also reduces the inhaled anesthetic requirements of animals thus reducing the dose dependant effects of inhaled anesthetics on the cardiopulmonary system.[46] Specific analgesic techniques using local anesthetic drugs are discussed later in this chapter.

Alpha-2 agonists

Alpha-2 receptor agonists (Table 9-5) bind to both pre and postsynaptic receptors throughout the central nervous system. Activation of these receptors results in neuronal hyperpolarization and a decrease in sympathetic nervous system activity.[47] Alpha-2 receptors are closely located to structures involved in pain processing and activation is thought to interfere with sensory transmission and reduce the release of pain related neurotransmitters resulting in analgesia, sedation, and muscle relaxation.[48]

Alpha-2 agonists have profound effects on the cardiovascular system, commonly producing bradycardia and/or bradyarrhythmias, as well as decreases in contractile force, stroke volume, and cardiac output. After administration, blood pressure will transiently increase followed by a decrease in blood pressure from baseline values.[49]

Administration of Alpha-2 agonists will results in a dose dependent decrease in respiratory rate and tidal volume, which can result in significant respiratory acidosis and hypoxemia in some animals. Marked relaxation of the muscles of the upper airway also occurs; therefore, patency of the upper airway should be ensured and monitored.[50]

Vomiting and retching can occur after administration of an alpha-2 agonist, especially in cats.[51] Gastrointestinal motility is decreased[52] and urine output will increase.[53] Hypoinsulinemia resulting in a transient hyperglycemia has also been reported in dogs after alpha-2 agonist administration.[54]

The usefulness of alpha-2 agonists as sole analgesic agents is limited by their short duration of action and dose dependant cardiopulmonary depression. However, alpha-2 agonists, when given in conjunction with other analgesics such as opioids, are extremely effective analgesic agents. Patient selection should be considered carefully and the use of alpha-2 agonists should be limited to animals without significant systemic disease or dysfunction. It is important to recognize that the sedative effects of alpha-2 agonists persist for a longer period of time than the analgesic effects.[55] Therefore, adequate analgesia cannot be assumed based only on behavioral evaluation of the patient.

Table 9-4. Local Anesthetics used in the Treatment of Peri-operative Pain.

Drug	Dosage	Onset	Duration	Notes
Lidocaine	Dog: ≤ 6 mg/kg Cat: ≤ 3 mg/kg	10 minutes	60-120 minutes	Effective topically, can be used intravenously
Mepivacaine	Dog: ≤ 6 mg/kg Cat: ≤ 3 mg/kg	5 minutes	90-180 minutes	Less tissue irritation Not effective topically
Bupivacaine	Dog: 2 mg/kg Cat: 1 mg/kg	20 minutes	240-360 minutes	Not effective topically Selective sensory blockade with limited motor blockade, selectively cardiotoxic
Etidocaine	Dog: 3 mg/kg	5 minutes	180-300 minutes	Not effective topically Preferential motor blockade, cardiotoxicity similar to bupivacaine.
Ropivicaine	Dog: 2 mg/kg	5 minutes	180-300 minutes	Less cardiotoxic than bupivacaine
EMLA cream		Apply topically 60 minutes before procedure. Cover with occlusive dressing	1-2 hours following removal of cream	1:1 mixture of lidocaine and prilocaine; do not apply to damaged or broken skin, middle ear, or ocular structures; Prevent licking and/or oral ingestion

Table 9-5. Alpha-2 agonists used in the Treatment of Peri-operative Pain.

Drug	Dosage	Duration	Notes
Xylazine	Dog: 0.1-0.5 mg/kg IM, IV Cat: 0.1-0.5 mg/kg IM, IV	0.5-1.0 hour 0.5-1.0 hour	Sedation, bradycardia Vomiting (esp. in cats)
Dexmedetomidine	Dog: 0.5 mcg/kg IV 5-15 mcg/kg IM Cat: 5- 20 mcg/kg IM	2-3 hours 2-3 hours	
Romifidine 0.5-1.5 hour	Dog: 10-20 mcg/kg IV, IM Cat: 20-40 mcg/kg IV, IM	0.5-1.5 hour 0.5-1.5 hour	
Alpha-2 Antagonist: Atipamezole	Dog: 0.05-0.2 mg/kg IV,IM Or 2-5 times dexmedetomidine dose Cat: 0.05-0.2 mg/kg IV,IM Or 2-5 times the dexmedetomidine dose	1-3 hour	IV administration usually reserved for emergencies; can cause excitement, delirium, and vomiting

Analgesic Adjuncts

There are other classes of drugs that are not regarded as analgesics but may be helpful in the treatment of refractory pain states (Table 9-6). These drugs may enhance analgesia produced by traditional analgesic drugs by interacting with receptors within the pain pathway or altering nerve conduction pathways in pain modulating systems. It should be noted that while the drugs discussed here can play an important role in treating pain, especially in cases of refractory pain states, most produce little to no analgesia when used by themselves. They should be used in conjunction with known analgesics such as opioids.

Nociceptor activation and bombardment of the dorsal horn of the spinal cord leads to activation of N-methyl-D-aspartate (NMDA) receptors, which are thought to play a role in central sensitization. Ketamine is an N-methyl-D-aspartate (NMDA) receptor antagonist and is thought to produce analgesia and limit hyperalgesic states.[56] It appears that ketamine is most effective when administered preemptively and its short duration of action suggests that administration via a constant rate infusion is beneficial.[57] When administered as a constant rate infusion in dogs undergoing forelimb amputation, ketamine significantly reduced postoperative pain scores and increased animal activity three days postoperatively.[58] Analgesic doses of ketamine are considerably lower than those used to produce anesthesia, but potential side effects include sympathetic stimulation of the cardiovascular system, respiratory depression, and stimulation of the central nervous system.

Amantadine is another NMDA receptor antagonist that has been used in humans for the treatment of neuropathic pain and in patients with opioid tolerance. The pharmacology of amantidine has not been well established in dogs and cats and behavioral effects can be seen at high doses.

The anticonvulsant, gabapentin, has been used in humans with chronic pain syndromes.[60] The exact mechanism of action is unclear, although gabapentin is known to bind to receptors within the brain and may enhance the action of gamma-aminobutyric acid (GABA).[61] There are no controlled studies involving the use of gabapentin to treat pain in dogs and cats however there are anecdotal reports of its use in animals.[62] It appears that gabapentin may work synergistically with other drugs in producing analgesia and may inhibit the development of hyperalgesia due to injury. Gabapentin is metabolized by the liver and excreted by the kidneys. Side effects reported in humans include sleepiness, fatigue, and weight gain with long term administration.[61]

Tramadol is a centrally acting analgesic that has a low affinity for mu opioid receptors and is less potent than morphine.[63] Tramadol inhibits norepinephrine uptake and facilitates serotonin release, which contributes to its analgesic effects.[64] It has been shown

Table 9-6. Other Agents used in the Treatment of Perioperative Pain.

Drug Class	Drug	Dosage	Duration
NMDA Antagonist	Ketamine	Dog: 2 mg/kg IV, IM Cat: 2 mg/kg IV, IM	20 minutes 20 minutes
NMDA Antagonist	Amantidine	Dog: 3-5 mg/kg PO Cat: 3-5 mg/kg PO	24 hours 24 hours
Anticonvulsant	Gabapentin	Dog: 1.25-10mg/kg PO Cat: 1.25-10 mg/kg PO	24 hours 24 hours
Other	Tramadol	Dog: 5 mg/kg PO 2-4 mg/kg IV Cat: 1-2 mg/kg IV	6 hours 6 hours Unknown
Glucocorticoid	Prednisolone	Dog: 0.25-0.5 mg/kg PO Cat: 0.25-0.5 mg/kg PO	24-48 hours 24-48 hours
Tricyclic antidepressant	Amitriptyline	Dog: 1.0mg/kg PO Cat: 0.5-1.0 mg/kg PO	12-24 hours 12-24 hours
Phenothiazine	Acepromazine	Dog: 0.02-0.1 mg/kg IV, IM, SC Cat: 0.02-0.1 mg/kg IV, IM, SC	2-6 hours
Benzodiazepine	Diazepam	Dog: 0.1-0.5 mg/kg IV, IM Cat: 0.1-0.5 mg/kg IV, IM	1-3 hours 2-4 hours

that tramadol can be used safely to control pain after ovariohysterectomy and other soft tissue procedures in dogs.[65] Tramadol is metabolized by the liver and side effects include nausea and vomiting and prolonged administration can result in constipation or diarrhea.[66]

Although glucocorticoids are not analgesic drugs, their use as potent anti-inflammatory agents may contribute to treating pain associated with inflammatory conditions such as otitis externa and osteoarthritis.[68] Glucocorticoids inhibit and reduce inflammation by inhibiting phospholipase A_2 and by stabilizing cellular membranes.[68] Potential side effects of long-term glucocorticoid therapy include iatrogenic Cushing's disease, while abrupt termination of glucocorticoid administration may lead to an Addisonian crisis. Glucocorticoids also affect the gastrointestinal mucosa, which may lead to ulceration and perforation.[69] Immunosuppression and delayed wound healing may occur especially when higher doses are administered.

Tricyclic antidepressants can also play a role in pain management. Amitriptyline works in the central nervous system to block the reuptake of serotonin and norepinephrine.[70] Amitriptyline has been shown in humans to be beneficial in the treatment of neuropathic and chronic pain states by enhancing the actions of opioids.[71] There are no controlled studies using Amitryptilline in veterinary patients however it is thought that the tricyclic antidepressants would have similar analgesic effects in animals.

Finally, sedatives such as acepromazine and diazepam may be useful in potentiating or prolonging the effects of analgesic agents. If these sedatives are used, careful evaluation of the patient must continue as the central nervous system depression and sedation may mask signs of untreated pain.

Multimodal Analgesic Techniques

Systemic analgesic agents are often combined with local or regional anesthetic techniques to produce a balanced analgesic protocol that may maximize analgesic efficacy.

Local Anesthetic Techniques

Local anesthetic agents block transmission in all nerve fibers and are ideally suited for preemptive administration (Table 9-7). Local nerve block techniques are relatively easy to perform and have few complications. The benefits of performing these techniques include a significant reduction in inhaled anesthetic requirements and reduction in postoperative pain. Some of the techniques can be performed on conscious animals however most local techniques are easier to perform on sedated or anesthetized patients. The clinician should base their choice of which local anesthetic agent to use for a procedure on how quickly the local anesthetic is needed to work, the route of administration, and the expected duration of pain (Figure 9-1).

Topical local anesthetics can be used to desensitize cutaneous areas for minor, relatively noninvasive procedures. EMLA cream can be applied to the skin overlying a vessel before venepuncture, while 2% lidocaine jelly can be used to desensitize mucosal surfaces such as the urethra before catheterization.[72] If local anesthetics are used on mucosal surfaces, doses should be calculated carefully, as these drugs are readily absorbed into the systemic circulation.

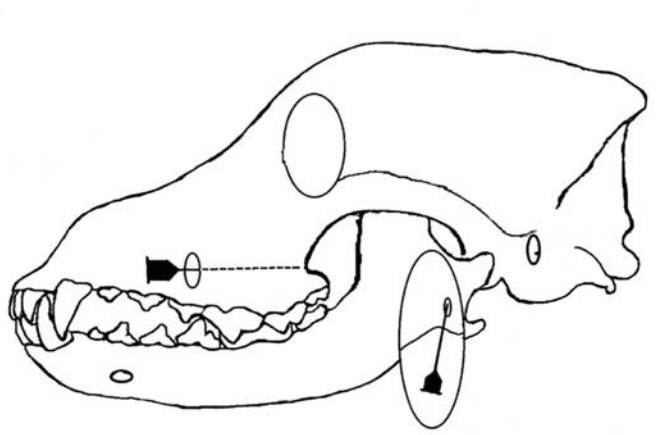


Figure 9-1. Lateral view of a dog's skull demonstrating needle placement for maxillary and mandibular alveolar nerve blocks. The mandibular foramen (oval inset) is on the medial side of the right mandible.

Most commonly, local anesthetics are infused around surgical sites allowing for procedures such as skin mass excision and repair of lacerations to be performed without general anesthesia although sedation is often required. After aseptically preparing the surgical site, local anesthetic should be infiltrated into all of the effected tissue planes. The needle is inserted into the skin and the plunger aspirated to prevent accidental intravenous injection. Total doses should be calculated carefully to avoid toxicity. If infiltration of lidocaine is being performed in a conscious patient, the lidocaine can be mixed with sodium bicarbonate (0.1 ml of 1mEq/ml $NaHCO_3$ to 0.9 ml of 2% lidocaine) to reduce the discomfort felt by the animal on injection. Infiltration of local anesthetic into more invasive surgical sites can be continued over a period of time by using a fenestrated catheter attached to a reservoir. The catheter is placed in the surgical site and the reservoir is filled with local anesthetic. The reservoir can then be set to slowly deliver the local anesthetic to the surgical site over a period of days.

Local anesthetic infiltration into a surgical incision site either before the incision is made or just prior to closure is an effective analgesic technique. Infiltration of local anesthetic along the muscle of the abdominal wall of a celiotomy incision helps to control abdominal wall pain. If the block is performed before closure, a sterile syringe, needle, and local anesthetic agent are delivered to the surgeon aseptically. The musculature and subcutaneous tissues along both sides of the incision are then injected uniformly and wound closure proceeds normally.

Animals recovering from thoracotomy may benefit from blocking the intercostal nerves prior to incisional closure and/or the instillation of local anesthetics into the pleural space.[74] If the patient has a thoracostomy tube, a local anesthetic such as 0.5% bupivacaine can be administered through the tube (1.5 mg/kg in the dog, flushing the tube with saline after administration). The animal is positioned to allow the local anesthetic solution to bathe the

incision site (incision side down) for 10 to 20 minutes after instillation. If the animal does not have a thoracostomy tube in place, the local anesthetic can be instilled by aseptically placing an over the needle catheter into the pleural space. Complications of this procedure include infection and pneumothorax.[75]

Local anesthetics can also be infused into the peritoneal cavity using a similar technique. An over the needle catheter is aseptically placed into the abdomen at the level of the umbilicus. A mixture of local anesthetic and saline (total volume 10-20 mls) is then instilled. This technique may be helpful for those patients suffering from abdominal pain. Doses are calculated carefully, remembering that local anesthetic drug uptake will occur rapidly, particularly if the peritoneum is inflamed.[76]

Epidural Technique

Analgesia and/or anesthesia caudal to the diaphragm can be achieved with an epidural injection (Figure 9-2). The technique is relatively easy to perform and does not require specialized equipment. Injections are performed with the patient chemically restrained or anesthetized because the patient must remain still during the procedure. The hanging drop technique is described below. The animal is placed in sternal recumbency with the hind limbs extending cranially.The hair overlying the lumbosacral space is clipped and the skin is aseptically prepared. Sterile gloves are worn and the lumbosacral space is identified by placing the thumb and middle finger of the non-dominant hand on the cranial edges of the wings of the ilia. The index finger of the same hand then palpates the spinal process of the seventh lumbar vertebrae. The lumbosacral space is identified as a depression caudal to the spinous process. An appropriately sized spinal needle (20-22 gauge) is then introduced on midline at an angle that is perpendicular to the skin. Once the needle has passed through the skin, the stylet is removed and a small amount of sterile saline is placed into the hub of the needle. The needle is then slowly advanced through the overlying tissues until it passes through the ligamentum flavum. Commonly, a distinctive pop is felt and the saline in the hub of the needle is drawn into the space. If the needle encounters bone before puncturing the ligamentum flavum, it is withdrawn slightly and redirected. After the needle is directed into the epidural space, the hub of the needle is observed for the presence of blood or cerebral spinal fluid. If neither is present, the epidural injection is preformed. If blood is present, the needle is withdrawn and the process repeated. If cerebral spinal fluid is flowing from the needle, a decision to inject the analgesic into the subarachnoid space must be made. If it is decided to proceed with the injection, the dose of the analgesic must be reduced by at least 50%.[77] After injection, the needle is completely withdrawn. If injecting a local anesthetic epidurally, the animal is placed with the affected side down for a period of 5 to 10 minutes.

Epidural injections can also be performed in lateral recumbency. The procedure is the same, with the area over the lumbosacral space clipped and aseptically prepared. The anatomic landmarks are identified, and the spinal needle is advanced through the skin. In this position, however, the stylet remains in place until the needle is thought to have penetrated the ligamentum flavum. Once the needle is in the epidural space, the stylet is removed and the hub of the needle is observed for blood or cerebrospinal fluid.

A test injection of a small amount of air can be performed to confirm the needle placement. If the needle is correctly placed, there should be little to no resistance to injection of air.[78] The injection of drug is performed, the needle is withdrawn and the animal is placed with the affected area down if local anesthetic drug is administered. It should be noted that, in cats, the spinal cord usually ends at the first sacral vertebra making it more likely to puncture the dura during needle placement and obtain cerebrospinal fluid during epidural injection.[77]

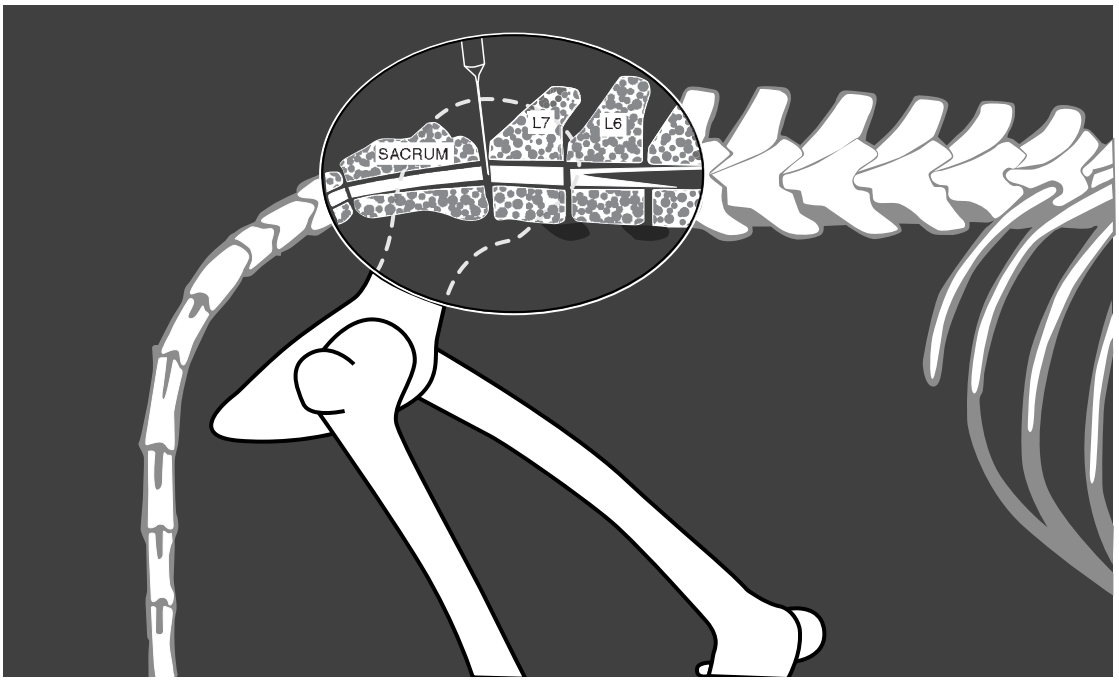


Figure 9-2. Lumbosacral epidural injection.

Table 9-7. Selected Local Anesthetic Techniques

Block	Area Desensitized	Materials
Infraorbital nerve block[91]	Bone, soft tissue, and teeth rostral to maxillary first molar including hard and soft palate on side injected	Tuberculin syringe; 27 or 25 gauge, 3/4 to 1 inch needle Dog: 0.1 to 0.5 ml of 0.5% bupivacaine Cat: 0.1 to 0.3 ml of 0.5% bupivacaine
Mandibular nerve block[91]	Bone, teeth, soft tissue, and tongue on infiltrated side	Tuberculin syringe; 27 or 25 gauge, 3/4 to 1 inch needle Dog: 0.1 to 0.5 ml of 0.5% bupivacaine Cat: 0.1 to 0.3 ml of bupivacaine
Mental nerve block[91]	Bone, teeth, and soft tissue rostral to the second premolar on the injected side	Tuberculin syringe; 27 or 25 gauge, 3/4 to 1 inch needle Dog: 0.1 to 0.5 ml of 0.5% bupivacaine Cat: 0.1 to 0.3 ml of 0.5% bupivacaine
Auriculotemporal and great auricular nerve blocks[92]	External and internal ear	Syringe; 22 gauge, 1 inch needle
Radial, Ulnar, Median, and Musculocutaneous nerve block (RUMM)[93]	Anesthesia distal to the elbow joint	Two 20 or 22 gauge 1 inch needles Syringe
Radial, Ulnar, and Median nerve block (RUM)[93]	Anesthesia to distal forelimb	Three 22 or 25 gauge, 3/4 to 1 inch needles Syringe
Intravenous Regional (IVRA) Analgesia/Anesthesia[94]	Anesthesia of limb distal to tourniquet	Tourniquet, Esmarch bandage, intravenous catheter, syringe, 20 gauge 1 inch needle
Intercostal nerve block[94]	Tissues of thorax on side injected	22 gauge 1 inch needle Syringe
Intraarticular[94]	Joint infused	22 - 25 gauge, 3/4 to 1 inch needle Syringe

Technique	Notes
Palpate infraorbital foramen dorsal to upper third premolar. Needle can be advanced into the foramen in larger dogs.	Complications include damage to nerve and soft tissue (rare), Cardiotoxicity due to inadvertent intravenous administration of bupivacaine. Calculate doses carefully. Aspirate before injection.
Palpate mandibular foramen intraorally–lingual surface of mandible, 2/3 of distance from last molar to angular process of the mandible. Insert needle intraorally near foramen.	Complications include damage to nerve and soft tissue (rare). Cardiotoxicity due to inadvertent intravenous administration of bupivacaine. Calculate doses carefully. Aspirate before injection.
Dog: Palpate the middle mental foramen. Insert needle into the submucosa in a rostral to caudal direction. Injection should be ventral to the rostral root of second premolar. Cat: Place needle in submucosa caudal and ventral to lower canine	Complications include damage to nerve and soft tissue (rare), Cardiotoxicity due to inadvertent intravenous administration of bupivacaine. Calculate doses carefully. Aspirate before injection.
Auriculotemporal nerve is located caudal and dorsal to masseter muscle and rostral to the ventral ear canal. Great auricular nerve is ventral to wing of atlas and caudal to vertical ear canal.	Preoperative performance of block may reduce inhalant requirements during total ear canal ablation and may improve recovery postoperatively
Palpate the lateral aspect o the epicondyle of the humerus. Move proximally and palpate the radial nerve between the brachialis and triceps muscles. Palpate the medial aspect of the epicondyle of the humerus. Move proximally and palpate the median, ulnar, and musculocutaneous nerves between the triceps and biceps muscles. The brachial artery is adjacent to these nerves and can be felt pulsating.	Useful for patients with radial, ulnar, and/or metacarpal fractures. Due to proximity of the nerves to the brachial artery and vein, syringes must be aspirated before injection.
Three injection sites: 1. Medial to the accessory carpal pad 2. Lateral and slightly proximal to accessory carpal pad 3. Dorso-medial aspect of proximal carpus	Useful for cats undergoing onychectomy. Calculate dose of local anesthetic carefully.
Place intravenous catheter in accessible vein. Desanguinate the limb with Esmarch bandage. Place tourniquet immediately proximal to bandage. Remove Esmarch bandage. Inject lidocaine through intravenous catheter. Slowly remove tourniquet within 90 minutes.	**Do not use bupivacaine due to cardiotoxicity when given IV.** Ischemic injury can occur to limb if tourniquet is not released within 90 minutes.
Percutaneous injection: Aseptically prepare skin over intercostal nerves. Introduce needle caudal to each rib near the intervertebral foramen. Advance needle to rib, then withdraw slightly into the tissues caudal to rib. Aspirate, then inject. Intraoperative injection: Nerves can be identified and injected from the pleural side of thorax.	Due to overlapping innervation, at least three consecutive intercostal nerves must be blocked. Commonly, at least two intercostal nerves cranial and caudal to the affected area are blocked, in addition to the site of incision. If performed percutaneously, complications include pnuemothorax, intrathoracic injection, and pulmonary laceration
Anatomic landmarks depend on joint being injected. Aseptically prepare skin over joint. Place needle into joint space. Remove joint fluid if needed. Inject enough local anesthetic to result in slight distension in the joint capsule	Can use local anesthetics and/or morphine. Complications include infection if not performed aseptically.

If repeated injections or continuous administration of epidural analgesics is desired, placement of an epidural catheter should be considered. A Tuohy or Hustead needle is required to place an epidural catheter. These needles have a curve at the tip that aid in directing the catheter cranially when placed into the epidural space. There are a variety of epidural catheters available that are characterized by their size and material used to construct the catheter. Epidural catheters made of nylon or those with a wire spiral within the wall of the catheter are resistant to kinking, while others have a wire guide in the lumen of the catheter and are more flexible. Polyamide catheters are softer, more flexible and kink more easily.[77] Prior to beginning the procedure, the clinician measures the animal to determine how much of the catheter needs to be inserted, making sure to account for the length of the Tuohy needle used for catheter placement. For a hind limb procedure, the catheter may only need to be inserted to the level of the fifth or sixth lumbar vertebrae, abdominal procedures require the catheter to be advanced to the second or third lumbar vertebrae, while for a thoracotomy the catheter should be advanced to the fifth or sixth thoracic vertebrae.

The animal is clipped and prepped using the anatomic landmarks for a epidural injection. A keyhole drape is placed over the lumbosacral space and the landmarks are palpated with sterile gloved hands. A small stab incision is made in the skin overlying the lumbosacral space using a sterile #11 blade to facilitate the passing of the Tuohy needle. The Tuohy needle is placed into the stab incision, and advanced through the overlying tissues until the ligamentum flavum is penetrated. Needle placement in the epidural space can be confirmed with a test injection of a small amount of air. The epidural catheter is then passed through the needle to the desired spinal segment. If the catheter has been advanced beyond the end of the Tuohy needle, no attempt should be made to withdraw it through the needle, as the catheter may be sheered off by the sharp edge of the needle. Once the catheter is in place, the wire stylet is removed if present, and an adapter is attached to the end of the catheter. A bacterial filter and injection cap primed with saline or analgesic are then connected to the catheter. The catheter should then be secured to skin at its exit site. A radiograph can be taken to confirm the placement of the catheter. Additionally, catheter placement can be guided by fluoroscopy, if available. If cleanliness and sterility are maintained, epidural catheters can remain in place for days to weeks.[79]

Complications of both single epidural injection and epidural catheter placement include infection, cranial spread of local anesthetic resulting in motor blockade of respiratory muscles, hypotension when using local anesthetics, and urine retention. Muscle spasms of the rear legs, pruritis, epidural hemorrhage, and spinal cord or nerve root trauma have also occurred. Contraindications for epidural injection include pyoderma at the site of injection, coagulopathy, and sepsis.[77] Drugs commonly used in epidural injections and infusions are listed in Table 9-8. *It is emphasized that preservative free formulations of these drugs should be used for epidural injection.*

Transdermal Analgesic Administration

Transdermal administration of analgesics allows for delivery and maintenance of sustained concentrations of a drug avoiding the peaks and troughs associated with intermittent parenteral administration. Fentanyl and lidocaine are available in transdermal formulations and their use has been investigated in veterinary clinical patients.[80-81]

Table 9-8. Drugs used for Epidural Injections

Drug	Dose	Duration
Morphine	0.1 mg/kg	20-60 minute onset
	0.0125 mg/kg/hour for constant rate infusion	16-24 hour duration
Buprenorphine	5-10 mcg/kg	45-60 minute onset
	1.25 mcg/kg/hour for constant rate infusion	8-12 hour duration
		May result in less urine retention
2.0% Lidocaine	4 mg/kg	5 minute onset
		45-90 minute duration
0.5% Bupivacaine	1 mg/kg	20 minute onset
		120-360 minute duration
0.125% Bupivacaine	0.1-0.2 mg/kg/hour for constant rate infusion	Note: Lower concentration may lessen degree of motor blockade
2.0 % Mepivacaine	4 mg/kg	5 minute onset
		60-90 minute duration
0.5% Ropivacaine	1 mg/kg	15 minute onset
		90-420 minute duration
Morphine and Bupivacaine	0.1 mg/kg of morphine and 1mg/kg of bupivacaine.	20 minute onset
	6 ml maximum volume	12-24 hour duration

To apply a fentanyl patch, the hair of the animal is clipped and any gross debris is removed from the surface of the skin with water or saline. Alcohol should not be used as it will alter the lipids present on the epidermis, which will affect drug absorption. Once the area is completely dry, the patch is placed firmly onto the skin and held in place for one to two minutes. The patch should be placed in an area that will minimize patient removal and/or possible oral ingestion, as overdose may occur. Commonly, patches are placed on the dorsum of the neck or lateral thorax. A light bandage can then be placed over the patch. Transdermal patches should not be placed in direct contact with heating pads, as increases in cutaneous blood flow will increase drug absorption.[82]

Fentanyl patches are available in 25, 50, 75, and 100 mcg/hour concentrations. Clinicians should select a patch that will deliver a dose of 3-5 mcg/kg/hour in their patient. Once the patch has been placed, steady-state plasma concentrations are obtained in 18 to 24 hours in the dog while in the cat, 6 to 12 hours is required for steady plasma concentrations to be reached. Parenteral administration of opioids should be provided to animals when indicated to provide analgesia during the lag time until effective plasma concentrations are reached. The patch is designed to deliver fentanyl over a period of 72 hours, but they may be effective for longer periods. Studies have shown that there is significant inter and intra-individual variation in plasma fentanyl concentrations after patch application.[83] For this reason, patients should be carefully monitored for signs of pain and/or side effects.

Complications associated with the use of fentanyl patches include respiratory depression, sedation, inadequate analgesia, skin irritation, failure of the patch to adhere to the skin, and human abuse. In cats, mydriasis, agitation, and dysphoria may be observed.[83] If significant respiratory depression is observed, the patch should be removed and an opioid antagonist administered. Once a patch is removed, plasma levels decrease over a period of twelve hours. Patches should be disposed of carefully in the same manner as other controlled substances.

Lidocaine patches have been approved for use in humans for the treatment of peripheral neuropathies such as post-herpetic neuralgia and have generated interest in both human and veterinary pain management.[84] It is thought that application of a lidocaine patch produces local tissue concentrations that are high enough to produce local analgesia, without complete sensory block, for periods up to 24 hours.[85] The lidocaine patch is a 10 by 14 cm patch that contains 700 mg of 5% lidocaine. In human studies, once the patch is applied, up to 35 mg of lidocaine is absorbed topically, producing analgesia within 30 minutes,[85] with a half-life of 6-8 hours.[86] The amount of lidocaine absorbed is directly proportional to the area of skin that is covered and the length of time the patch is in contact with the area.[85] In contrast to transdermal fentanyl, transdermally administered lidocaine has a very slow rate of systemic absorption, which makes systemic lidocaine toxicity unlikely.[85] The pharmacokinetics of the lidocaine patch in dogs and cats are similar to those observed in human studies, showing significant tissue levels at the site of patch application, with peak plasma concentrations taking 10-36 hours to be achieved due to slow systemic absorption.[87,88]

To apply a lidocaine patch, the hair over the area should be clipped and the skin cleaned if needed. It is believed that the lidocaine patch acts by local nervous tissue penetration and not systemically like the fentanyl patch, thus the lidocaine patch must be placed close to or directly over the painful area. Unlike the fentanyl patch, the lidocaine patch can be cut to fit the patient or site of application without altering drug delivery. In surgical patients, the patch can be cut to the length of the incision and cut pieces should be placed on either side of the incision. Unused, cut portions of the patch can be saved for use at a later time. Seemingly, lidocaine patches can be left in place for three to five days with minimal side effects.[88] Side effects of lidocaine patches in humans include skin irritation erythema, hives, and edema associated with the lidocaine patch. These complications typically resolved within hours of patch removal.[89] In dogs, skin irritation/inflammation has been noted after patches have been in place for 72 hours.[88] Although systemic toxicity is unlikely, animals should be monitored for signs of overdose that include bradycardia, hypotension, facial twitching, and seizures.

Fentanyl and lidocaine patches are useful as analgesic adjuncts but should not be used as the sole method of providing analgesia to animals with moderate to severe pain.

Constant Rate Drug Infusions (CRI)

Constant rate drug infusions administered intravenously through an indwelling catheter are used to manage pain effectively while limiting the peaks and troughs of intermittent analgesic administration. This technique has been found to be particularly effective in animals whose pain has been refractory to intermittent administration of analgesics. Typically, a loading dose of the analgesic is administered parenterally followed by a constant rate infusion of the analgesic. Analgesics may be delivered using a syringe pump, or added to the patient's maintenance fluids. An example of the calculations used for constant rate infusions can be found in Table 9-9. Opioids, local anesthetics, and analgesic adjunct drugs have been used in constant rate infusions to treat pain in animals. Appropriate doses for these drugs are found in Table 9-10.

Table 9-9. Calculations for constant Rate Infusions.

You are presented with a 15 kg dog. You would like to start a lidocaine constant rate infusion.

1. Calculate loading dose
   - 15 kg x 2 mg/kg = 30 mg or 1.5 ml of 2% lidocaine. Administer over 20 minutes
2. Calculate maintenance fluid rate
   - (15 kg x 60 ml/kg/24 hours)/24 hours = 37.5 ml/hour
   - Assuming that you have a 1 L bag of fluids, this bag will last for 26.6 hours
3. Calculate how much lidocaine you will need
   - 50 mcg/kg/min = 3mg/kg/hour
   - 3mg/kg/hour x 15kg x 26.6 hours=1197 mg or 59.85 mls of 2% lidocaine
4. Prepare the fluid for administration by first removing 59.85 mls from the fluid bag. Then add the lidocaine to achieve the exact concentration desired.

Table 9-10. Drugs used as constant Rate Infusions for the treatment of Peri-operative Pain.

Drug	Dosage	Notes
Morphine	Dog: Loading dose: 0.1-0.25 mg/kg IV (slowly) CRI: 0.1-0.5 mg/kg/hour IV Cat: Loading dose: 0.05-0.1 mg/kg IV (slowly) CRI: 0.05-0.2 mg/kg/hour IV	Histamine release occurs even at low doses,[31] 48% reduction in isoflurane requirement of dogs[95] Morphine is commonly combined with lidocaine or lidocaine and ketamine (MLK). MLK caused a 45% reduction in the isoflurane requirement of dogs
Fentanyl	Dog: Loading dose: 2-5 mcg/kg IV CRI: 2-5 mcg/kg/hour IV for analgesia CRI: 10-45 mcg/kg/hour IV for surgical analgesia Cat: Loading dose: 1-3 mcg/kg IV CRI: 1-4 mcg/kg/hour IV for analgesia CRI: 10-30 mcg/kg/hour IV for surgical analgesia	54-66% reduction in isoflurane requirement of dogs
Butorphanol	Dog: Loading dose: 0.2 mg/kg IV CRI: 0.1-0.2 mg/kg/hour IV Cat: Loading dose: 0.2 mg/kg IV CRI: 0.1-0.2 mg/kg/hour IV	
Ketamine	Dog: Loading dose: 0.5-2.0 mg/kg IV CRI: 0.5 mg/kg/hour IV during surgery CRI: 0.1 mg/kg/hour IV postoperatively Cat: Loading dose: 0.5 mg/kg IV CRI: 0.1-0.5 mg/kg/hour IV	25% reduction in isoflurane requirement of dogs[95]
Lidocaine	Dog: Loading dose: 2 mg/kg IV CRI: 50-100 mcg/kg/min IV Cat: Loading dose: 0.5-1.0 mg/kg IV CRI: 10 mcg/kg/min IV	19% reduction in isoflurane requirement of dogs[46]
Dexmedetomidine	Dog: Loading dose: 0.5 mcg/kg IV CRI: 0.5-1.5 mcg/kg/hour IV	Significant cardiopulmonary changes occur even with microdoses[49]

Analgesic Protocols

The clinician should be familiar with various analgesic drugs and drug delivery techniques available for administration of these agents. Use of combinations of drugs and techniques in a well-planned multimodal and balanced analgesic protocol will provide the safest and most effective clinical control of pain. The analgesic regimens described for the canine in Table 9-11 are examples of multimodal analgesic plans. All analgesic protocols should be designed to meet a specific patient's needs and potentially modified in response to regular and frequent pain assessments.

References

1. Muir WW: *In* Gaynor JS and Muir WW,ed.: Handbook of veterinary pain management. St. Louis: Mosby, Inc., 2002, p 46.

2. Lamont LA, Tranquilli WJ and Grim KA: Physiology of pain, *Veterinary Clinics of North America: Small Animal Practice* 4: 703 2000.

3. Grubb BD: Peripheral and central mechanisms of pain, *Br J Anaesth* 1: 8, 1998.

4. Wright A: Recent concepts in the neurophysiology of pain, *Man Ther* 4: 196, 1999.

Table 9-11. Examples of Analgesic Protocols

Procedure	Preoperative analgesics	Intraoperative analgesics	Postoperative analgesics
Canine exploratory laparotomy for small intestinal resection and anastomosis	• 0.5 mg/kg morphine IM-20 minutes before anesthetic induction	• Additional 0.25 mg/kg morphine IV as needed • 2 mg/kg lidocaine IV over 20 minutes followed by 50 mcg/kg/min as constant rate infusion	• 0.5 mg/kg morphine IM every 4 hours for first 24 hours • Continue lidocaine CRI for first 24 hours
Lateral thoracotomy	• 0.1 mg/kg oxymorphone IM-20 minutes before anesthetic induction	• Morphine (0.1 mg/kg/hr) and lidocaine (50 mg/kg/hr) constant rate infusion • Intercostal nerve blocks with 1 mg/kg of bupivacaine prior to closure	• Continue morphine and lidocaine CRI for 24 hours • 0.5 mg/kg morphine IM if needed for rescue analgesia • Instill 1 mg/kg of bupivacaine (diluted with saline to volume of 10-20 ml) into the thorax via thoracostomy tube every 6 hours
Total ear canal ablation	• 0.1 mg/kg oxymorphone IM-20 minutes before anesthetic induction	• Auriculotemporal and great auricular nerve blocks with 2 mg/kg bupivacaine during sterile prep • 5 mcg/kg fentanyl loading dose IV followed by 5 mcg/kg/hour constant rate infusion	• Continue fentanyl constant rate infusion for first 24 hours • 4 mg/kg carprofen SC at recovery
Radius/Ulna fracture repair	• 0.1 mg/kg hydromorphone IM-20 minutes before anesthetic induction	• RUMM block with 2 mg/kg bupivacaine during surgical prep • 0.05 mg/kg hydromorphone IV as needed	• 0.1 mg/kg hydromorphone IM every 4 hours for first 24 hours • 2 mg/kg ketoprofen SC at recovery
Dorsal hemilaminectomy	• 0.5 mg/kg morphine IM-20 minutes before anesthetic induction	• 0.25 mg/kg morphine IV as needed • 0.1 mg/kg preservative free morphine placed on the spinal cord • Incisional block with 2 mg/kg bupivacaine prior to closure	• 0.5 mg/kg morphine IM every 4 hours • If pain is not easily controlled, consider an IV morphine (5 mcg/kg/min), lidocaine (50 mcg/kg/min), ketamine (2 mcg/kg/min) constant rate infusion
Stifle arthroscopy	• 0.5 mg/kg morphine IM-20 minutes before anesthetic induction	• Epidural injection with 0.1 mg/kg preservative free morphine • Intra-articular injection with 2 mg/kg bupivacaine	• 0.5 mg/kg morphine IM every 4 hours • 4 mg/kg carprofen SC at recovery

5. Hellyer PW: *In* Gaynor JS and Muir WW,ed.: Handbook of veterinary pain management. St. Louis: Mosby, Inc, 2002, p 82.

6. Conzemius MG, Hill CM, Sammarco JL, *et al.*: Correlation between subjective and objective measures used to determine severity of postoperative pain in dogs, *J Am Vet Med Assoc* 11: 1619, 1997.

7. Hudson JT, Slater MR, Taylor L, *et al.*: Assessing repeatability and validity of a visual analogue scale questionnaire for use in assessing pain and lameness in dogs, *Am J Vet Res* 12: 1634, 2004.

8. Holton LL, Scott EM, Nolan AM, *et al.*: Comparison of three methods used for assessment of pain in dogs, *J Am Vet Med Assoc* 1: 61, 1998.

9. Firth AM and Haldane SL: Development of a scale to evaluate postoperative pain in dogs, *J Am Vet Med Assoc* 5: 651, 1999.

10. Morton CM, Reid J, Scott EM, *et al.*: Application of a scaling model to establish and validate an interval level pain scale for assessment of acute pain in dogs, *Am J Vet Res* 12: 2154, 2005.

11. Dobromylskyj P, Flecknell PA, Lascelles BD, *et al.*: *In* Flecknell P and Waterman-Pearson A,ed.: Pain management in animals. London: W. B. Saunders, 2000, p 53.

12. Vaisanen MA, Tuomikoski SK and Vainio OM: Behavioral alterations and severity of pain in cats recovering at home following elective ovariohysterectomy or castration, *J Am Vet Med Assoc* 2: 236, 2007.

13. Troncy E, Junot S, Keroack S, *et al.*: Results of preemptive epidural administration of morphine with or without bupivacaine in dogs and cats undergoing surgery: 265 cases (1997-1999), *J Am Vet Med Assoc* 5: 666, 2002.

14. Katz J: Pre-emptive analgesia: Evidence, current status and future directions, *Eur J Anaesthesiol Suppl* 8, 1995.

15. Katz J: Pre-emptive analgesia: Importance of timing, *Can J Anaesth* 2: 105, 2001.

16. Livingston A: Mechanism of action of nonsteroidal anti-inflammatory drugs, *Vet Clin North Am Small Anim Pract* 4: 773, 2000.

17. Vanegas H and Schaible HG: Prostaglandins and cyclooxygenases (correction of cycloxygenases) in the spinal cord, *Prog Neurobiol* 4: 327, 2001.

18. Nolan AM: *In* Flecknell P and Waterman-Pearson A,ed.: Pain management in animals. London: W. B. Saunders, 2000, p 21.

19. Cayen MN, Kraml M, Ferdinandi ES, *et al.*: The metabolic disposition of etodolac in rats, dogs, and man, *Drug Metab Rev* 2: 339, 1981.

20. Luna SP, Basilio AC, Steagall PV, *et al.*: Evaluation of adverse effects of long-term oral administration of carprofen, etodolac, flunixin meglumine, ketoprofen, and meloxicam in dogs, *Am J Vet Res* 3: 258, 2007.

21. Elwood C, Boswood A, Simpson K, *et al.*: Renal failure after flunixin meglumine administration, *Vet Rec* 26: 582, 1992.

22. MacPhail CM, Lappin MR, Meyer DJ, *et al.*: Hepatocellular toxicosis associated with administration of carprofen in 21 dogs, *J Am Vet Med Assoc* 12: 1895, 1998.

23. Gray AC, Coupar IM and White PJ: Comparison of opioid receptor distributions in the rat central nervous system, *Life Sci* 7: 674, 2006.

24. Gray AC, Coupar IM and White PJ: Comparison of opioid receptor distributions in the rat ileum, *Life Sci* 14: 1610, 2006.

25. Simonds WF: The molecular basis of opioid receptor function, *Endocr Rev* 2: 200, 1988.

26. Atcheson R and Lambert DG: Update on opioid receptors, *Br J Anaesth* 2: 132, 1994.

27. Garrett ER and Chandran VR: Pharmacokinetics of morphine and its surrogates. X: Analyses and pharmacokinetics of buprenorphine in dogs, *Biopharm Drug Dispos* 4: 311, 1990.

28. Garner HR, Burke TF, Lawhorn CD, *et al.*: Butorphanol-mediated antinociception in mice: Partial agonist effects and mu receptor involvement, *J Pharmacol Exp Ther* 3: 1253, 1997.

29. Florez J, McCarthy LE and Borison HL: A comparative study in the cat of the respiratory effects of morphine injected intravenously and into the cerebrospinal fluid, *J Pharmacol Exp Ther* 2: 448, 1968.

30. Urthaler F, Isobe JH and James TN: Direct and vagally mediated chronotropic effects of morphine studied by selective perfusion of the sinus node of awake dogs, *Chest* 2: 222, 1975.

31. Guedes AG, Rude EP and Rider MA: Evaluation of histamine release during constant rate infusion of morphine in dogs, *Vet Anaesth Analg* 1: 28, 2006.

32. Ennis M, Schneider C, Nehring E, *et al.*: Histamine release induced by opioid analgesics: A comparative study using porcine mast cells, *Agents Actions* 1-2: 20, 1991.

33. Kromer W: Endogenous and exogenous opioids in the control of gastrointestinal motility and secretion, *Pharmacol Rev* 2: 121, 1988.

34. Gupta YK, Bhandari P, Chugh A, *et al.*: Role of endogenous opioids and histamine in morphine induced emesis, *Indian J Exp Biol* 1: 52, 1989.

35. Yokohata K, Kimura H, Ogawa Y, *et al.*: Biliary motility. Changes in detailed characteristics correlated to duodenal migrating motor complex and effects of morphine and motilin in dogs, *Dig Dis Sci* 6: 1294, 1994.

36. Gross JB, Comfort MW, Mathieson DR, *et al.*: Elevated values for serum amylase and lipase following the administration of opiates: A preliminary report, *Proc Staff Meet Mayo Clin* 5: 81, 1951.

37. French ED, Vasquez SA and George R: Behavioral changes produced in the cat by acute and chronic morphine injection and naloxone precipitated withdrawal, *Eur J Pharmacol* 4: 387, 1979.

38. Butterworth JFt and Strichartz GR: Molecular mechanisms of local anesthesia: A review, *Anesthesiology* 4: 711, 1990.

39. Liu PL, Feldman HS, Giasi R, *et al.*: Comparative cns toxicity of lidocaine, etidocaine, bupivacaine, and tetracaine in awake dogs following rapid intravenous administration, *Anesth Analg* 4: 375, 1983.

40. Moller RA and Covino BG: Cardiac electrophysiologic effects of lidocaine and bupivacaine, *Anesth Analg* 2: 107, 1988.

41. Lynch C, 3rd: Depression of myocardial contractility in vitro by bupivacaine, etidocaine, and lidocaine, *Anesth Analg* 6: 551, 1986.

42. Liu P, Feldman HS, Covino BM, *et al.*: Acute cardiovascular toxicity of intravenous amide local anesthetics in anesthetized ventilated dogs, *Anesth Analg* 4: 317, 1982.

43. Davis JA, Greenfield RE and Brewer TG: Benzocaine-induced methemoglobinemia attributed to topical application of the anesthetic in several laboratory animal species, *Am J Vet Res* 8: 1322, 1993.

44. Vasseur PB, Paul HA, Dybdal N, *et al.*: Effects of local anesthetics on healing of abdominal wounds in rabbits, *Am J Vet Res* 11: 2385, 1984.

45. Kona-Boun JJ, Cuvelliez S and Troncy E: Evaluation of epidural administration of morphine or morphine and bupivacaine for postoperative analgesia after premedication with an opioid analgesic and orthopedic surgery in dogs, *J Am Vet Med Assoc* 7: 1103, 2006.

46. Valverde A, Doherty TJ, Hernandez J, *et al.*: Effect of lidocaine on the minimum alveolar concentration of isoflurane in dogs, *Vet Anaesth Analg* 4: 264, 2004.

47. Aantaa R, Marjamaki A and Scheinin M: Molecular pharmacology of alpha 2-adrenoceptor subtypes, *Ann Med* 4: 439, 1995.

48. Lemke KA: Perioperative use of selective alpha-2 agonists and antagonists in small animals, *Can Vet J* 6: 475, 2004.

49. Pypendop BH and Verstegen JP: Hemodynamic effects of medetomidine in the dog: A dose titration study, *Vet Surg* 6: 612, 1998.

50. Klide AM, Calderwood HW and Soma LR: Cardiopulmonary effects of xylazine in dogs, *Am J Vet Res* 7: 931, 1975.

51. Vaha-Vahe T: Clinical evaluation of medetomidine, a novel sedative and analgesic drug for dogs and cats, *Acta Vet Scand* 3: 267, 1989.

52. Nakamura K, Hara S and Tomizawa N: The effects of medetomidine and xylazine on gastrointestinal motility and gastrin release in the dog, *J Vet Pharmacol Ther* 4: 290, 1997.

53. Burton S, Lemke KA, Ihle SL, et al.: Effects of medetomidine on serum osmolality; urine volume, osmolality and ph; free water clearance; and fractional clearance of sodium, chloride, potassium, and glucose in dogs, *Am J Vet Res* 6: 756, 1998.

54. Burton SA, Lemke KA, Ihle SL, *et al.*: Effects of medetomidine on serum insulin and plasma glucose concentrations in clinically normal dogs, *Am J Vet Res* 12: 1440, 1997.

55. Cullen LK: Medetomidine sedation in dogs and cats: A review of its pharmacology, antagonism and dose, *Br Vet J* 5: 519, 1996.

56. Felsby S, Nielsen J, Arendt-Nielsen L, *et al.*: Nmda receptor blockade in chronic neuropathic pain: A comparison of ketamine and magnesium chloride, *Pain* 2: 283, 1996.

57. Hamilton SM, Johnston SA and Broadstone RV: Evaluation of analgesia provided by the administration of epidural ketamine in dogs with a chemically induced synovitis, *Vet Anaesth Analg* 1: 30, 2005.

58. Wagner AE, Walton JA, Hellyer PW, *et al.*: Use of low doses of ketamine administered by constant rate infusion as an adjunct for postoperative analgesia in dogs, *J Am Vet Med Assoc* 1: 72, 2002.

59. Snijdelaar DG, Koren G and Katz J: Effects of perioperative oral amantadine on postoperative pain and morphine consumption in patients after radical prostatectomy: Results of a preliminary study, *Anesthesiology* 1: 134, 2004.

60. Gilron I: Gabapentin and pregabalin for chronic neuropathic and early postsurgical pain: Current evidence and future directions, *Curr Opin Anaesthesiol* 5: 456, 2007.

61. Stoelting RK: 30 *In* Stoelting RK,ed.: Pharmacology and physiology in anesthetic practice. Philadelphia: Lippincott Williams & Wilkins, 1999, p 506.

62. Davis JL, Posner LP and Elce Y: Gabapentin for the treatment of neuropathic pain in a pregnant horse, *J Am Vet Med Assoc* 5: 755, 2007.

63. Eggers KA and Power I: Tramadol, *Br J Anaesth* 3: 247, 1995.

64. Ide S, Minami M, Ishihara K, et al.: Mu opioid receptor-dependent and independent components in effects of tramadol, *Neuropharmacology* 3: 651, 2006.

65. Mastrocinque S and Fantoni DT: A comparison of preoperative tramadol and morphine for the control of early postoperative pain in canine ovariohysterectomy, *Vet Anaesth Analg* 4: 220, 2003.

66. KuKanich B and Papich MG: Pharmacokinetics of tramadol and the metabolite o-desmethyltramadol in dogs, J Vet Pharmacol Ther 4: 239, 2004.

67. Sparkes AH, Heiene R, Lascelles BD, *et al.*: ISFM and AAFP consensus guidelines: long-term use of NSAIDS in cats, *J Feline Med Surg* 12: 521, 2010.

68. Johnston SA and Fox SM: Mechanisms of action of anti-inflammatory medications used for the treatment of osteoarthritis, *J Am Vet Med Assoc* 10: 1486, 1997.

69. Hanson SM, Bostwick DR, Twedt DC, *et al.*: Clinical evaluation of cimetidine, sucralfate, and misoprostol for prevention of gastrointestinal tract bleeding in dogs undergoing spinal surgery, *Am J Vet Res* 11: 1320, 1997.

70. Bryson HM and Wilde MI: Amitriptyline. A review of its pharmacological properties and therapeutic use in chronic pain states, *Drugs Aging* 6: 459, 1996.

71. Tura B and Tura SM: The analgesic effect of tricyclic antidepressants, *Brain Res* 1-2: 19, 1990.

72. Siderias J, Guadio F and Singer AJ: Comparison of topical anesthetics and lubricants prior to urethral catheterization in males: A randomized controlled trial, *Acad Emerg Med* 6: 703, 2004.

73. Radlinsky MG, Mason DE, Roush JK, *et al.*: Use of a continuous, local infusion of bupivacaine for postoperative analgesia in dogs undergoing total ear canal ablation, *J Am Vet Med Assoc* 3: 414, 2005.

74. Conzemius MG, Brockman DJ, King LG, *et al.*: Analgesia in dogs after intercostal thoracotomy: A clinical trial comparing intravenous buprenorphine and interpleural bupivacaine, *Vet Surg* 4: 291, 1994.

75. Tattersall JA and Welsh E: Factors influencing the short-term outcome following thoracic surgery in 98 dogs, *J Small Anim Pract* 12: 715, 2006.

76. Wilson DV, Barnes KS and Hauptman JG: Pharmacokinetics of combined intraperitoneal and incisional lidocaine in the dog following ovariohysterectomy, *J Vet Pharmacol Ther* 2: 105, 2004.

77. Wetmore LA and Glowaski MM: Epidural analgesia in veterinary critical care, *Clin Tech Small Anim Pract* 3: 177, 2000.

78. Roelants F, Veyckemans F, Van Obbergh L, *et al.*: Loss of resistance to saline with a bubble of air to identify the epidural space in infants and children: A prospective study, *Anesth Analg* 1: 59, 2000.

79. Ruppen W, Derry S, McQuay HJ, *et al.*: Infection rates associated with epidural indwelling catheters for seven days or longer: Systematic review and meta-analysis, *BMC Palliat Care* 3, 2007.

80. Weil AB, Ko J and Inoue T: The use of lidocaine patches, *Compend Contin Educ Pract Vet* 4: 208, 2007.

81. Hofmeister EH and Egger CM: Transdermal fentanyl patches in small animals, *J Am Anim Hosp Assoc* 6: 468, 2004.

82. Shomaker TS, Zhang J and Ashburn MA: Assessing the impact of heat on the systemic delivery of fentanyl through the transdermal fentanyl delivery system, *Pain Med* 3: 225, 2000.

83. Egger CM, Duke T, Archer J, *et al.*: Comparison of plasma fentanyl concentrations by using three transdermal fentanyl patch sizes in dogs, *Vet Surg* 2: 159, 1998.

84. Rowbotham MC, Davies PS, Verkempinck C, *et al.*: Lidocaine patch: Double-blind controlled study of a new treatment method for post-herpetic neuralgia, *Pain* 1: 39, 1996.

85. Gammaitoni AR, Alvarez NA and Galer BS: Safety and tolerability of the lidocaine patch 5%, a targeted peripheral analgesic: A review of the literature, *J Clin Pharmacol* 2: 111, 2003.

86. Gammaitoni AR, Galer BS, Onawola R, *et al.*: Lidocaine patch 5% and its positive impact on pain qualities in osteoarthritis: Results of a pilot 2-week, open-label study using the neuropathic pain scale, *Curr Med Res Opin* S13, 2004.

87. Weiland L, Croubels S, Baert K, *et al.*: Pharmacokinetics of a lidocaine patch 5% in dogs, *J Vet Med A Physiol Pathol Clin Med* 1: 34, 2006.

88. Ko J, Weil A, Maxwell L, *et al.*: Plasma concentrations of lidocaine in dogs following lidocaine patch application, *J Am Anim Hosp Assoc* 5: 280, 2007.

89. Gammaitoni AR, Alvarez NA and Galer BS: Pharmacokinetics and safety of continuously applied lidocaine patches 5%, *Am J Health Syst Pharm* 22: 2215, 2002.

90. Hellyer PW and Gaynor JS: How I treat acute postsurgical pain in dogs and cats, *Compend Contin Educ Pract Vet* 140 1998.

91. Beckman B and Legendre L: Regional nerve blocks for oral surgery in companion animals, *Compend Contin Educ Pract Vet* 6: 439 2002.

92. Buback JL, Boothe HW, Carroll GL, *et al.*: Comparison of three methods for relief of pain after ear canal ablation in dogs, *Vet Surg* 5: 380, 1996.

93. Lemke KA and Dawson SD: Local and regional anesthesia, *Vet Clin North Am Small Anim Pract* 4: 839, 2000.

94. Gaynor JS and Mama KR: *In* Gaynor JS and Muir WW,ed.: Handbook of veterinary pain management. St. Louis: Mosby, 2002, p 261.

95. Muir WW, 3rd, Wiese AJ and March PA: Effects of morphine, lidocaine, ketamine, and morphine-lidocaine-ketamine drug combination on minimum alveolar concentration in dogs anesthetized with isoflurane, *Am J Vet Res* 9: 1155, 2003.

96. Steagall PV, Teixeira Neto FJ, Minto BW, *et al.*: Evaluation of the isoflurane-sparing effects of lidocaine and fentanyl during surgery in dogs, *J Am Vet Med Assoc* 4: 522, 2006.

Section B

Nervous System and Organs of Special Sense

Chapter 10

Nervous System

Peripheral Nerve Sheath Tumors

Daniel Brehm

Introduction

Tumors of the peripheral nervous system represent approximately 27% of all canine nervous system tumors.[1] These tumors most commonly affect the spinal nerve roots in the caudal cervical and cranial thoracic region and the nerves of the brachial plexus.[2] A variety of terms has been used to refer to tumors of the peripheral nervous system, including schwannoma, neurilemoma, neurinoma, neurofibroma, and neurofibrosarcoma.[2] The term Peripheral Nerve Sheath Tumor (PNST) (sometimes also referred to as Malignant PNST) is currently used to refer to these tumors based on their presumptive common cell of origin, the Schwann cell, and similar biologic behavior.[2] Some pathologists also use the term PNST as synonymous with or closely related to the tumor hemangiopericytoma and place it within the category of soft tissue sarcoma, again based on a presumptive similar cell of origin.[3] Hemangiopericytomas are generally found in the skin and subcutaneous tissues–frequently on the limbs-and are characterized by a locally aggressive, but usually systemically passive biological behavior. Although the histiogenesis of PNST involving the spinal nerve roots and plexus nerves and those found in the skin and subcutaneous tissues may be similar, the clinical signs associated with them are very different. The predominant focus of this chapter will be on peripheral nerve sheath tumors which affect the major spinal and cranial peripheral nerves, plexus nerves, and nerve roots.

Peripheral nerve sheath tumors are characterized as being locally aggressive, invasive neoplasms with a very low metastatic potential.[2] Many sites affected by PNST have been described, including the nerves of the lumbosacral plexus, the sciatic nerve, the thoracic ventral spinal nerve roots, and the trigeminal and vagus nerves.[2,4-8] These tumors are difficult to treat because of their invasive nature and frequent proximity to the spinal cord. One of the most common complications of treatment is tumor recurrence.[2] Peripheral nerve sheath tumors are uncommon in cats, although there are reports of these tumors causing spinal cord compression at the mid thoracic and thoracolumbar vertebrae.[9]

Histology / Biologic Activity

Peripheral nerve sheath tumors are histologically heterogeneous, comprising cells which are either spindle or oval to round in shape and arranged in interlacing bundles to[10,11] sheets and cords of pleomorphic cells.[2] Divergent differentiation is seen, with tumors described with fibrous, chondroid, osteoid, myxoid, and squamous and glandular[9,11,12] epithelioid components.[2] Malignant cellular criteria are typically present,[9,10] including anaplasia, multinucleation, high mitotic index, and necrosis.[2] Immunohistochemically, most PNST are positive for vimentin and S-100, and negative[10,12,13] for alpha-smooth muscle actin.[9] The gross characteristics of PNST vary depending on location. Those involving the spinal and plexus nerves often appear as firm, white-grey, fusiform or bulbous thickenings[9] (Figure 10-1). The masses are typically locally aggressive, extending proximally and distally along the nerve with poor circumscription.[2,7,9,14] The tumor may involve one or multiple nerves within the plexus and can extend through the vertebral foramen into the spinal canal. These tumors do not typically invade the soft tissues surrounding the nerves, but they can invade the spinal cord after extension into the spinal canal.[3]

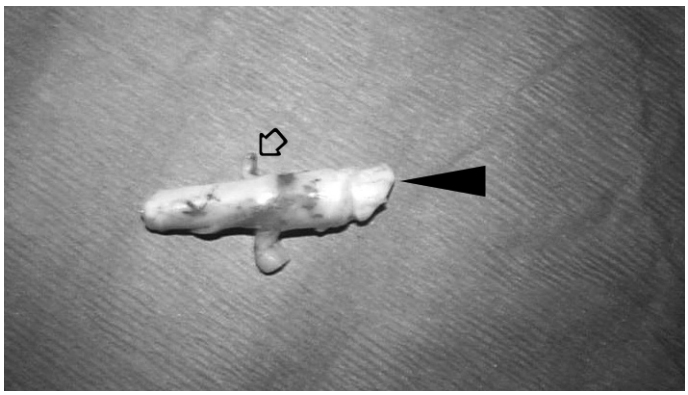


Figure 10-1. Postoperative resected section of a brachial plexus nerve containing a peripheral nerve sheath tumor. The nerve is markedly enlarged due to the tumor (closed arrow). The open arrow points to a normal size nerve within the plexus adjacent to the tumor.
Photo courtesy of Dr Robert Toal, DACVR

Clinical Signs

The presenting signs of PNST depend upon the location of the neoplasm and the degree of involvement of the affected nerve tissue. Signs will differ depending on whether the tumor affects a single peripheral nerve, multiple nerves within a plexus, nerve roots, or the spinal cord. Peripheral nerve sheath tumors are usually slow growing, so clinical signs are often present over a period of weeks to months or longer.[2,7,15] Peripheral nerve sheath tumors most commonly affect the nerves of the brachial plexus and the spinal nerve roots in the caudal cervical and cranial thoracic spine.[2,9,14-16] The most common presenting sign of tumors in this location is a chronic, progressive, unilateral forelimb lameness, seen in approximately 78% of cases in one study.[2] The lameness often has an insidious onset with an

unknown cause. The lameness is usually initially weight bearing, but tends to progress to a non weight bearing status over time. Many dogs react painfully to manipulation of the limb and to deep axillary palpation, although the exact painful site is difficult to discern. A palpable mass is present in only approximately 37% of cases.[2] Moderate to severe muscle atrophy of the affected limb is commonly seen, occurring in approximately 93% of cases in one study.[2] Paresis and neurological deficits of the affected limb may be seen as the tumor compromises nerve function. Additional signs, including paraparesis, loss of the cutaneous trunci reflex, and ipsilateral Horner's syndrome can be seen if the tumor extends through the intervertebral foramen to involve the spinal cord. Signs of spinal cord involvement may develop after a period of forelimb lameness, concurrent with the lameness, or as an initial finding depending on the site of origin of the tumor.[9]

Peripheral nerve sheath tumors in other locations manifest with different presenting signs. A smaller population of PNST affects the nerves of the lumbosacral plexus.[2,4] These tumors present with a unilateral hind limb lameness which can progress to unilateral or bilateral hind limb paresis if the tumor invades the spinal canal. Peripheral nerve sheath tumors have been described specifically affecting the sciatic nerve and presented with signs of a hind limb lameness and associated sciatic nerve deficits.[5] Rectal examination of these dogs revealed a palpable intrapelvic mass not visible on survey radiographs. Peripheral nerve sheath tumors have also been reported to affect the trigeminal nerve.[7] The main presenting sign of these tumors was unilateral atrophy of the temporalis and masseter muscles, seen in all ten described dogs. One case report described a dog presenting with chronic vomiting, coughing, and signs of respiratory distress and with clinical findings of Horner's syndrome, ipsilateral laryngeal hemiplegia, and a ventral cervical mass identified via ultrasonography.[8] At necropsy, a PNST was identified affecting the vagosympathetic trunk. An intrathoracic PNST has been described in a dog which presented for a persistent, productive cough and regurgitation.[6] This tumor was believed to originate from the ventral thoracic spinal nerve roots.

The differential diagnoses for the most common presenting sign of PNST is any musculoskeletal disorder which produces a forelimb lameness. Many affected dogs have some degree of concurrent elbow or shoulder joint disease which can make definitive diagnosis of the PNST initially difficult. Because there is often a painful reaction on manipulation of the shoulder region, shoulder-area soft tissue injuries, such as biceps tendon or infraspinatus or supraspinatus muscle injuries, may be presumed to be the causative problem.[17] Although chronic musculoskeletal injuries can be associated with muscle atrophy, the atrophy seen with PNST tends to be more severe. Peripheral nerve sheath tumors also must be differentiated from other spinal nerve diseases, such as nerve root disease secondary to intervertebral disc compression.

Diagnostics

Survey radiographs may provide useful information in the workup of PNST. It is useful to characterize orthopaedic disease and to help rule out primary bone diseases such as proximal humeral or vertebral osteosarcoma. The most common described radiographic abnormality with PNST is widening of an intervertebral foramen when tumors extend into the vertebral canal.[18] Survey radiographs are generally of limited use in the diagnosis of PNST because only a small percentage of cases demonstrate detectable abnormalities.

Myelography is a more useful radiographic diagnostic tool and is essential in cases in which there is suspicion of tumor extension to the vertebral canal (Figure 10-2). In one study, approximately 95% of cases with nerve root involvement had abnormal myelograms.[2] Myelography also accurately identified the lack of macroscopic vertebral canal or nerve root involvement in 9 of 10 cases in which the PNST was located within the brachial plexus. A normal myelogram does not rule out PNST nor does it fully rule out involvement of the nerve roots, but it can be very useful to better plan the surgical approach or approaches needed for treatment.[2]

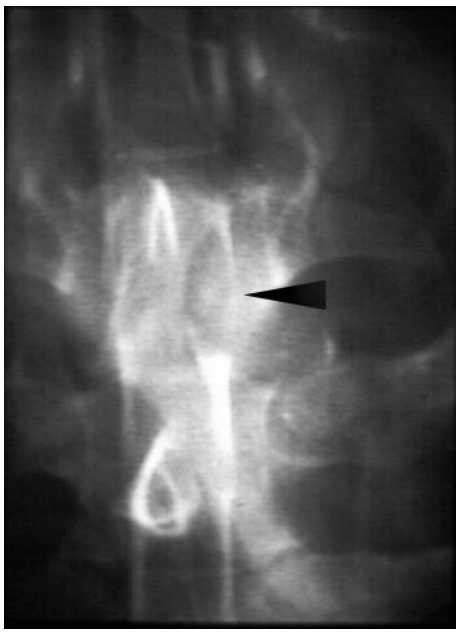


Figure 10-2. Image of a ventrodorsal projection of a cervical myelogram demonstrating an intradural-extramedullary pattern due to extension of a peripheral nerve sheath tumor into the spinal canal (arrow). the plexus adjacent to the tumor.
Photo courtesy of Dr Robert Toal, DACVR

Advanced imaging techniques including computed tomography (CT) and magnetic resonance imaging (MR) have become valuable tools in the diagnosis of PNST. These imaging modalities have greater diagnostic sensitivity than conventional radiography and can provide important pre-treatment information on tumor localization and the degree of tumor extension.[4,5,7,14,15,17] Computed tomography was used to identify masses of the brachial plexus in 24 dogs in one study.[15] Twenty of the 24 cases (83%) demonstrated either uniform or heterogenous contrast enhancement. Tumors as small as one cm in diameter were identified; however, it should be noted not all masses identified on CT are associated with neuronal structures. Magnetic resonance imaging has been used in the diagnosis of PNST's of the radial nerve, trigeminal nerve, and in an intrathoracic location.[6,7,14] The majority of the

lesions were isointense on T1-weighted images and either isointense or hyperintense on T2-weighted images (Figure 10-3). All of the lesions demonstrated contrast enhancement. MR is becoming the preferred advanced diagnostic test due to its superior resolution of the tumor boundary and the absence of beam-hardening artifacts.[7]

Electromyography (EMG) is a useful tool in assisting with the diagnosis of PNST. Because of the destructive nature of PNST, the electrical conductivity through affected nerves is frequently altered. A primary goal of EMG, used in conjunction with other diagnostic tests, is to differentiate between muscle atrophy due to denervation and muscle atrophy due to disuse.[18] In the clinical setting, this applies to differentiation between muscle atrophy seen with nerve disease and that seen with orthopaedic disease.[2,7,14] It is not specific for PNST since other types of nerve injury (such as brachial plexus avulsion injuries) can produce EMG changes.[19] When used in cases of PNST, EMG can help determine the extent and severity of the nerve damage caused by the tumor, in effect helping to localize the tumor.[19] In one study, all twenty nine dogs in which EMG was performed demonstrated abnormal, spontaneous electrical activity in muscles of the tumor-affected limb.[2] In a separate study, EMG studies were used to confirm the diagnosis of sciatic nerve tumors in two dogs.[5] Changes seen on EMG studies include fibrillation potentials, positive sharp waves, and bizarre high frequency discharges.[7,19]



Figure 10-3. Transverse view of a T1-weighted, post contrast magnetic resonance image of a cervical peripheral nerve sheath tumor. The arrow points to the widened nerve root extending close to the vertebra. Photo courtesy of Dr Robert Toal, DACVR

Surgical Treatment

The goals of treatment of PNST include eradication of the tumor, relief of pain associated with the tumor, and stabilization of neurological dysfunction caused by the tumor. The primary mode of therapy of PNST is aggressive surgical resection of all affected nerve tissue.[2] The tumor may be approached peripherally if it is located outside of the spinal canal, via a laminectomy if it involves the spinal canal, or from both approaches if the tumor involves both canal and peripheral locations. If the tumor has resulted in severe neurological dysfunction of an affected forelimb, or if resection of the tumor will significantly compromise forelimb function, amputation of the limb may be necessary with resection of the tumor. The basic principle of tumor removal is to resect all affected nerve tissue with a wide margin of grossly normal nerve proximal and distal to the mass. This frequently requires resection of multiple nerve branches due to the highly invasive nature of the tumor. Incomplete excision is common despite aggressive surgical treatment because of the difficulty of discerning normal from abnormal nerve tissue during surgery.[2] All resected tissue should be submitted for histopathology with proximal and distal edges marked with ink to assist the pathologist in assessing completeness of excision.

Surgical Approaches to the Brachial Plexus

The main and usually best approach to the brachial plexus is the craniolateral approach.[20] This provides a wide exposure to the plexus nerves and allows exploration and treatment of the peripheral nerves to the level of the spinal canal. Full exploration of the caudal plexus nerve roots requires transection of the scalenus muscle and cranial rotation of the first rib following an osteotomy near the costochondral junction. The craniomedial approach to the plexus provides better exposure of the peripheral nerves distal to the plexus.[19,20] This approach, though, provides limited access to the proximal portions of the plexus nerves, and it typically involves more muscle dissection than the craniolateral approach.[20] Both approaches can be easily modified into a forequarter amputation if the degree of tumor resection will result in a dysfunctional limb.

Craniolateral Approach[20]

The dog is placed in lateral recumbency with the affected limb, shoulder area, and caudal neck prepared for aseptic surgery. A skin incision is made at the cranial border of the mid scapula and extending distal to the greater tubercle of the humerus. The omotransversarius muscle is transected over the cranial edge of the scapula. Dissection continues ventrally dorsolateral to the cleidobrachialis muscle. The omotransversarius and cleidobrachialis muscles are elevated cranially and cranioventrally, respectively and the scapula is elevated caudally to expose the brachial plexus. The plexus nerves are better defined after separation from the loose subscapular connective tissue. The scalenus muscle may need to be transected to expose the seventh and eighth cervical and first thoracic ventral nerve branches. The first rib can be osteotomized just proximal to the costochondral junction and rotated cranially and laterally to further expose the first and second thoracic ventral nerve roots if these need to be treated as well. This will require ligation of the first intercostal artery and vein and transection of the first intercostal space musculature.

Craniomedial Approach[19]

The dog is placed in lateral recumbency, with the affected limb retracted caudally. An incision is made from the caudal aspect of the jugular furrow, medial to the greater tubercle of the humerus, and to the axilla. An incision is made at the medial edge of the cleidobrachialis muscle. The cranial edge of the superficial pectoralis muscle is transected near to its insertion on the humerus. The plexus is exposed by lateral retraction of the limb and blunt dissection around the nerves.

Surgical Approach to the Lumbosacral Plexus

The lumbosacral plexus is a comparatively uncommon site for PNST. In one study, only eight of the 51 cases had tumors affecting either the lumbosacral nerve roots or the sciatic nerve.[2] Clinical signs associated with tumors affecting the lumbosacral plexus nerve roots include hind limb lameness and hind limb paresis or paraparesis.[2,5] Tumors in this area may be more difficult to locally resect because of the limited access to the lumbosacral nerve trunk. A lumbosacral nerve sheath tumor was completely excised in one study via a hemipelvectomy.[4]

Approach to the Lumbosacral Nerve Trunk[21]

The patient is positioned in ventral recumbency. A dorsal skin incision is made from the craniodorsal iliac spine caudally to the ischiatic spine. The gluteal fascia and underlying superficial gluteal muscle are incised and the sacrospinalis muscle fibers are separated over the dorsal iliac spine and body. The middle gluteal muscle is incised along the dorsal aspect of the ilial wing and body. Blunt intrapelvic dissection following retraction of the middle gluteal and sacrospinalis muscles exposes the lumbosacral nerve trunk.

Laminectomy

A laminectomy is needed in cases in which the PNST extends from a peripheral location into the spinal canal or when the tumor originates at the nerve roots within the canal.[2,12] A hemilaminectomy is usually performed to allow exposure of the nerve roots and the ventrolateral aspect of the spinal cord. The laminectomy may need to be made over several intervertebral spaces if the tumor involves multiple nerves. After exposure of the spinal cord and nerve root, a durotomy is performed to allow transection of the nerve root at the level of the cord. The nerve root is then dissected out from the surrounding epaxial musculature as far as possible. Unless all of the tumor-affected nerve tissue can be removed, a second surgery to remove the diseased tissue from a peripheral approach is necessary. It is more typical, though, that the laminectomy is performed subsequent to a peripheral approach to remove tumor tissue extending into the spinal canal.

Adjuvant Therapy

Chemotherapy and radiation therapy are of questionable benefit in the treatment of PNSTs affecting the major nerves of the brachial and lumbosacral plexes. There is minimal data describing the efficacy of adjuvant therapies for PNST in these locations. The majority of information relative to radiation therapy efficacy refers to the peripherally located, soft tissue sarcoma categorization of nerve sheath tumors (hemangiopericytomas). Radiation therapy as an adjunct to incomplete surgical excision of canine soft tissue sarcomas resulted in a reported disease free interval of 1082 days with a survival rate of 76% at five years.[22] If PNSTs affecting the plexus nerves have a biological response similar to those placed in the soft tissue sarcoma category, then adjuvant radiation therapy could be considered an appropriate part of the management of these tumors. The major problem with plexus-located tumors is their proximity to the spinal cord. A recurrent tumor, or a tumor which continues to grow despite radiation therapy will have more profound clinical consequences than those tumors located distally on a limb or on the dog's trunk, and this will likely lead to shorter disease free intervals and survival times.[2] At this time, without further data specific to PNSTs affecting the major plexus nerves, radiation therapy can only be considered as a reasonable, but not proved adjunct to surgery.

Prognosis

The prognosis of PNST is generally guarded to poor.[2] The highly infiltrative nature of PNST and the difficulty of identifying the true extent of the tumor make complete surgical excision difficult to achieve. The proximity of many of these tumors to the spinal canal also limits complete excision. Prognosis has been linked to tumor location. In one study, tumors were divided into three anatomical groups: tumors distal to the brachial or lumbosacral plexus (Peripheral Group), tumors involving nerves within the plexus (Plexus Group), and tumors involving the vertebral canal (Root Group).[2] The median survival time of dogs in the Root Group was five months. The median survival time of the Plexus group was 12 months. Although there was no statistical difference, the trend was for dogs in the Plexus Group to survive longer than dogs in the Root Group. This survival difference is a reflection of the proximity of the tumor to the spinal cord in the Root Group and the profound clinical effects tumors in this location can have on the patient. Over 82% of all dogs in this study followed to death or at least three months following diagnosis had either recurrence of clinical signs or an unaltered, progressive worsening of presenting clinical signs. Most of the dogs either died directly from or were euthanized due to the effects of the tumor. In the study describing trigeminal nerve sheath tumors, only three of the ten dogs were treated surgically.[7] One of these cases was alive without disease progression 27 months after surgery, one was alive four months after surgery, and one was euthanized from progressive disease five months after surgery. Survival times of the non-treated cases ranged from five to 21 months.

Conclusion

Peripheral nerve sheath tumors are aggressive tumors which can be difficult to definitively diagnose and successfully treat. Tumor recurrence, or unabated progression of presenting clinical signs are the most common complications of treatment. The hallmark signs of PSNT, which should be an impetus to pursue further diagnostics, are a chronic, progressive forelimb lameness and marked muscle atrophy. The treatment of choice for these tumors is aggressive surgical excision, which may require peripheral excision of the mass, limb amputation, laminectomy, or a combination of these procedures. The efficacy of adjuvant therapies is not clear at this time. The best approach to these tumors will likely be early and aggressive intervention, using diagnostics such as electromyography and MR imaging sooner rather than later in the diagnostic workup, to hopefully identify the tumor before it has had opportunity to invade multiple nerves or the spinal canal. Because of the aggressive nature of these tumors, the overall prognosis of PNST still has to be considered guarded to poor.

References

1. Hayes HM, Priester WA, Pendergrass TW: Occurrence of nervous-tissue tumors in cattle, horses, cats and dogs. *Int J Cancer* 15:39, 1975.

2. Brehm DM, Vite CH, Steinberg HS et al.: A retrospective evaluation of 51 cases of peripheral nerve sheath tumor in the dog. *J Am Anim Hosp Assoc* 31:349, 1995.

3. MacEwen EG, Powers BE, Macy D, *et al.*: Soft tissue sarcomas *In* Withrow SJ, MacEwen EG, eds.: Small animal clinical oncology. Philadelphia: W.B. Saunders Company, 2001, p. 283.

4. Miles JD, Dyce J, Mattoon, JS: Computed tomography for the diagnosis of a lumbosacral nerve sheath tumour and management by hemipelvectomy. *J Small Anim Pract* 42:248, 2001.

5. Abraham LA, Mitten RW, Beck C et al.: Diagnosis of sciatic nerve tumour in two dogs by electromyography and magnetic resonance imaging. *Aust Vet J* 81:42, 2003.

6. Essman SC, Hoover JP, Bahr RJ *et al.:* An intrathoracic malignant peripheral nerve sheath tumor in a dog. *Vet Radiol Ultrasound* 43:255, 2002.

7. Bagley RS, Wheeler SJ, Klopp L *et al.:* Clinical features of trigeminal nerve-sheath tumors in 10 dogs. *J Am Anim Hosp Assoc* 34:19, 1998.

8. Ruppert C, Hartmann K, Fischer A *et al.:* Cervical neoplasia originating from the vagus nerve in a dog. *J Small Anim Pract* 41:119, 2000.

9. Braund KG: Neoplasia of the Nervous System *In* Braund KG, ed.: Clinical Neurology in Small Animals - Localization, Diagnosis and Treatment. Ithaca: IVIS, 2003.

10. Chijiwa I, Ulchida K, Tateyama S.: Immunohistochemistry evaluation of canine peripheral nerve sheath tumors and other soft tissue sarcomas. *Vet Pathol* 41:307, 2004.

11. Sawamoto O, Yamate J, Kuwamura M et al.: A canine peripheral nerve sheath tumor including peripheral nerve fibers. *J Vet Med Sci* 61:1335, 1999.

12. Patnaik AK, Zachos TA, Sams AE *et al.:* Malignant nerve-sheath tumor with divergent and glandular differentiation in a dog: a case report. *Vet Pathol* 39:406, 2002.

13. Garcia P, Sanchez B, Sanchez MA *et al.:* Epithielioid malignant peripheral nerve sheath tumour in a dog. *J Comp Pathol* 131:87, 2004.

14. Platt SR, Graham J, Chrisman CL *et al.:* Magnetic resonance imaging and ultrasonography in the diagnosis of a malignant peripheral nerve sheath tumor in a dog. *Vet Radiology & Ultrasound* 40:367, 1999.

15. Rudich SR, Feeney DA, Anderson KL *et al.:* Computed tomography of masses of the brachial plexus and contributing nerve roots in dogs. *Vet Radiology & Ultrasound* 45:46, 2004.

16. Carmichael S, Griffiths IR.: Tumours involving the brachial plexus in seven dogs. *Veterinary Record* 108:435, 1981.

17. McCarthy RJ, Feeney DA, Lipowitz AJ: Preoperative diagnosis of tumors of the brachial plexus by use of computed tomography in three dogs. *J Am Vet Med Assoc* 202:291, 1993.

18. LeCouteur RA: Tumors of the nervous system *In* Withrow SJ, MacEwen EG, eds.: Small animal clinical oncology. Philadelphia: W.B. Saunders Company, 2001, p. 500.

19. Farnback CG: Peripheral nerve testing and electromyography *In* Newton CD, Nunamaker DM, eds.: Textbook of small animal orthopaedics. Philadelphia: J.B. Lippincott Company, 1985, p 1115.

20. Sharp, NJ: Craniolateral approach to the canine brachial plexus. *Vet Surg* 17:18, 1988.

21. Smith MM, Waldron DR: Approach to the lumbosacral nerve trunk *In* Smith MM, Waldron DR eds.: Atlas of approaches for general surgery of the dog and cat. Philadelphia: W.B. Saunders Co., 1993, p 350.

22. McKnight JA, Mauldin GN, McEntee MC, *et al.:* Radiation treatment for incompletely resected soft-tissue sarcomas in dogs. *J Am Vet Med Assoc* 217:205, 2000 .

Peripheral Nerve Biopsy

John H. Rossmeisl Jr.

Peripheral nerve biopsies are routinely performed in veterinary practice and are essential in some cases, along with complete clinical and electrophysiologic examinations, for accurate diagnosis of neurologic disease. General indications for peripheral nerve biopsy include neurologic deficits referable to an anatomic area innervated by the nerve, clinical signs consistent with flaccid paresis or paralysis, hyporeflexia to areflexia, neurogenic muscular atrophy, and sensory deficits of the innervated area. Evaluation of an appropriately collected nerve biopsy may also provide prognostic information, and rarely, a specific etiology for the observed clinical signs.[1]

Selection of Biopsy Sites

Although it is possible to biopsy virtually any nerve, whether it be of a mixed, motor, or purely sensory variety, several criteria are used to guide selection of a specific peripheral nerve for biopsy. A priority is that the clinical neurologic examination has provided evidence that the selected nerve is affected by the neuropathy. When possible, clinical evidence of specific nerve involvement is further confirmed by electrophysiologic examination such as nerve conduction studies. Nerves selected for biopsy should be easily identifiable, relatively consistent in their neuroanatomic location, able to be protected from entrapment and recurrent trauma, and accessible with minimal patient morbidity.[1] In addition, ideally the nerve should have published normal, quantitative electrophysiologic and morphometric data available for comparative study, and innervate a skeletal muscle that is amenable to biopsy for which normal data is available.[1-3]

In cases where generalized clinical neurologic disease is present, biopsy of the mixed function common peroneal nerve will usually provide a representative specimen. The common peroneal nerve is a preferred biopsy site as many generalized peripheral neuropathies preferentially affect the pelvic limbs prior to the thoracic limbs and normal morphometric and electrophysiologic data for the common peroneal nerve exists for both cats and dogs.[1,3] The common peroneal nerve is also easily visualized as it courses over the lateral head of the gastrocnemius muscle. The flat structure and readily identifiable fascicles make the nerve especially amenable to biopsy. In the pelvic limb, the tibial nerve is a frequently biopsied nerve, as is the ulnar nerve in the thoracic limb. The purely sensory caudal cutaneous antebrachial nerve and caudal cutaneous sural nerve are the most commonly sampled thoracic and pelvic limb nerves in cases in which sensory neuropathy is suspected.

Peripheral Nerve Biopsy Techniques

Peripheral nerve biopsy is usually performed under general anesthesia. There are two basic techniques used to obtain peripheral nerve biopsies, nerve transection and the fascicular biopsy technique. The fascicular biopsy technique is preferred over nerve transection since fascicular biopsy allows for the structural and functional preservation of the majority of the remaining nerve, and thus is associated with minimal or

transient clinical morbidity. Specialized equipment is generally not needed, but operating loupes to improve the surgeon's visualization of the operative field are valuable. The fascicular biopsy technique will be described here through an approach to the common peroneal nerve. Detailed descriptions of the surgical approaches to several other peripheral nerves have been published elsewhere.[1,2]

The animal is placed in lateral recumbency, and an area extending from the distal third of the femur to the proximal third of the tibia is prepared for aseptic surgery. The common peroneal nerve can be palpated percutaneously as it courses on the lateral aspect of the stifle just caudal to the proximal tibia and fibula. A 5- to 7-cm oblique skin incision extending from just caudal to the lateral femoral condyle to the proximal fibula will expose the underlying fascia of the biceps femoris muscle, through which the target nerve can be palpated (Figure 10-4). The biceps femoris fascia is elevated and a 5-cm fascial incision made which will allow visualization of the underlying common peroneal nerve as it courses over the lateral head of the gastrocnemius muscle (Figure 10-4- inset). Perineural fat and fascia should be carefully and bluntly dissected off of the visible portion of the nerve. The caudal 1/3 of the proximal end of the exposed nerve is isolated using a ligature of 5-0 or 6-0 silk suture. Gentle traction placed on the proximal ligature allows for the longitudinal division using ophthalmic scissors of a 2- to 4-cm long distal fascicular biopsy specimen. Fascicular biopsy specimens should not exceed 30% of the diameter of the parent nerve from which they are harvested. In the event that the underlying disease process or inherent structure of the nerve complicates visualization of individual nerve fascicles, the exposed nerve segment can be atraumatically spread over a sterile tongue depressor or scalpel handle, which can aid identification of fascicles (Figure 10-5). The biceps femoris fascia is closed with absorbable suture, and the skin closed routinely. Application of an external protective dressing is usually not necessary. Although it was originally reported that neuromas occur frequently following fascicular biopsy, more recent clinical experiences with large numbers of patients suggest that biopsy-related complications are rare.[2,3] In the case of peroneal nerve biopsy, the most commonly reported complication consists of transient proprioceptive deficits and knuckling of the pes, both of which usually resolve within 5 days of the procedure.

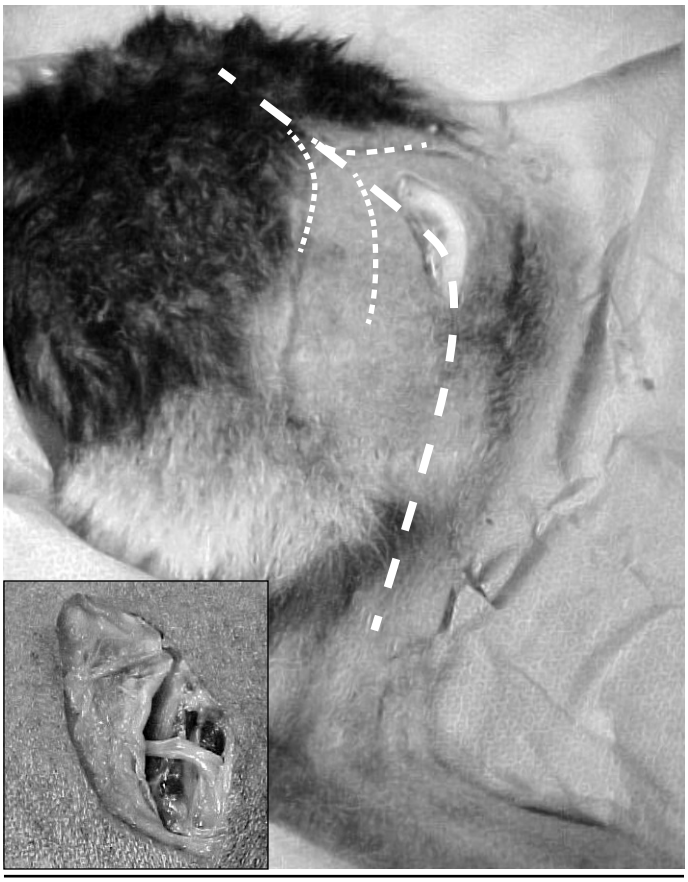


Figure 10-4. Fascicular biopsy of the common peroneal nerve is initiated by making a 5- to 7-cm slightly oblique skin incision extending from just caudal to the lateral femoral condyle to the proximal fibula. The common peroneal nerve (dashed lines) can be percutaneously palpated beneath the fascia of the biceps femoris muscle as it courses on the lateral aspect of the stifle just caudal to the proximal tibia and fibula. Performance of a 5-cm fascial incision will allow for visualization of the underlying common peroneal nerve as it courses over the lateral head of the gastrocnemius muscle (Figure 10-4 inset).

Processing of Nerve Biopsy Specimens

Nerve biopsies require special handling to avoid artifact formation while in fixative. In order to prevent significant contracture of the biopsy sample, several techniques have been described to maintain the length of the nerve biopsy prior to fixation. These techniques include pinning the nerve at both ends to a section of tongue depressor with 25 to 27 gauge hypodermic needles or securing the nerve to a length of the stem of a standard wooden cotton tipped applicator by placing a circumferential suture of

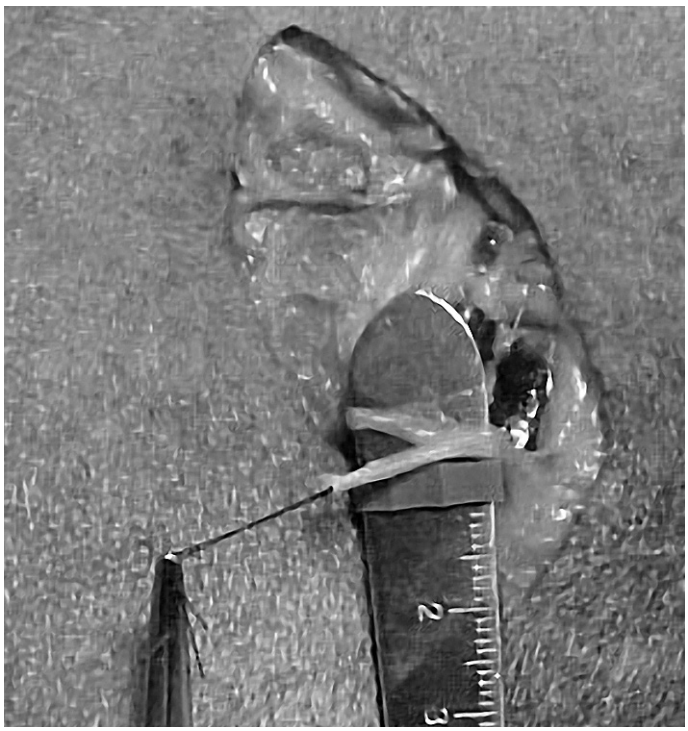


Figure 10-5. Minimal traction placed on the proximal silk ligature allows for the excision of a 2 to 4-cm long distal fascicular biopsy specimen. Gentle spreading of the isolated nerve over a scalpel handle facilitates identification of individual nerve fascicles.

5-0 or 6-0 silk at either end of the biopsy. The nerve may also be suspended directly in the fixative using a stainless steel weight attached to the free end of the original silk suture that was placed in the proximal portion of the nerve during the biopsy procedure.

Ideally, the specialized laboratory that will be receiving and processing the nerve sample should be contacted prior to performance of the biopsy so that laboratory requests for specific fixatives can be followed. Nerve biopsy specimens are preferably fixed in both 2.5% glutaraldehyde and 10% formalin.[1] If biochemical or specific immunohistochemical studies are desired, snap-freezing of unfixed nerve tissue may be required. Formalin-fixed specimens are embedded in plastic and routinely stained with hematoxylin and eosin, Luxol fast blue, or Gomori trichome stains and evaluated with light microscopy for evidence of axonal degeneration, overt demyelination, or inflammatory or neoplastic cellular infiltrates. Fixation of samples in glutaraldehyde allows for preparation of semithin and ultrathin sections for more detailed light microscopic and ultrastructural examinations, respectively. Quantitative morphometric analysis of myelinated and unmyelinated axonal numbers and diameters and nerve fiber densities may be performed so that disorders of myelin may be identified. Glutaraldehyde fixation also allows for examination of single teased fiber preparations. Evaluation of teased fiber specimens is especially useful for identification of disorders of myelinated fibers. The technique allows for the quantitative assessment of the lengths and morphology of successive myelin internodes in a single nerve fiber. This procedure permits characterization of specific demyelinating processes such as segmental and paranodal demyelination, as well as remyelination.[4] In addition, information regarding current nerve fiber degeneration can be obtained from examination of teased fiber specimens.

References

1. Braund KG: Nerve and muscle biopsy techniques. *Prog Vet Neurol* 2: 35, 1980.

2. Braund KG, Walker TL, Vandevelde M: Fascicluar nerve biopsy in the dog. *AmJ Vet Res* 40: 1025, 1979.

3. Dickinson PJ, LeCouteur RA. Muscle and nerve biopsy. *Vet Clin North America Sm Anim Pract* 32: 63, 2002.

4. Braund KG. Diagnostic techniques-nerve and muscle biopsy evaluation. In: Braund KG, ed. Clinical syndromes in veterinary neurology. 2nd ed. St. Louis: Mosby, 1994, p 376.

Chapter 11

Muscle Biopsy

Skeletal Muscle Biopsy Techniques

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The diagnostic approach to a patient with suspected neuromuscular disease begins with a thorough history and complete neurologic examination, which will often yield information regarding the component of the motor unit affected. Performance of electrodiagnostic tests in patients with neuromuscular disease often provides important information pertaining to the specific localization and extent of the disease within the motor unit, however it is necessary in some cases to perform skeletal muscle biopsy, often in conjunction with peripheral nerve biopsy. Morphologic evaluation of biopsy specimens will confirm clinical and electrophysiologic findings and is required to diagnose and classify the underlying disease responsible for the clinical signs.

General clinical indications for muscle biopsy include generalized or focal muscle weakness, stiffness, contracture, atrophy, myalgia, or hypertrophy.[1,2] Less commonly encountered clinical abnormalities that are suggestive of underlying motor unit disease include muscle fasciculations, rippling, myokymia, and myotonia. Identification of biochemical alterations such as an elevated serum creatine kinase concentration, lactic acidemia, or myoglobinuria, in any animal with clinical signs compatible with myopathic disease is also an indication to perform muscle biopsy. It is recommended that at least two muscle samples from distant locations, such as the thoracic and pelvic limbs, be examined when attempting to confirm the presence of a generalized neuromuscular disorder.[1,2]

Selection of Biopsy Sites

Several criteria should be considered prior to selection of the specific biopsy site. Primarily, there should be historical, clinical, and, ideally, electromyographic (EMG) evidence that the specific muscle is affected by the underlying disease.[2] Chronically affected, severely atrophied muscles are poor candidates for biopsy, as meaningful interpretation of biopsies sampled from such sites is often impeded by significant replacement of myofibers with adipose and fibrous tissues.[1] Muscles should also be evaluated for any previous disease, trauma, intramuscular injections, or surgery that could result in morphologic artifacts in the biopsy specimen. It is noteworthy that needle EMG evaluation can also induce focal muscle necrosis in areas of needle insertion.[1] Subsequently, when performing an EMG examination of a patient with a suspected generalized neuromuscular disease, it is preferred to electrophysiologically evaluate one side of the patient's body, and then utilize the results of the EMG examination to obtain biopsy samples from affected muscles on the contralateral side.[1,2]

The muscle selected for biopsy should be readily accessible and easily identified through a minimally invasive surgical approach; be able to be sampled with minimal resulting morbidity to the native muscle or surrounding soft-tissues; and ideally have previously published normative data regarding myofiber size, type, and distribution available for comparison.[1,2] Thoracic limb muscles commonly selected for biopsy include the distal thirds of the medial or long heads of the triceps brachii, or proximal portion of the superficial digital flexor. In the pelvic limb, the distal third of the biceps femoris or vastus lateralis, and proximal third of the lateral head of the gastrocnemius or cranial tibial muscles are frequently sampled. Reference data for both the dog and cat are available for each of these muscles.[1] If disease of the muscles of mastication is suspected, the temporalis muscle is the preferred biopsy site.

Additional factors to consider prior to selecting a biopsy site is the suspected localization of the disease within the motor unit, which is based on the differential diagnoses formulated following completion of the clinical examination. Biopsy of specific muscles or certain regions within a muscle may be required to provide the highest diagnostic yield. For example, when ultrastructural, immunohistochemical, or in vitro electrophysiological examination of the motor end plate is required, as would be necessary to confirm a diagnosis of congenital or seronegative, acquired myasthenia gravis, it is recommended that biopsy of a muscle, such as external intercostals, anconeus, or similar muscle that has high concentration of end plates and is able to be harvested intact from origin to insertion be performed.[1] In these circumstances, it is generally advised to discuss the proposed site and method of processing of muscle biopsy specimens with the laboratory or pathologist that will be charged with interpreting the biopsy before the procedure to facilitate collection of a diagnostic sample.

In situations where the specific location of the disease within the motor unit is unable to be determined following clinical examination and adjunctive electrophysiologic testing is unavailable, it is prudent to consider sampling anatomic sites that are amenable to simultaneous biopsy of muscle and peripheral nerve through a single surgical approach.[2] In the pelvic limb, the biceps femoris and lateral head of the gastrocnemius muscles, as well as the common peroneal nerve are all accessible through a single incision placed over the caudolateral aspect of the distal femur and proximal tibia. In the thoracic limb, performance of an oblique incision extending from the medial humeral condyle to the point of the olecranon provides satisfactory exposure to the distal third of the medial head of the triceps and superficial digital flexor muscle, as well as the ulnar nerve at the level of the elbow.

Skeletal Muscle Biopsy Procedures

Two muscle biopsy techniques have been described, the open and percutaneous needle-biopsy procedures.[1,3,4] The percutaneous method offers the advantages of not requiring general anesthesia for completion, being minimally invasive, and has been shown to be capable of providing diagnostic quality samples in dogs using readily available, inexpensive, commercial biopsy needles (Perfectum 11-gauge needle, Popper and Sons, Inc., New Hyde Park, NY) with minimal morbidity.[3,4] The primary limitations of the percutaneous procedure are the small sample size of tissue obtained using this method, and inability to prevent contraction of myofibers after sampling.[1,4]

Although open muscle biopsy procedures can also be performed using local anesthetics, general anesthesia is usually indicated to facilitate completion of electrodiagnostic testing that often precedes performance of open muscle biopsy. If local anesthesia is considered for open biopsy, care must be taken not to infiltrate the anesthetic agent deep into the muscle that has been selected for biopsy.[2] Open muscle biopsy is readily performed with basic surgical instrumentation.

The skin overlying the biopsy site should undergo routine aseptic preparation, regardless of the type of biopsy procedure performed. When using the open technique, the skin and any superficial fascia are incised, carefully dissected, and retracted to facilitate visualization of the myofiber orientation of the muscle selected for biopsy. Manipulation of the muscle biopsy site with forceps should be avoided. Following identification of the intended biopsy site, there are three similar methods by which biopsies intended for routine histochemical analysis can be harvested: the stay suture procedure, the muscle clamp method, and the free hand technique. It is not necessary to maintain biopsy specimens that will be subjected to routine analyses in a stretched position.[1,4]

To harvest the muscle biopsy using the stay suture procedure, a 0.5 cm diameter, 2 cm long strip of muscle is created by placement of two stay sutures. The stay sutures should be placed perpendicular to the longitudinal orientation of the myofibers, and be tied loosely so as not to excessively constrict the myofibers. After the stay sutures are in place, two 2 cm long incisions are made parallel to the direction of the myofibers and extending just beyond the proximal stay suture immediately distal to the other stay suture in order to further isolate the muscle (Figure 11-1). The two stay sutures can be used to manipulate the biopsy specimen atraumatically during the remainder of the procedure.

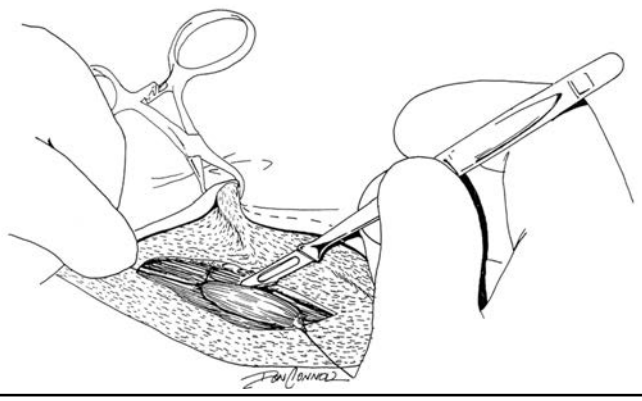


Figure 11-1. Following placement of the two stay sutures at both ends of the desired biopsy site, incisions are made along each side of the biopsy specimen in a direction parallel to the long axis of the myofibers.

While holding the proximal stay suture, the isolated segment of muscle is undermined using a scalpel blade or sharp dissection scissors (Figure 11-2), with a desired final biopsy thickness of approximately 0.5 cm. Complete separation of the biopsy specimen from the native muscle belly is achieved by cutting of the ends of the biopsy sample proximal and distal to the stay sutures (Figure 11-3), in a fashion that permits removal of both stay sutures with the biopsy specimen.

When using a commercial clamp system (Price muscle biopsy clamp, V. Mueller Instrument, Chicago, IL) to perform open muscle biopsy, a cylinder of muscle is created by first making two 2 cm long incisions parallel to the direction of the myofibers, with the intent of separating an approximately 0.5 cm diameter segment of muscle between the two incisions. The muscle clamp system is then applied to the ends of the incised segment of muscle (Figure 11-4). Using the handle of the muscle clamp to manipulate the biopsy specimen, the isolated muscle cylinder within the clamp is undermined and collected in a manner identical to that described for the stay suture technique.

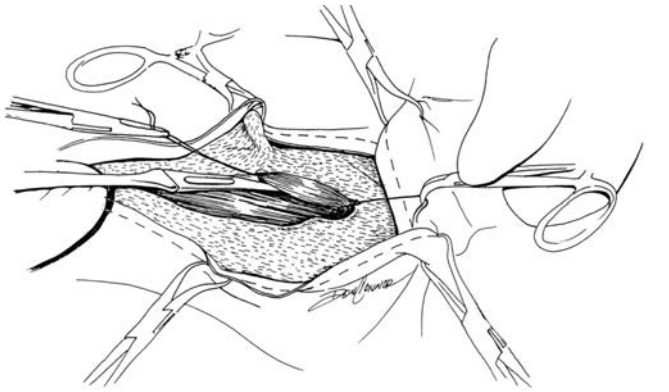


Figure 11-2. After completion of the two parallel incisions, the biopsy specimen is undermined by sharp dissection with a scalpel blade.

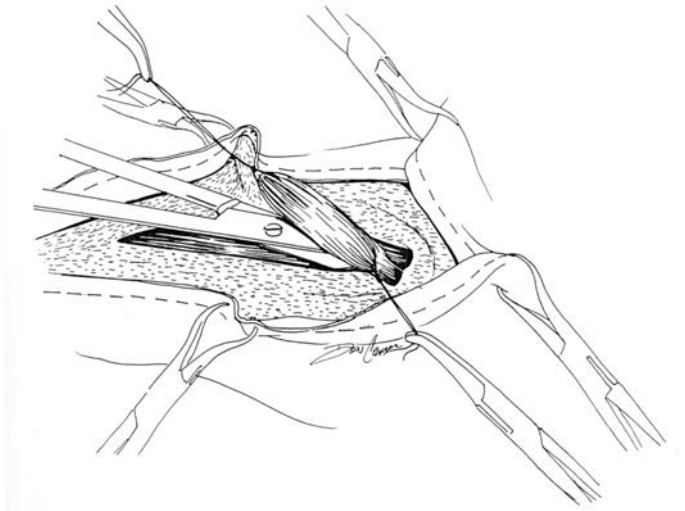


Figure 11-3. Once the muscle has been completely undermined, the biopsy sample is separated from the native muscle belly by cutting the myofibers adjacent to the sutures with sharp scissors or a scalpel blade in a fashion that allows for removal of both stay sutures with the biopsy specimen.

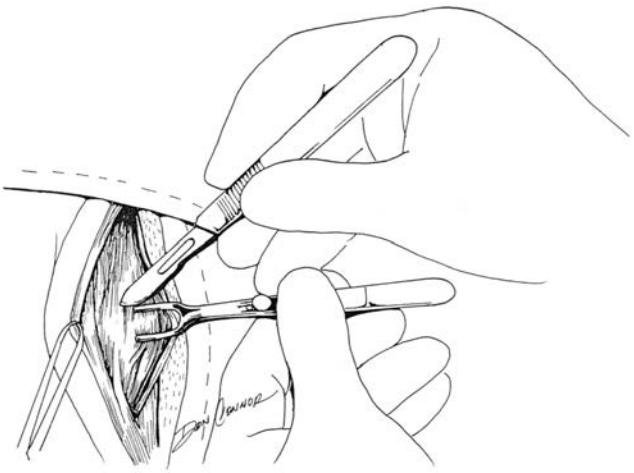


Figure 11-4. An alternative technique to the stay suture method of open biopsy involves placing a commercial muscle clamp system on the muscle after parallel incisions have been made adjacent to the desired specimen.

The procedure for the free hand, open biopsy is similar to that described for the stay suture and muscle clamp methods. The primary difference with the free hand technique is that instead of utilizing a stay suture or muscle clamp to manipulate the muscle specimen during procurement of the biopsy, the proximal end of the biopsy specimen is minimally but directly handled with microsurgical forceps. Following completion of the biopsy procedure, the end of muscle specimen that was manipulated with the forceps is trimmed using a sharp, fresh scalpel blade to remove any artifacts caused by direct handling of the muscle.[2]

If an open muscle biopsy procedure is planned, it is important to consider the potential need to obtain samples for electron microscopic evaluation. These samples are ideally collected first with minimal manipulation of the myofibers. A muscle biopsy clamp system should be considered if muscle is being harvested for ultrastructural evaluation, as these clamps prevent both handling artifacts and myofiber contracture after excision and immersion in fixative.[1] Alternatively, if a muscle biopsy clamp is not available, a 0.25 to 0.5 cm in diameter, 1.5 cm long cylinder of muscle can be created by performing a modification of the previously described stay suture technique. In order to maintain the muscle in a stretched position during completion of the biopsy, the isolated cylinder of muscle is secured to a 2 cm length of small diameter wooden dowel using the long ends of the stay sutures, prior to undermining and complete separation of the biopsy specimen. Biopsy samples destined for ultrastructural evaluation are typically fixed in glutaraldehyde, and muscle biopsy clamps applied to these samples can be removed without compromising sample quality after 24 hours of fixation.[1] Following collection of the biopsy for electron microscopic analysis, additional biopsies for routine histochemical examinations can be obtained from adjacent myofibers.

The degree of hemorrhage associated with muscle biopsy procedures is usually minimal, and can often be controlled with digital pressure after harvesting the biopsy. Suture ligation may be required if a larger intramuscular vessel is encountered. The use of electrocautery should be avoided until all muscle

biopsy samples have been obtained. Closure of the superficial muscular fascia and subcutaneous tissues is performed with an absorbable suture, and the skin is closed with sutures or staples. Application of external wound dressings following open muscle biopsy is rarely necessary. Complications associated with both the open and percutaneous muscle biopsy techniques are uncommon, but can include hematoma formation, wound dehiscence, and infection.[1,3]

Processing of Muscle Biopsy Specimens

Most freshly harvested muscle biopsy specimens are transported without delay to specialized diagnostic laboratories for processing.[2] Therefore, prior to obtaining the muscle biopsies, it is crucial to contact the individual laboratory to which the samples are being sent to obtain specific instructions regarding recommended handling of harvested tissue, and to coordinate timely shipping and receiving of tissue samples. The histochemical and cytochemical characteristics of freshly collected muscle biopsy specimens can be acceptably preserved for approximately 30 hours if biopsy specimens are placed on gauze pads lightly moistened with physiologic saline, subsequently sealed in an airtight container, and maintained at 4° C until processing occurs.[2] This method allows for appropriately handled and packaged samples to be safely transported overnight to the diagnostic laboratory.

Once harvested, proper processing of muscle biopsy specimens is necessary to prevent introduction of processing artifacts and prevent loss of metabolic substrates and tissue enzymes. Immersion of muscle biopsy specimens in formalin provides limited diagnostic information, but may allow for morphologic characterization of any cellular infiltrates present in the sample. The method of obtaining and preserving muscle in glutaraldehyde for ultrastructural analysis has been previously described and reviewed.[1,2] Routine histochemical analysis of muscle is ideally performed on biopsy specimens that are processed by fresh freezing using the gum tragacanth-isopentene-liquid nitrogen method.[1,3] Uncontrolled freezing of muscle biopsy specimens can result in massive artifact formation that can completely compromise the diagnostic quality of the sample.

Muscle biopsies are readily obtained, and when properly performed and processed, are capable of providing essential information regarding a specific etiology for, the underlying disease process occurring within the muscle. The normal morphologic and histochemical characteristics of skeletal muscle using a standard battery of stains have been reviewed extensively elsewhere.[1,2] Even in cases in which a specific etiological diagnosis is not obtained from the biopsy, certain pathologic abnormalities that can be identified in muscle biopsy samples often provide insight into the basic underlying mechanism of the disease. For example, visualization of any of the following changes in a biopsy specimen are consistent with denervation of the muscle, and thus are coined neuropathic lesions: angular myofiber atrophy, small grouped myofiber atrophy, fiber type grouping, pyknotic nuclear clumping, or large grouped myofiber atrophy.[1,2] Primary myopathies are usually divided into inflammatory and non-inflammatory types based on the presence or absence of inflammatory cell infiltrates in representative biopsy specimens, respectively. Morphologically, there are a variety of non-specific findings in muscle biopsies that are suggestive of myopathic disease. These include myofiber splitting, degeneration or regeneration, necrosis and phagocytosis, internalized nuclei, and vacuolization.[1,2] Increased amounts of fibrous or adipose tissues within muscle biopsy specimens can be a feature of both primary myopathic and neuropathic muscular disease.

References

1. Dickinson PJ, LeCouteur RA. Muscle and nerve biopsy. *Vet Clin North America Sm Anim Pract* 32: 63, 2002.

2. Braund KG. Diagnostic techniques- nerve and muscle biopsy evaluation. In: Braund KG, ed. Clinical syndromes in veterinary neurology. 2nd ed. St. Louis: Mosby, 1994, p 376.

3. Reynolds AJ, Fuhrer L, Valentine BA, Kallflez FA. New approach to percutaneous muscle biopsy in dogs. *Am J Vet Res* 56(8): 982, 1995.

4. Magistris MR, Kohler A, Pizzolato G, et al. Needle muscle biopsy in the investigation of neuromuscular disorders. *Muscle Nerve* 21: 194, 1998.

Chapter 12

Eye

Surgery of the Eyelids

J. Phillip Pickett

Anatomy

The eyelids function to maintain the health of the ocular surface. The eyelid muscles enable the lids to close over the ocular surface which helps distribute the pre-corneal tear film and protect the corneal and conjunctival surfaces from injury. Tactile cilia (lashes) sense approaching objects before they contact the globe, thus initiating the protective blink response. Glandular tissues secrete portions of the pre-corneal tear film (tarsal or Meibomian glands secrete the oily portion of the pre-corneal tear film and goblet cells of the conjunctiva secrete the mucinous portion of the pre-corneal tear film).

Important anatomic structures of the eyelids are illustrated in Figures 12-1A, B. The outermost surface of the eyelids is covered by relatively loose, haired skin in the dog and cat. Dogs usually have only upper eyelashes or cilia originating from the eyelid margin while cats do not have true eyelashes. On the lower eyelid, beneath the lid margin and parallel to the lid margin is a 1-2 mm wide zone of hairless skin. This nonhaired-haired demarcation is a surgical surgical landmark for entropion correction surgeries. Beneath the skin near the lid margins run the muscle fibers of the orbicularis oculi muscles. These muscle fibers (innervated by the palpebral branch of the facial nerve) run parallel to the lid margin and are responsible for eyelid closure. The upper eyelid has four muscles innervated by the occulomotor, facial, and sympathetic nerves that actively elevate the upper eyelid. Sensation to the eyelids is provided by the ophthalmic and maxillary branches of the trigeminal nerve. At the medial canthus, the medial palpebral ligament retracts the canthus medially; at the lateral canthus, the retractor anguli ligament/muscle retracts the lateral canthus laterally. Defects in the aforementioned liagamentous supportive structures may result in entropion and ectropion. Deep to the eyelid skin and orbicularis oculi muscles lies the connective tissue tarsal plate which contains the tarsal (Meibomian) glands. These glands are alligned perpendicular to the lid margin and there are approximately 30-40 per lid in dogs and cats. The gland openings may be seen with magnification along the lid margins. The tarsal plates are not as rigid in dogs and cats as in man, and their flaccidity may contribute to ectropion and entropion in some canine breeds. The innermost layer of the eyelids is the palpebral conjunctiva. This conjunctiva is firmly adherent to the tarsal plate area of the eyelids, but is loosely attached to the underlying eyelid stroma in the palpebral fornices.

Near the eyelid margins on the upper and lower lids, approximately 1-3 mm lateral to the medial canthus, are the openings (punctum) of the nasolacrimal duct system. These punctum lay at the medial most aspect of the cartilaginous tarsal plate and are just inside the eyelid margin on the palpebral conjunctival surfaces. The palpebral surface of the third eyelid conjunctiva at the medial canthus has a raised haired structure; the lacrimal caruncle.

Surgical Procedures

Temporary tarsorrhaphy

Temporary partial or complete closure of the palpebral fissure can be used to protect the globe following proptosis, extra- or intra-ocular surgery, or under conditions where the cornea may be overly exposed (e.g. palpebral nerve paralysis). If the temporary tarsorrhaphy is to be left in place for more than 48 hours, stents should be placed between the suture material and the eyelid skin to prevent the sutures pulling through the eyelid or cutting into the skin (Figures 12-2A, B). Pieces of sterilized "postal" rubber bands or a similar latex or silicon material make excellent stents for this purpose. If the tarsorrhaphy is to be maintained for more that 3-6

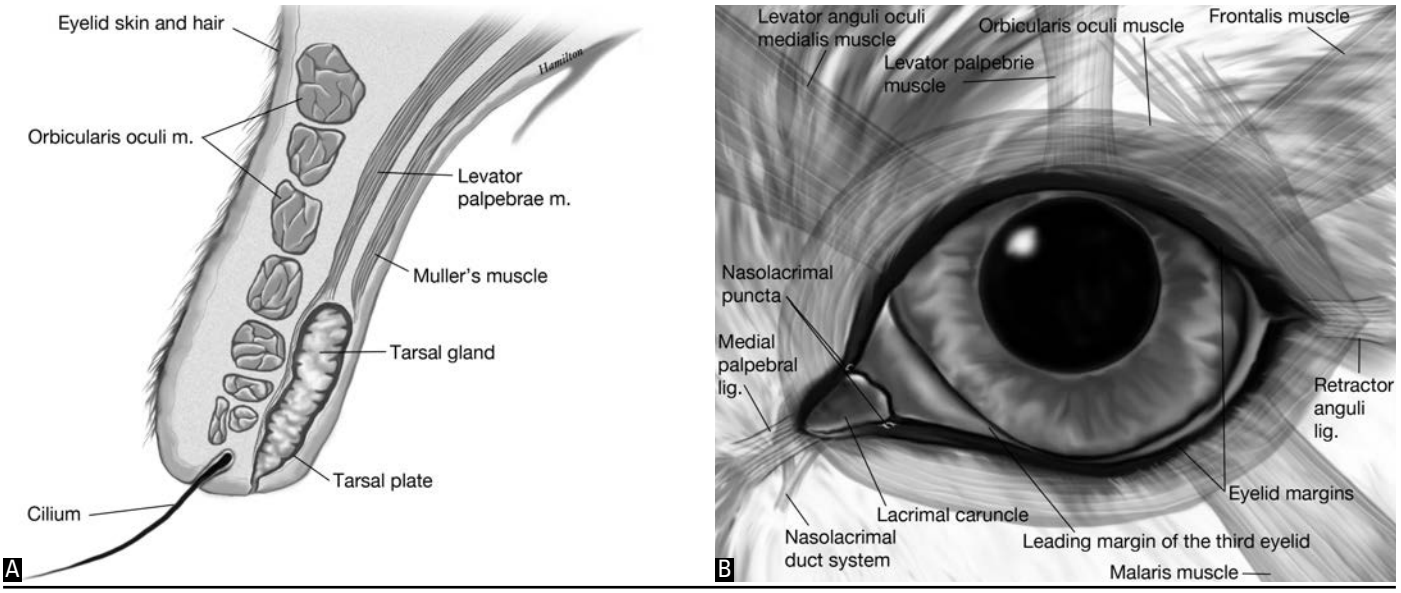


Figure 12-1. Applied eyelid anatomy. **A.** Cross section of canine upper eyelid. **B.** Frontal view of superficial and deep structures of the eyelid.

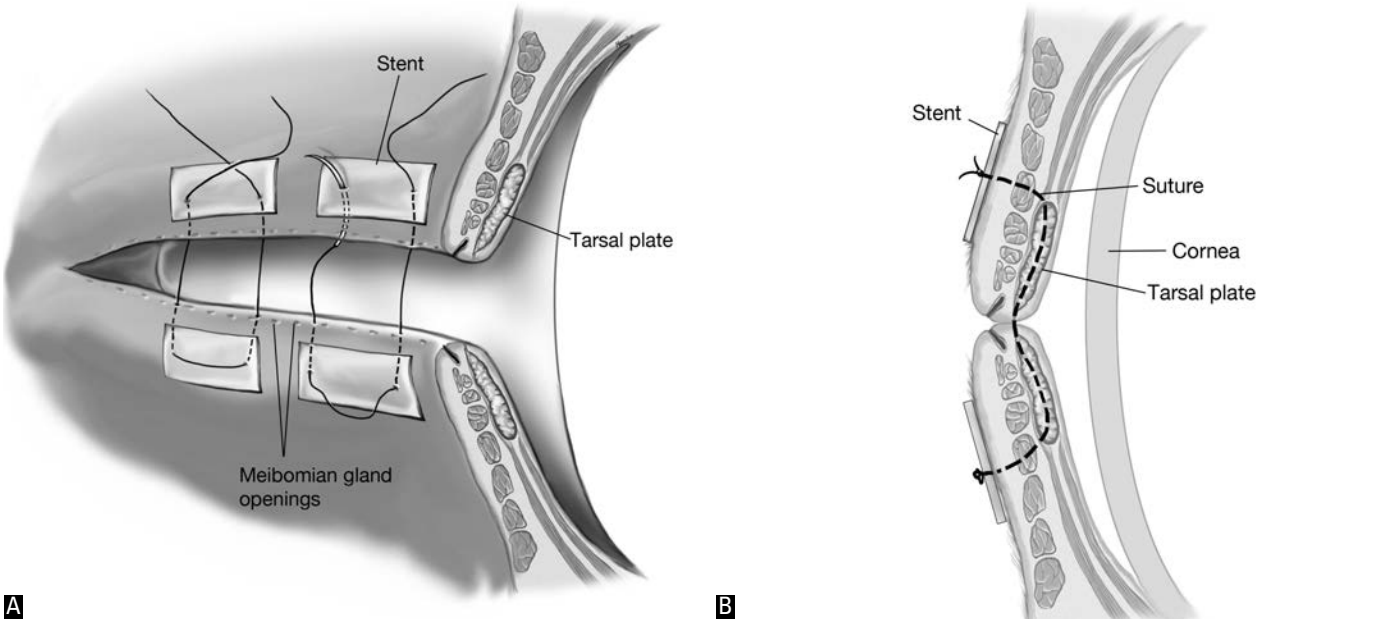


Figure 12-2. Proper placement of temporary tarsorrhaphy sutures over stents. **A.** Frontal view of placed tarsorrhaphy suture over a stent and details of placement of suture through eyelid and stent. **B.** Cross section of tarsorrhaphy suture placement over stent.

days, non-reactive suture such as monofilament or braided nylon is preferred to more reactive suture such as silk. Fine suture (5-0 to 6-0) with a small cutting needle allows proper placement of the suture. The needle should be passed first through the 4 mm x 6 mm stent and then through the eyelid skin 3-6 mm from the eyelid margin. By passing the needle into the tarsal plate, the needle should exit the eyelid margin at the level of the Meibomian gland openings. The needle should then be passed into the opposite lid margin at the Meibomian gland openings through the tarsal plate, and then out through the eyelid skin approximately 3-6 mm from the lid margin. The needle should then be passed through the stent material away from the lid, and then passed back through the stent material towards the lid. The needle is then passed through skin, tarsal plate, and Meibomian gland openings as previously described, across and through the opposite lid, and finally through the first piece of stent material so that the needle exits the same side of the stent material where the original suture bite took place. When finished, the completed suture pattern resembles a horizontal mattress pattern through eyelids and stents. Meticulous exit and entry of the needle at the Meibomian gland openings will result in excellent eyelid margin apposition with little to no risk of suture abrading the corneal surface. The suture should be tied tightly so that post-operative loosening and corneal abrasion by the suture may not occur.

Eyelid Laceration Repair

Full thickness eyelid lacerations that occur perpendicular to the eyelid margin are commonly seen secondary to fight wounds and other sharp trauma. Proper closure will result in a functional eyelid and a cosmetically acceptable palpebral fissure. The technique for eyelid laceration closure described may also be used to remove a full thickness eyelid tumor or to shorten an eyelid margin for correction of ectropion.

The skin, stroma, and conjunctiva of the eyelids are extremely vascular, and minimal debridement of damaged tissue following an eyelid laceration is recommended. Following surgical preparation of the skin and conjunctival surfaces with povidine iodine solution diluted with saline (10% povidine iodine solution diluted with saline to 1% final iodine concentration) and saline rinse, debridement of the wound with a scalpel blade is performed until the skin edge begins to hemorrhage. Closure of eyelid lacerations is performed with fine, absorbable suture (6-0 Vicryl) so as to appose the edges of the lacerated tarsal plate (Figure 12-3A-E). The first bite of the needle should enter the tarsal plate away from the lid margin and exit the tarsal plate close to the lid margin edge of the tarsal plate (Figure 12-3B). The needle is then passed to the opposite side of the wound and into the tarsal plate in the area closest to the lid margin to exit the tarsal plate away from the lid margin. If performed properly, the suture pattern approximates a horizontal mattress pattern with no suture passing through the palpebral conjunctiva (therefore there will be no possibility of suture rubbing the cornea) with the knot being tied and buried within the eyelid stroma away from the eyelid margin. A simple continuous pattern trailing away from the eyelid margin completes closure of the palpebral tarsal plate/conjunctiva with the final knot being buried within the eyelid stroma (Figure 12-3C). It is important to place suture bites so that no suture is passing through the palpebral conjunctiva that could abrade the corneal surface. A fine, braided, synthetic absorbable suture is preferred over larger, monofilament, and/or catgut suture material, especially in thin-lidded dogs and cats. If the eyelid stroma is excessively swollen, or the patient is a large dog, additional simple interrupted sutures to close the more external orbicularis oculi muscle are indicated. Skin closure must be meticulous at the eyelid margin so as to result in a smooth, anatomic eyelid margin. Three suture patterns have been described to appose the eyelid margin skin. I prefer to use a simple horizontal mattress pattern (Figure 12-3D) using fine (4-0 to 6-0) nonabsorbable (silk or nylon) braided suture followed by simple interrupted skin sutures. A cruciate or "figure of eight" suture (Figure 12-3E) involving the lid margin followed by simple

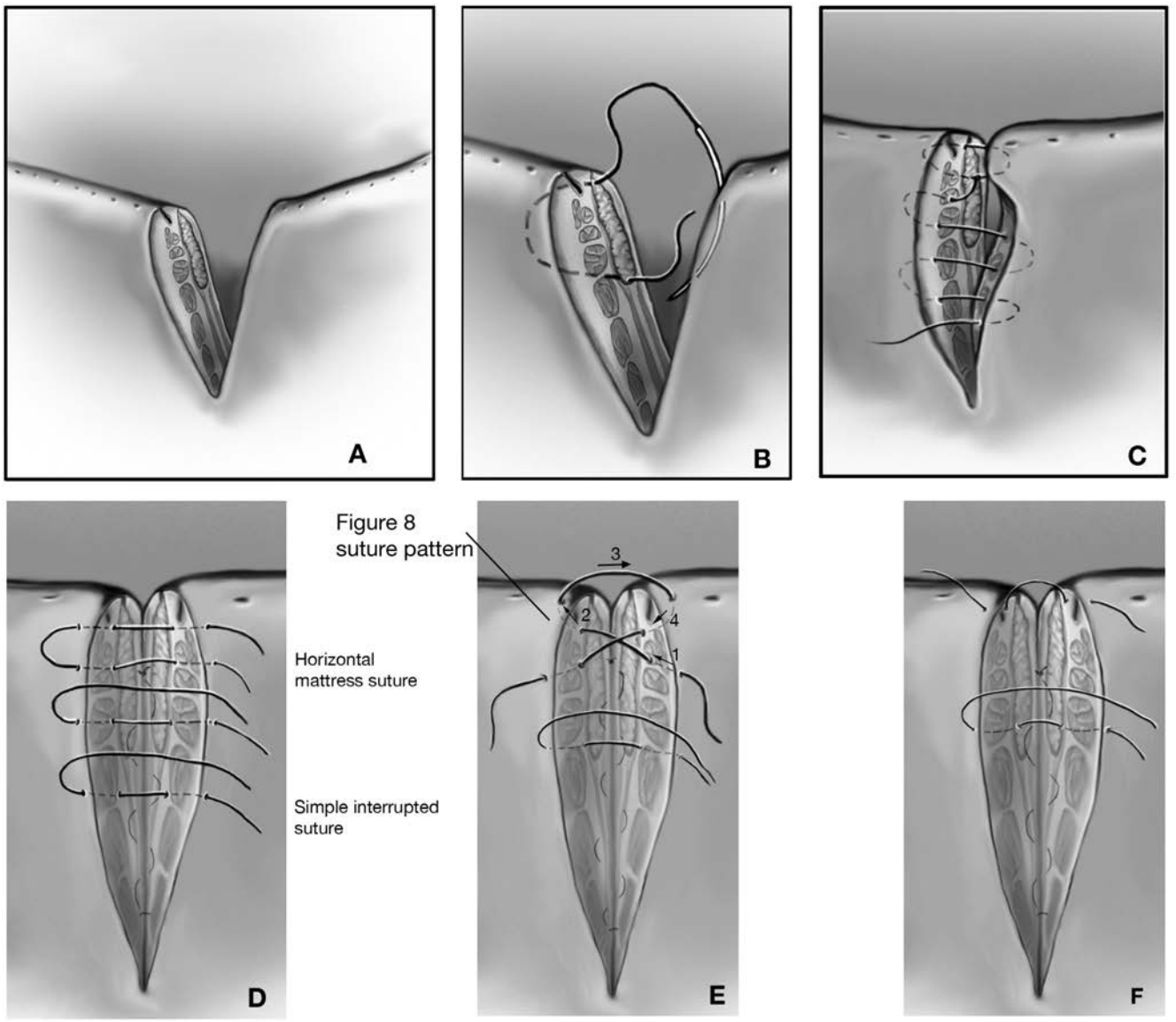


Figure 12-3. Full thickness eyelid laceration repair. **A.** Frontal/cross sectional view of full thickness eyelid laceration. **B.** Proper placement of fine, synthetic, absorbable suture in the tarsal plate to close the tarsal plate/lid stroma. **C.** The buried suture is tied so the knot is buried within the eyelid stroma and cannot abrade the corneal surface. A continuous pattern within the eyelid stroma finishes closure of the deep lid layers. It is important that the suture does not pass through the palpebral conjunctiva, either during the running stitch pattern or when the final knot is tied. **D.** Use of a horizontal mattress suture to close the eyelid margin followed by simple interrupted suture to close skin/orbicularis layer. The suture tags of the first suture may be left long and incorporated into the subsequent simple interrupted suture to prevent suture tag abrasion of the corneal surface. **E.** Use of a figure of eight or cruciate pattern to oppose the lid margin without suture tag abrasion of the cornea. **F.** Use of a simple interrupted suture to close eyelid margin. The suture should be placed very close to the lid margin, the tags left long, and the tags tied back from the corneal surface in the subsequent simple interrupted skin sutures.

interrupted skin sutures also results in excellent closure. A well placed simple interrupted suture at the lid margin (Figure 12-3F) with the suture tags being tied back by subsequent simple interrupted sutures can result in excellent anatomic closure as well, but it is important to tie the suture tags in a manner that does not allow the suture tags or the knot to come in contact with and abrade the corneal surface. If eyelid closure is precarious due to tissue friability and/or swelling, temporary tarsorrhaphy sutures, one on either side of the wound closure, can help immobilize the lids and "splint" the lid until healing is complete and sutures are removed 10 days post-operatively.

Full Thickness Eyelid Wedge Resection for Correction of Ectropion

Ectropion is eversion of the lower eyelid margin resulting in spillage of tears onto the face (epiphora) and excessive exposure of the palpebral and bulbar conjunctiva and cornea. Ectropion is usually seen in those canine breeds with heavy facial skin, excessively long palpebral fissures, and/or lax tarsal plates (e.g. hounds, giant breeds, and sporting breeds). A simple technique for "tightening" lower lid ectropion involves a full thickness wedge resection of the lid to shorten the lid margin (Figure 12-4 A-E) with closure of the wound being similar to that described for eyelid laceration repair.

A smooth eyelid margin to help stabilize the precorneal tear film meniscus is desirable, so the wedge resection to shorten the lid margin is performed laterally (Figure 12-4B). There should be some tarsal plate left on each side of the wedge to allow for closure of the wound in two layers. The initial incision is made using a scalpel with a Jaeger lid plate inserted into the cul-de-sac to stabilize the eyelid (Figure 12-4B). The incisions should be made perpendicular to the eyelid margin (parallel to each other) to the level of the edge of the tarsal plate and then taper to a point that ends in the deepest recess of the cul-de-sac (Figure 12-4C). The incisions may also be made using a Metzenbaum scissor, with the shape of the excised wedge being the same as that described for scalpel excision using a lid plate. It is important that the initial incisions from the lid margin through the length of the tarsal plate be parallel to each other so that upon closure, there will be a straight, non-indented eyelid margin. Closure of the wound is in 2 (or 3) layers as for an eyelid laceration (Figures 12-4 D and E).

Eyelid Tumor Resection

Eyelid margin tumors are commonly seen in dogs. Meibomian

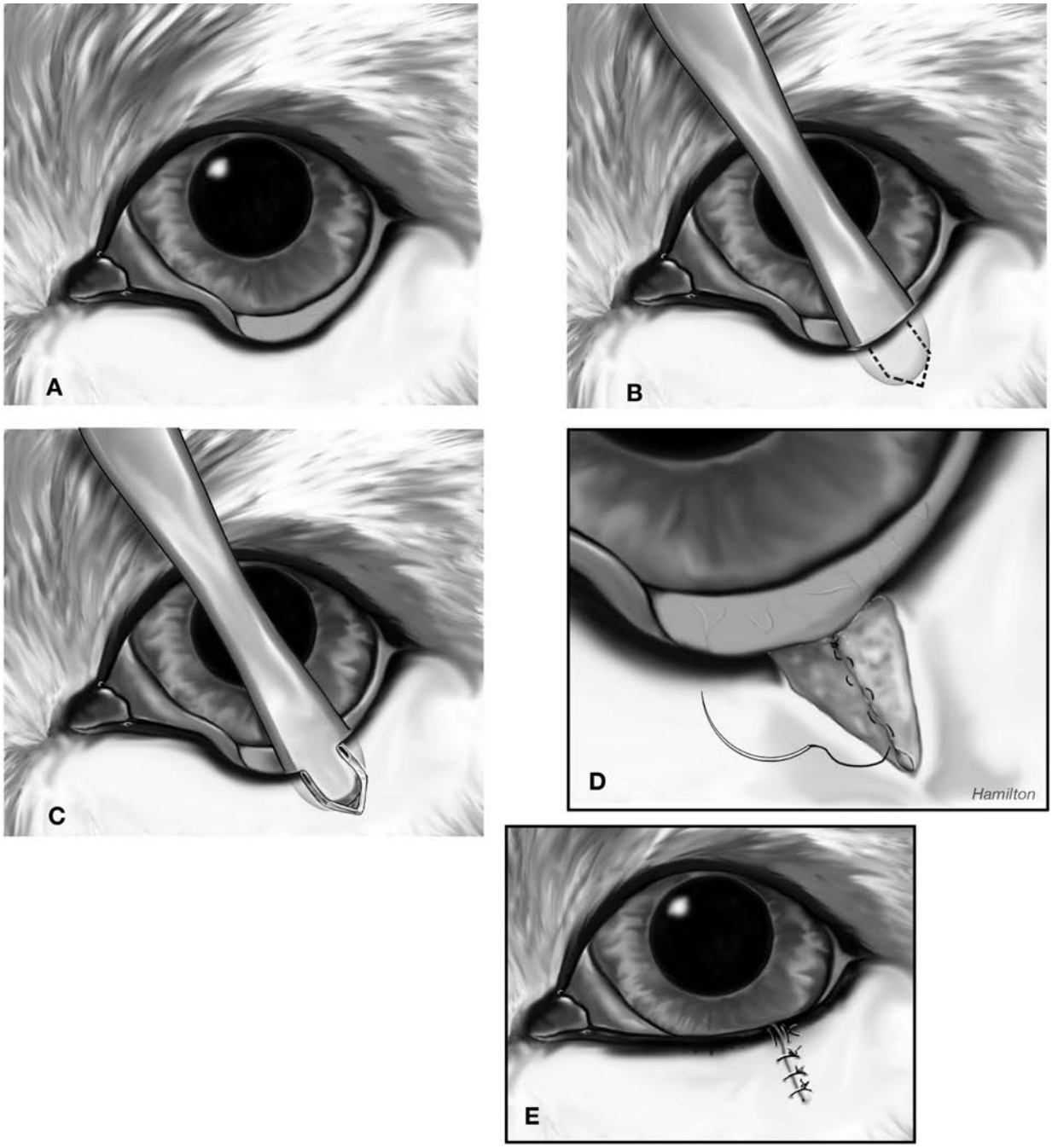


Figure 12-4. Full thickness eyelid resection to correct simple ectropion. **A.** Lower lid ectropion with exposure of ventral bulbar conjunctiva and cornea as well as lower lid conjunctiva. **B.** Use of Jaeger lid plate to excise full thickness wedge of eyelid. The excision should be made laterally so as to maintain a smooth eyelid margin. The initial cuts from the eyelid margin should be parallel through the tarsal plate and then taper to the depth of the cul-de-sac. **C.** With full thickness wedge removed, surgeon should be able to visualize the edges of the cut tarsal plate. **D.** Closure of deep eyelid tissue in same manner as described for eyelid laceration repair. **E.** Skin closure in the same manner as for eyelid laceration repair.

gland adenomas, mast cell tumors, papillomas, melanomas, and squamous cell carcinomas may occur in the lid. In cats, eyelid neoplasia is uncommon and most tumors are malignant. A full thickness wedge resection as described for ectropion correction and a two-layer closure as described for eyelid laceration is used to remove most eyelid tumors.

Depending on the species (cats have tight lid margins compared to dogs with more lax margins) and breed (hounds and sporting breeds have more lax lids than do toy breeds such as miniature poodles), approximately 1/4 to 1/3 of an eyelid may be removed and closed in the manner listed above for ectropion correction. It is important to excise the eyelid with incisons through the tarsal plate area being made parallel to each other and perpendicular to the lid margin to maintain a smooth, anatomic lid margin after healing.

If more than one-third of the lid margin is excised to obtain tumor free margins, closure may be complicated by inadequate surrounding tissue. This may result in excessive lid margin tension and poor lid function. A lateral canthotomy incision may enhance lid closure by allowing eyelid tissue to slide medially and be advanced to close the defect (Figure 12-5A-C). Following excision of the eyelid mass, a Metzenbaum scissor is used to

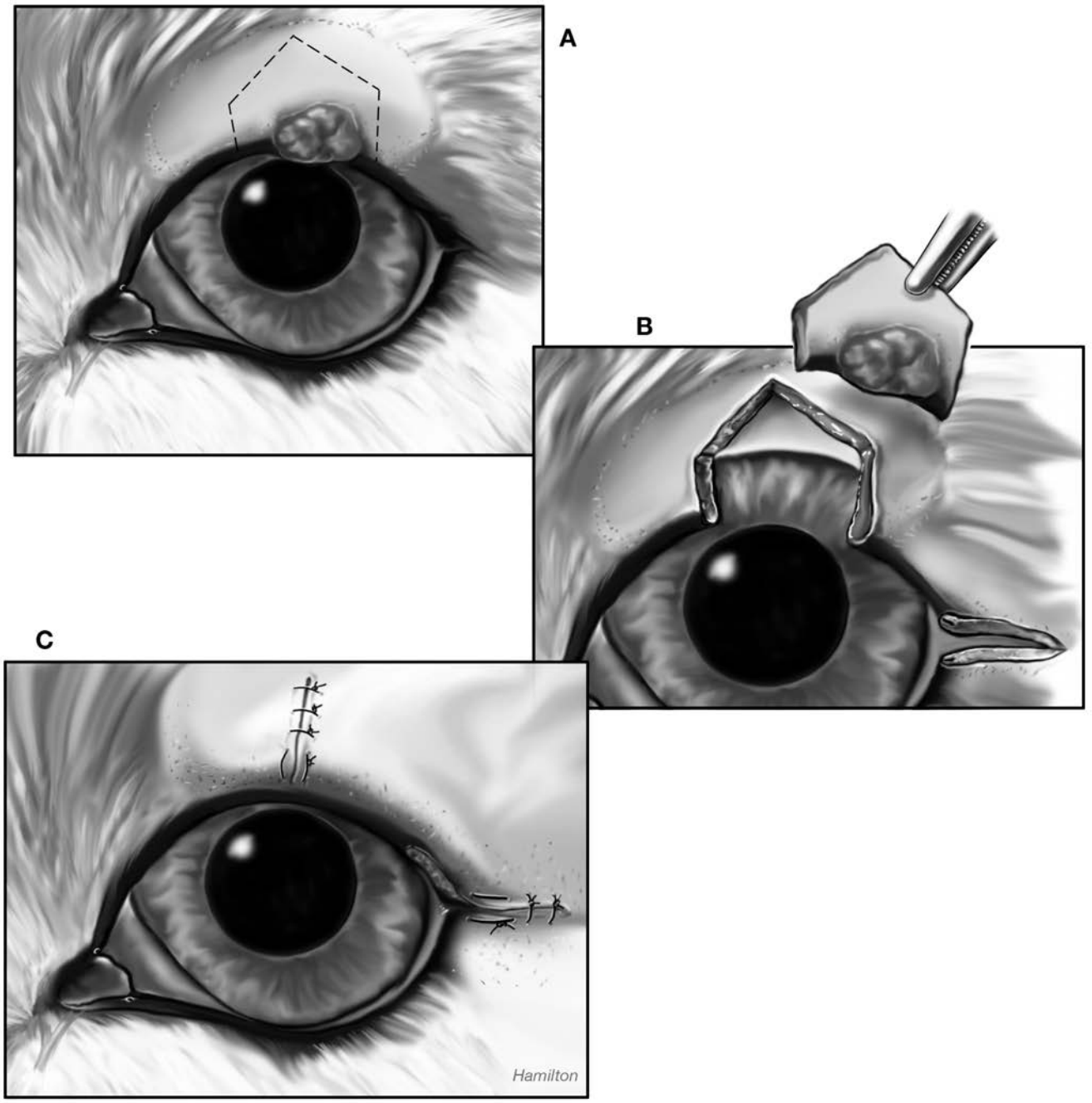


Figure 12-5. Wedge excision for removal of eyelid mass. **A.** Excision of 1/3 or more of eyelid margin to remove an eyelid mass. **B.** Lateral canthotomy is performed from canthus to the depth of the cul-de-sac with a Metzenbaum scissor taking care not to sever the orbital ligament. **C.** The eyelid margin wound is first closed in two layers. The lateral canthotomy is closed as it lies in two layers. This will result in a wound edge of the lateral canthotomy becoming the new eyelid margin. This is allowed to heal be second intention.

cut full thickness from the lateral canthus to the depths of the cul-de-sac laterally being cautious so as to not cut the lateral orbital ligament. This incision (Figure 12-5B) yields less lateral tension, which allows for a more effective two-layer closure of the lid wound. Closure of the lateral canthotomy using the two layer technique leaves a small wound margin at the lateral canthotomy incision to heal by second intention (figure 12-5C).

If one-half or more of the eyelid margin must be excised for tumor excison, a semicircular sliding skin flap is constructed to close the resulting defect. Following excision of the lid mass and a releasing lateral canthotomy (Figure 12-6A), the semicircular skin flap is constructed by making a curved skin incision extending laterally from the end of the lateral canthotomy extending approximately 1.5-2.5 times the width of the void to be filled (Figure 12-6B). Excision of a Burow's triangle of skin at the lateral terminus of the semicircular flap incision will minimize focal terminal distortion upon closure of the wound. The surgeon should use caution in making the skin incision and during undermining of the flap to not damage the superficial temporal artery located subcutaneously lateral to the lateral canthus. A two layer closure of the lid mass excision wound is followed by buried absorbable sutures placed to reduce dead space beneath the skin flap. The skin flap incision is closed in two layers up to the edge of the new lateral canthus. The newly formed eyelid margin created by the skin flap is left to heal by second intention. Complications may include trichiasis from facial hair, a flaccid lower eyelid that permits epiphora, or a flaccid upper eyelid (ptosis) due to excision of the levator palpebrae muscle in the original excision.

Entropion

Entropion is defined as inward turning/inversion of the eyelid(s). The condition is commonly seen in dogs and occasionally in cats resulting in frictional irritation of the conjunctival and corneal surfaces by eyelashes and/or facial hairs of the lid. This frictional

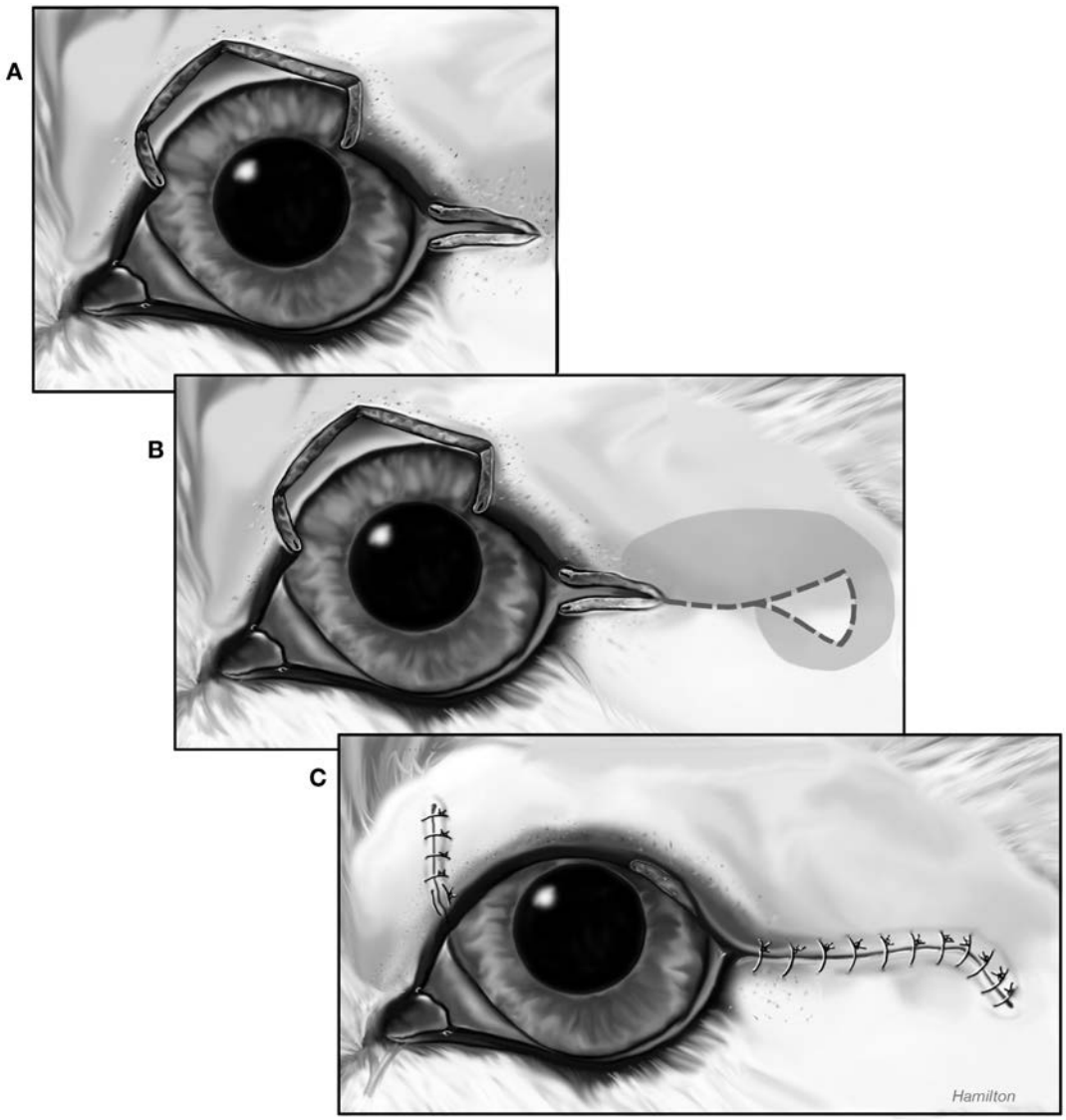


Figure 12-6. Wedge resection of a large eyelid mass with use of a semicircular flap to fill in eyelid margin void. **A.** Excision of 1/2 or more of eyelid margin to remove an eyelid mass in conjunction with lateral canthotomy. **B.** Dotted line indicates the semicircular graft cut and Burow's triangle. Cross-hatching indicates skin to be undermined to allow sliding of the graft. **C.** Eyelid margin excision site is first closed in two layers. Buried absorbable sutures reduce dead space under semicircular graft. Semicircular graft is closed up to the point of lateral canthus in two layers. The semicircular flap makes the new lateral aspect of the upper eyelid; the new eyelid margin is allowed to heal by second intention.

irritation is painful and may lead to corneal ulceration, corneal neovascularization and deposition of pigment on the corneal surface (pigmentary keratitis). In severe cases, vision loss from corneal scarring and opacification, corneal perforation, and loss of the globe from deep corneal ulceration are possible.

In cats, lower lid entropion may be seen in brachycephalic breeds (e.g. Persians and Himalayans) as a conformational defect due to the shortened face. Spastic entropion occurs when an ocular irritant causes severe blepharospasm that leads to rolling in of the eyelid margin. Since the frictional irritation of the facial hairs on the corneal surface causes more pain, spastic entropion becomes a cycle of pain, blepharospasm, and corneal irritation with continued pain and blepharospasm. Spastic entropion may be seen in young cats (< 6 months of age) of the brachycepahlic breeds and in adult cats with corneal pain due to infectious (e.g. feline herpes virus-1) or irritation induced keratitis conditions.

In dogs, spastic entropion is seen in young puppies of breeds (e.g. Shar Peis, Chow Chows, and others) with excessive facial skin and laxity of eyelid structures such as the retractor anguli muscle or ligament. In some puppies, when neonatal ankyloblepharon resolves and the eyelids open at 2 weeks of age, the eyelid margins begin to roll inward due to heavy facial skin and eyelid laxity. In adult dogs, spastic entropion may be seen in animals that have a painful ocular condition leading to excessive blepharospasm similar to that described for cats.

Lower eyelid entropion in dogs is commonly seen in younger dogs (less than one year of age) due to deep-set globes and conformational defects of the eyelids and facial structures. Lower eyelid entropion may also have a spastic component which should be considered when surgically correcting the defect.

Upper eyelid entropion occurs in those heavy faced breeds (e.g. bloodhounds, Shar Peis, Chow Chows, mastiffs, and others) where the extreme weight of the forehead skin and upper lids and a lack of connective tissue structures leads to the upper eyelid margins rolling over onto the ocular surface with the upper eyelashes abrading the corneal surface. Upper eyelid entropion usually has a major spastic component similar to that caused by lower eyelid entropion.

Lateral canthal entropion occurs mostly in heavy faced breeds (e.g. Shar Peis, Chow Chows, mastiffs, St. Bernards, Bernese mountain dogs, English bulldogs, and others) where there is also laxity of the retractor anguli ligament/muscle. This allows the lateral canthal structures to roll inward causing frictional irritation to the cornea and conjunctiva. A spastic component may be seen in cases of lateral canthal entropion. In those breeds (St. Bernard, mastiffs, Bernese mountain dogs, Newfoundlands, and others) with excessively long palpebral fissures (macropalpebral fissure) and lax tarsal plates, a combination of lateral canthal entropion and lower lid ectropion with an upward "notching" of the upper eyelid margin is seen.

Medial canthal entropion is seen primarily in brachycephalic breeds (pugs, Shi Tzus, Lhasa Apsos, and others). The brachycephalic conformation results in the medial palpebral ligament being too tight causing the medial aspect of the upper and lower eyelids to roll inward. Frictional irritation to the corneal surface by the medial canthal hairs and lashes leads to medial corneal neovascularization and subsequent pigment migration (pigmentary keratitis). This form of entropion seldom appears to be painful to the patient and usually does not have a spastic component similar to other forms of entropion.

Temporary Everting Suture Technique for Treatment of Spastic Entropion

Temporarily everting the eyelid margins is an effective method of disrupting the cycle of frictional irritation, pain, and blepharospasm caused by spastic entropion. This technique should always be used in young animals prior to more permanent skin removal entropion repair. It is difficult to evaluate how much tissue needs to be removed in the young patient with entropion, and overzealous tissue removal may result in eyelid scarring and/or ectropion in later life. Likewise, in an adult animal with no history of previous entropion, the practitioner should identify the underlying source of pain, treat that condition, and temporarily evert the eyelids for pain relief rather than performing permanent entropion corrective surgery. A simple technique to evaluate for spastic entropion is to apply a drop of topical anesthetic (0.5% proparacaine) to determine if blepharospasm abates. If topical anesthetic use relaxes the blepharospasm and resulting entropion, a temporary everting technique maintained for 7-10 days may result in resolution of the entropion without tissue excision. *Topical anesthetic is applied as a diagnostic test only and is contraindicated as therapy for spastic entropion.* Topical anesthetics are epithelial toxic, and by deadening the ocular surface to pain and sensation, further damage to the corneal surface may occur.

Periocular hair is shaved and the skin is prepared with dilute povidine iodine and saline. Multiple everting sutures of either a braided or monofilament synthetic (polypropylene or nylon) suture material are placed in the skin. Either vertical mattress (Figures 12-7A-D) or horizontal mattress (Figure 12-7E) sutures are used. I prefer multiple small (5-0 or 6-0) sutures versus fewer larger (2-0 or 3-0) sutures. In young patients, thin, friable skin may not hold a larger suture, and if the suture pulls through the skin, entropion resumes, and a noticeable scar may be present from the resulting defect. Suture placement depends on how much entropion is present. If only the lower lid is involved, only everting sutures involving the lower lid are used. It is not uncommon in Shar Peis, Chow Chows, and bulldogs for entropion to affect the upper and lower lids and lateral canthus (Figure 12-7F), thus everting sutures are placed in all 3 areas (Figure 12-7G). For the vertical mattress suture technique, the first bite into the skin should be very close to the outside edge of the lid margin and the needle directed away from the lid margin. The second bite should be further away from the lid margin so that when the knot is tied with appropriate tension, the eyelid margin is everted from the ocular surface. The suture tag closest to the globe should be cut close to the knot so as to not abrade the cornea while sutures are present. The suture tag directed away from the lid margin should be long to allow for suture removal in 7-10 days. For the horizontal mattress technique, the first bite

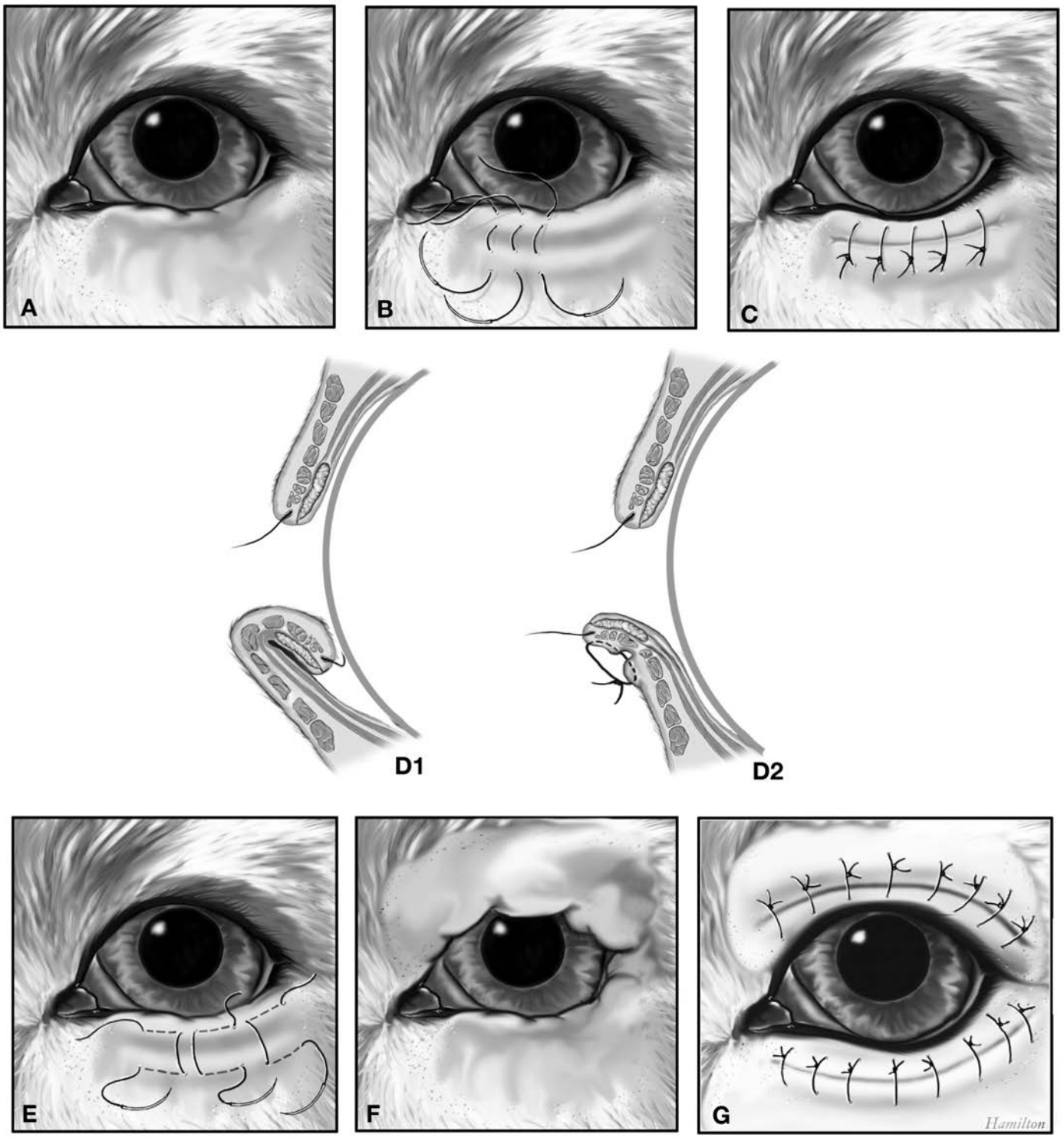


Figure 12-7. Temporary everting suture correction of spastic entropion. **A.** Lower eyelid entropion commonly seen with spastic entropion. **B.** Placement of multiple fine, synthetic vertical mattress sutures to evert the spastic entropion. Sutures may be placed and tied in sequence, or, in very small animals, all sutures may be pre-placed and then tied. **C.** Finished product using vertical mattress temporary everting sutures. Note how the suture tags closest to the lid margin are cut very short and the suture tags away from the lid margin are left long to aid in suture removal. **D.** Cross sectional view of spastic entropion and after temporary everting suture placement. Note that the lid margin is overly everted. This is preferred to prevent the patient from spasming eyelids and causing frictional irritation of the cornea by the sutures. **E.** Placement of horizontal mattress sutures for temporary eversion of lid margins. **F.** Upper, lower, and lateral canthal spastic entropion commonly seen in Shar Pei and Chow Chow puppies. **G.** Suture placement/final product for treatment of upper, lower, and lateral canthal spastic entropion.

should be close to the lid margin and the exit site of the needle equally close to the lid margin. The second bite will be further from the lid margin with the needle path being parallel to the first needle tract/lid margin. After tying the suture, the knot is rotated away from the lid margin and suture tags are cut to avoid corneal irritation. Prevention of post-operative self-trauma (or trauma by the bitch if puppies are still nursing) is important. If the cornea is ulcerated, symptomatic care with topical antibiotic ointment with or without use of atropine for cycloplegia and pain relief is indicated. Sutures should be left in as long as possible (7-10 days) to reduce blepharospasm and recurrence of entropion.

Modified Hotz-Celsus Technique for Correction of Simple Entropion

The simplest technique for correction of lower or upper lid entropion is a modification of the Hotz-Celsus technique used in man. Skin is excised and wound edges are sutured in a manner that everts the entropic area of the lid margin (Figure 12-8A-D). Prior to surgery, it is important to estimate how much tissue must be removed to correct the entropion without causing ectropion. This determination is made based on experience, but there are techniques and surgical landmarks that will aid the surgeon. Prior to patient sedation, a drop of topical anesthetic is placed in the affected eye and the patient placed on an elevated table for examination. The surgeon should examine the patient with magnification without touching the face or periocular structures. This will assist the surgeon in accurately estimating the amount of tissue to be excised. After anesthetic induction, hair removal, and disinfection of the surgical site, the patient is placed in lateral recumbency for surgery. A Jaeger lid plate is placed to tense the eyelid and an incision is made with a scalpel. The saline moistened Jaeger lid plate is placed in the cul-de-sac and an assistant tenses the eyelid by lifting the lid with the lid

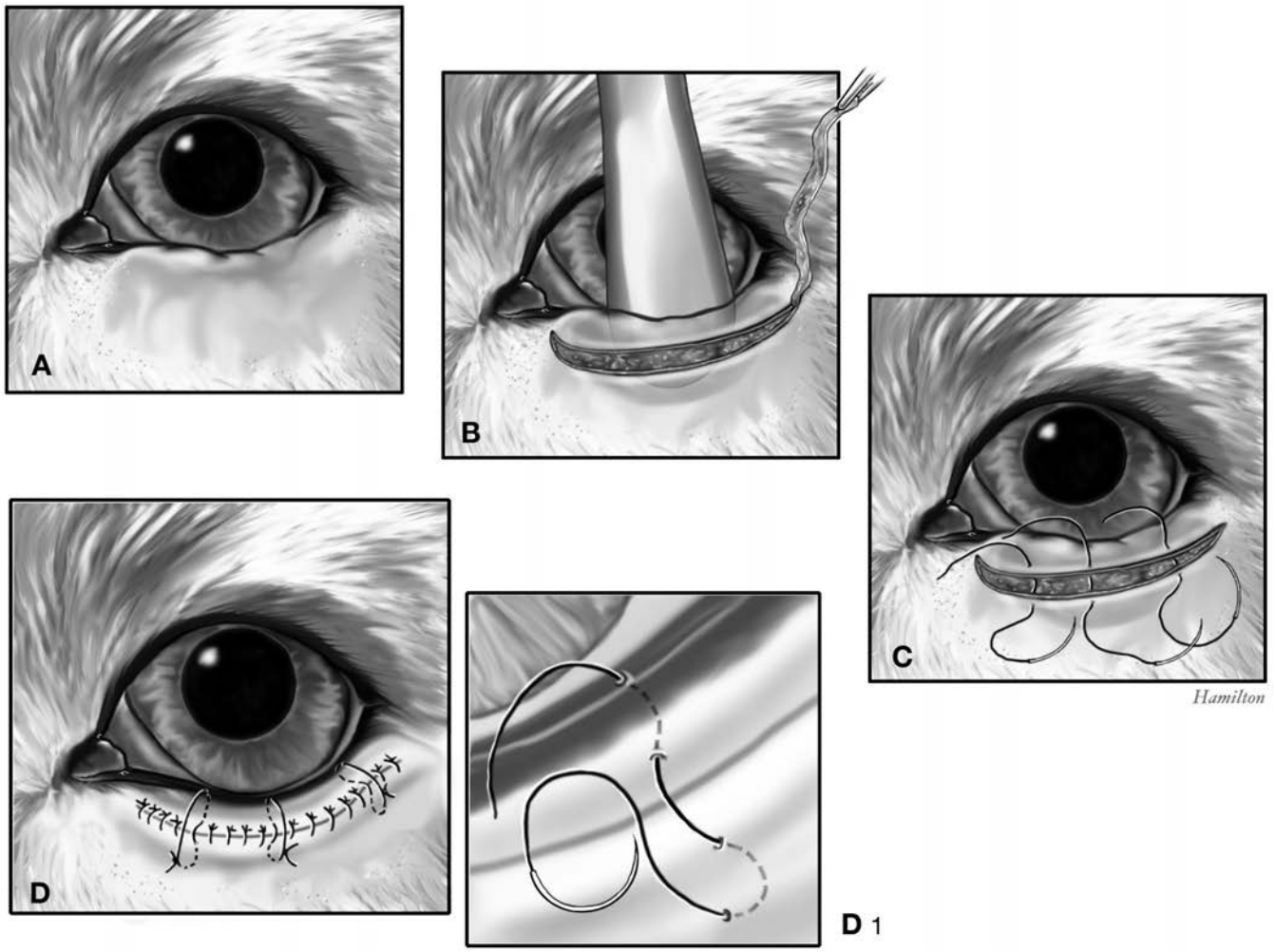


Figure 12-8. Modification of simple Hotz-Celsus procedure for entropion correction. **A.** Lower lid entropion. **B.** With the Jaeger lid plate in position, a smooth tapering skin incision can be made with a scalpel (bold dashed lines). The stippled area represents the area of the lid that was entropic. **C.** After excision of the skin, the Jaeger lid plate is removed and the skin is closed without tension. The first suture (1) is placed to halve the incision line. The next two sutures (2 and 3) are placed so as to quarter the incision line. **D.** depending on size of suture being used, sutures are placed 2-4 mm apart. Note that suture tags closest to the globe are cut short, those directed away from the globe are left long to enhance removal at a later date. Everting vertical mattress sutures are shown (**A, B,** and **C**) in this illustration. These are placed in those dogs with a severe spastic component to their entropion to prevent post-operative spasming with suture tag abrasion of the corneal surface. To accomplish this pattern (see inset), the first pass of the suture is across the wound (1) as with the other simple interrupted sutures to close the wound, and the second pass is through the skin away from the incision (2). When tied, these vertical mattress sutures evert the lid margins just like the everting sutures described above under spastic entropion correction.

plate (Figure 12-8 B). The surgeon uses thumb and index finger placed at the medial and lateral aspects of the area to be incised to tense the tissue for a smoother incision. The incision closest to the lid margin should be made at the level where the eyelid hair begins (lower eyelid) or about 1-2 mm away from the upper eyelashes (upper eyelid). The first incision should be made far enough from the lid margin to allow placement of sutures that will not abrade the cornea during healing. The surgical incisions and resulting wound should only be skin thickness, and no attempt should be made to remove orbicularis oculi muscle or tarsal plate structures. The second incision should be made distal to the initial incision at the point of greatest entropion and join the ends of the first incision in a smooth tapering fashion. The amount of tissue to remove is determined in the preoperative examination prior to sedation and by looking for a line of hair loss or skin discoloration due to the entropion. After the skin incisions, the skin is removed with the scalpel or a fine scissors. Following excision of tissue, the Jaeger lid plate should be removed and the skin sutured as it lies without tension (Figure 12-8C). The first nonabsorbable suture (4-0 or 5-0 monofilament or braided nylon or polypropylene) skin suture should approximately halve the wound defect. The next two sutures should be placed to divide the suture line into quarters. Since the second incision is in the form of an arc, it is longer than the initial skin incision that is parallel to and close to the lid margin. By utilizing a simple interrupted closure, bunching or "dog-ears" of one end of the suture line with a continuous suture pattern is prevented. The fine sutures should be placed close together (2-4 mm apart, depending on the size of the patient and suture size) and the suture tags closest to the eye should be cut close to the knot with the tags away from the eye being left longer. In animals with excessive preoperative blepharospasm and a spastic component to the entropion, intermittent vertical mattress sutures may be placed along the suture line to "overcorrect" the entropion until the skin sutures are removed at 10-14 days post-surgery (Figure 12-8D). In some cases, I "overcorrect" dogs of certain breeds (Chow Chow and Shar Peis) with vertical mattress sutures to prevent post-operative spasming with resulting suture contact of the corneal surface. Post-operative therapy consists of prevention of self-trauma, topical antibiotic ointment for treatment of corneal ulcers, systemic antibiotics, and non-steroidal anti-inflammatory drugs for pain.

"Arrowhead" Technique for Correction of Lateral Canthal Entropion

In those breeds with lateral canthal entropion but a normal length palpebral fissure (e.g. Shar Peis and Chow Chows), a modification of the Hotz-Celsus procedure (termed the "arrowhead" technique) may be used to evert the lateral canthal eyelid skin (Figure 12-9A-D). The Jaeger lid plate is used to tense the tissue, allowing smooth incision of the eyelid skin with a scalpel. The lid plate is placed in the lateral cul-de-sac and tensed upward by an assistant, simultaneously the surgeon tenses the lateral canthal tissue with the thumb and index finger on the upper and lower lids. The initial skin incisions should be approximately 2 mm from the lid margin along the upper and lower lids. Beginning about 6 mm from the lateral canthus, the skin incisions start to diverge from the lid margin and meet 5 mm lateral to the lateral canthus. (Figure 12-9B). This provides the surgeon additional tissue for closeing the resulting defect. The second incision begins at the medial-most extent of the first incision and gradually diverges from the first incisions. The point of intersection of the incisions lateral to the lateral canthus is dependent on how much eversion of the lateral canthus is necessary. In patients with minimal loose facial skin, closure of the "arrowhead" shaped skin incision may be adequate to correct the lateral entropion. In most dogs undergoing this procedure, however, a prosthetic lateral canthal ligament must be constructed to retract the lateral canthus and correct the defect. Prior to closure of the skin, blunt dissection is performed to undermine the skin over the lateral orbital ligament. Either a 4-0 monofilament nonabsorbable (nylon or polypropylene) or polydioxanone suture is used to first take a bite in the lateral most tip of the tarsal plate followed by passage of the suture through the periosteum over the orbital ligament. The surgeon may use two sutures (Figure 12-9C, upper) or a more complex placement of one suture (Figure 12-9C, lower) to pull the lateral canthus laterally and anchor it to the orbital ligament. Skin closure should begin at the lateral-most "point" of the "arrowhead" followed by a suture of the upper and then lower lid as for the traditional Hotz-Celsus technique (Figure 12-9D). In those dogs with upper, lower, and lateral canthal entropion, a skin incision of approximately 270° around the eyelid circumference (Figure 12-9E) may be made to result in correction of all abnormalities with one surgery. Temporary everting sutures as described for the Hotz-Celsus entropion correction are highly recommended in these patients. In patients with a macropalpebral fissure, this "arrowhead" correction technique corrects the entropion, but the ultimate exaggerated lateral placement of the lateral canthus may be cosmetically unacceptable, so the more complex lateral canthal reconstructive surgery described by Bigelbach is indicated.

Modification of Bigelbach's Combined Tarsorrhaphy-canthoplasty Technique for Repair of Lateral Canthal Entropion and Lower Lid Ectropion

In those dogs where a combination of macropalpebral fissure and lateral retractor anguli ligament laxity results in lateral canthal entropion and lower eyelid ectropion (e.g. St. Bernards, mastiffs, Newfoundlands, and similar breeds), a technique to shorten the palpebral fissure and retract the lateral canthus has been described (Figure 12-10A-G).

First, the amount of eyelid to be excised must be determined. From 20 to 30% of the lateral-most upper and lower lids may be removed and still retain normal function and an acceptable cosmetic appearance. The upper and lower eyelid margins are notched with a scissor or scalpel an equal distance from the lateral canthus (Figure 12-10B). The distance from these notches to the lateral canthus (D) is measured. Extending from the lateral canthus, sweeping upward and downward from the lateral canthus and following the general curvature of the eyelids, two skin incisions are made with a scalpel (Figure 12-10C). These incisions are two times D in length. The tips of the two curved incisions are connected by a vertical skin incision, and

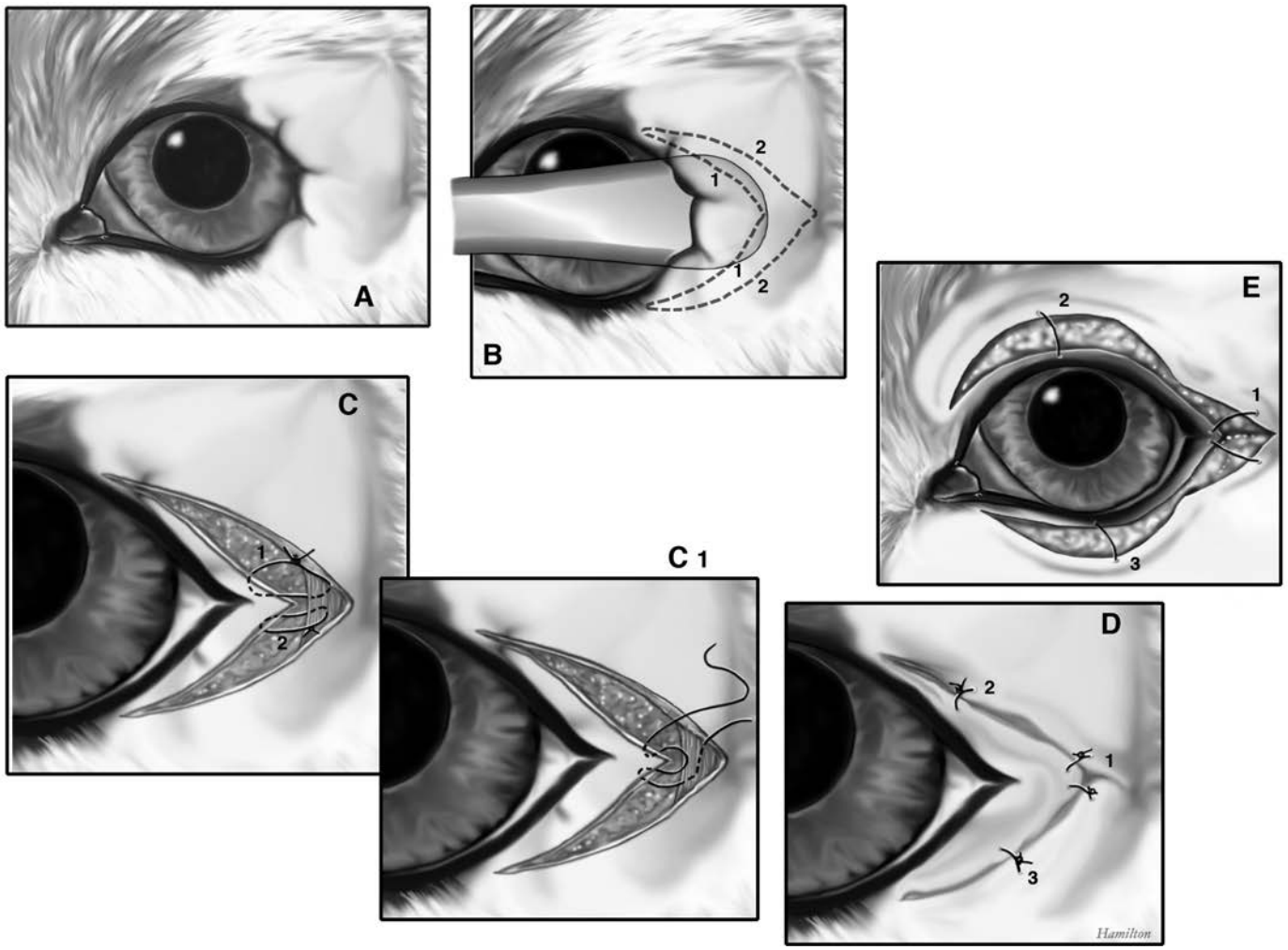


Figure 12-9. "Arrowhead" technique for correction of lateral canthal entropion. **A.** Lateral canthal entropion. **B.** Placement of Jaeger lid plate to tense tissue. Scalpel is used to incise skin as depicted by dashed lines. The incisions (1) 2 mm from the lid margins are made first. Approximately 5 mm from the lateral canthus, the incisions gradually diverge so that where the two initial incisions meet is approximately 5 mm lateral to the lateral canthus. The second incisions (2) diverge from the medial-most tips of the first incisions and meet lateral to the lateral canthus. This outlined skin is excised with a scalpel or small scissors. **C.** In loose skinned dogs, a prosthetic lateral canthal ligament is constructed prior to skin closure. Two sutures (1 and 2, upper diagram) of 4-0 monofilament absorbable or nonabsorbable material are placed to retract the lateral tarsal plates towards the orbital ligament. One continuous suture (lower diagram) may be used instead of two. **D.** Skin closure of the "arrowhead" begins with closure of the lateral-most aspect (sutures labeled 1) followed by closure of the middle of the upper lid incision (2), then the lower lid (3). The remainder of the suture line is then filled in with simple interrupted nonabsorbable sutures like was the case with the Hotz-Celsus procedure described above. **E.** For those patients with complex upper lid, lower lid, and lateral canthal entropion, a continuous upper lid, lower lid, and lateral canthal skin incision may be made. The lateral canthus is closed first (1), followed by closure of the middle of the upper and lower lid incisions (2 and 3). The remainder of the skin closure is as described above.

full thickness lid incisions are made from the original notches to the tips of the sweeping skin incisions using either a scissor or a Jaeger lid plate and a scalpel (figure 12-10D). The skin of the incision triangle is removed with scissor or scalpel, and the full thickness eyelid triangles from the upper and lower lids are removed with scissors (Figure 12-10E). The tarsal plate edges and ends of the severed orbicularis muscle of the upper and lower lids are tacked to the lateral orbital ligament with absorbable suture (5-0 Vicryl or 4-0 PDS) in the same manner as described for the "arrowhead" lateral canthal entropion repair (Figure 12-10E). The upper and lower eyelid stroma is sutured to the subcuticular fascia of the face in a buried, continuous pattern with the same absorbable suture (Figure 12-10F). The skin is closed to align the lateral canthus with the center of the vertical connecting incision (Figure 12-10G) using a single horizontal mattress suture of 4-0 braided nylon or silk. The remainder of the skin incision is closed with simple interrupted sutures.

Medial Canthoplasty to Correct Medial Entropion and to Shorten the Palpebral Fissure (Roberts and Jensen "pocket-flap" Technique).

Reconstruction of the medial canthus in brachycephalic breeds of dogs may correct medial entropion and reduce frictional irritation to the cornea that causes pigmentary keratitis. In addition, the shortening of the palpebral fissure reduces exposure of the cornea, enhances total closure of the lids during blinking and during sleep, reduces frictional irritation from nasal fold trichiasis, and may help to prevent proptosis in predisposed exophthalmic dogs.

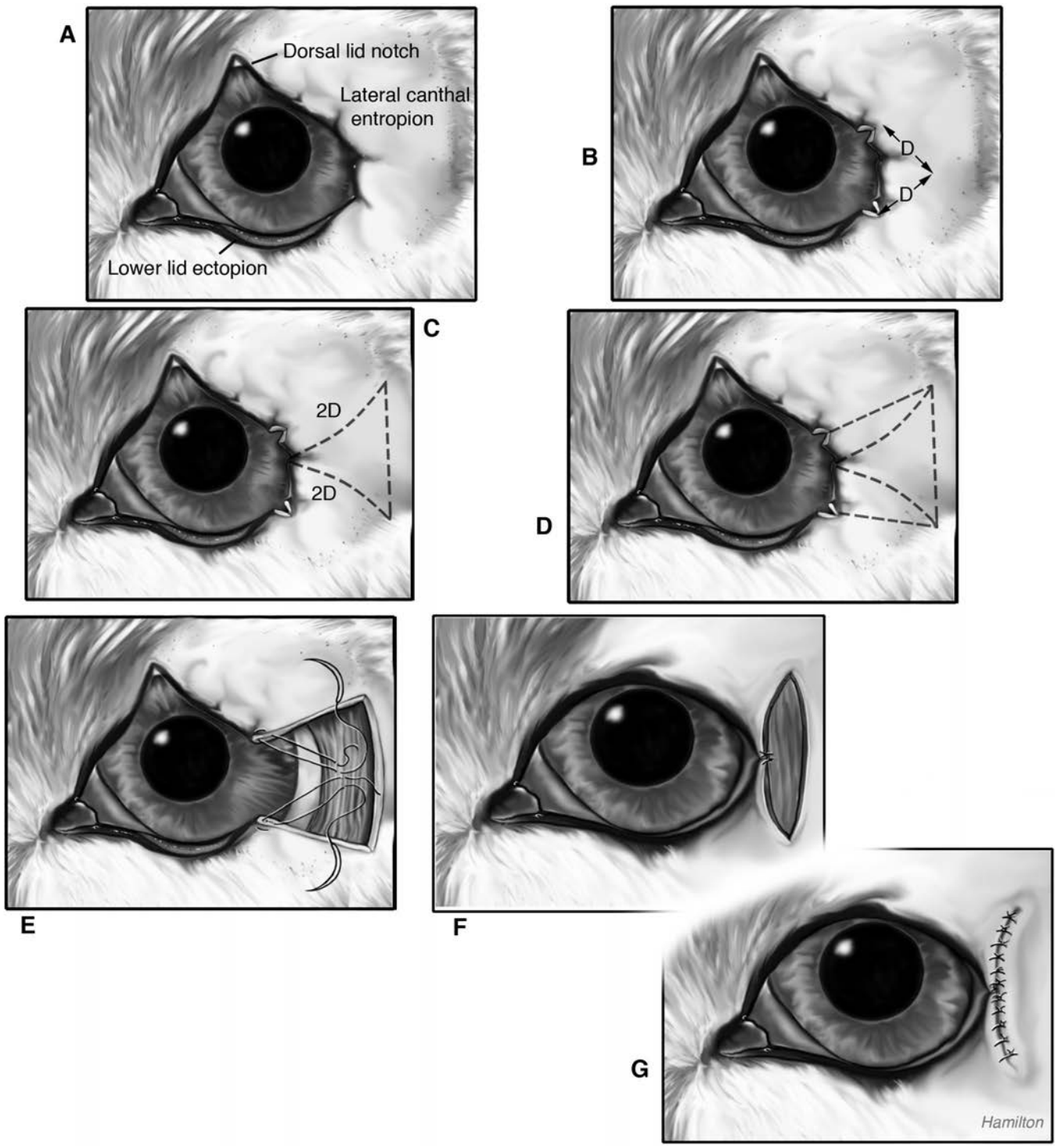


Figure 12-10. Correction of lateral canthal entropion, lower lid ectropion, and macropalpebral fissure (modification of Bigelbach's technique). **A.** Combination lateral canthal entropion, lower lid ectropion, and macropalpebral fissure. Many of these patients also have a defined "notch" of the upper eyelid margin due to tarsal plate malformation. **B.** Upper and lower eyelids are notched with scissor or scalpel. The distance D from notch to lateral canthus is noted. **C.** Sweeping skin incisions that roughly follow the curvature of the lid margins begin at the lateral canthus and extend a distance of approximately two times distance D. The distal tips of these skin incisions are connected with a skin incision. **D.** Using a Jaeger lid plate and scalpel or a scissor, the full thickness of the lids is cut at the previously notched sites extending to the tips of the skin incision. **E.** After removal of the full thickness lid pieces and triangular skin excision, the tarsal plate of upper and lower lids are tacked to a common point on the lateral orbital ligament using absorbable suture. **F.** The tarsal plate/lid stroma are tacked to the subcuticular tissue of the vertical portion of the skin incision. **G.** The points of the skin incisions of the upper and lower lids are sutured to a common point in the center of the vertical skin incision using a horizontal mattress suture of 4-0 nonabsorbable material. The remainder of the skin is closed with simple interrupted sutures of the same material.

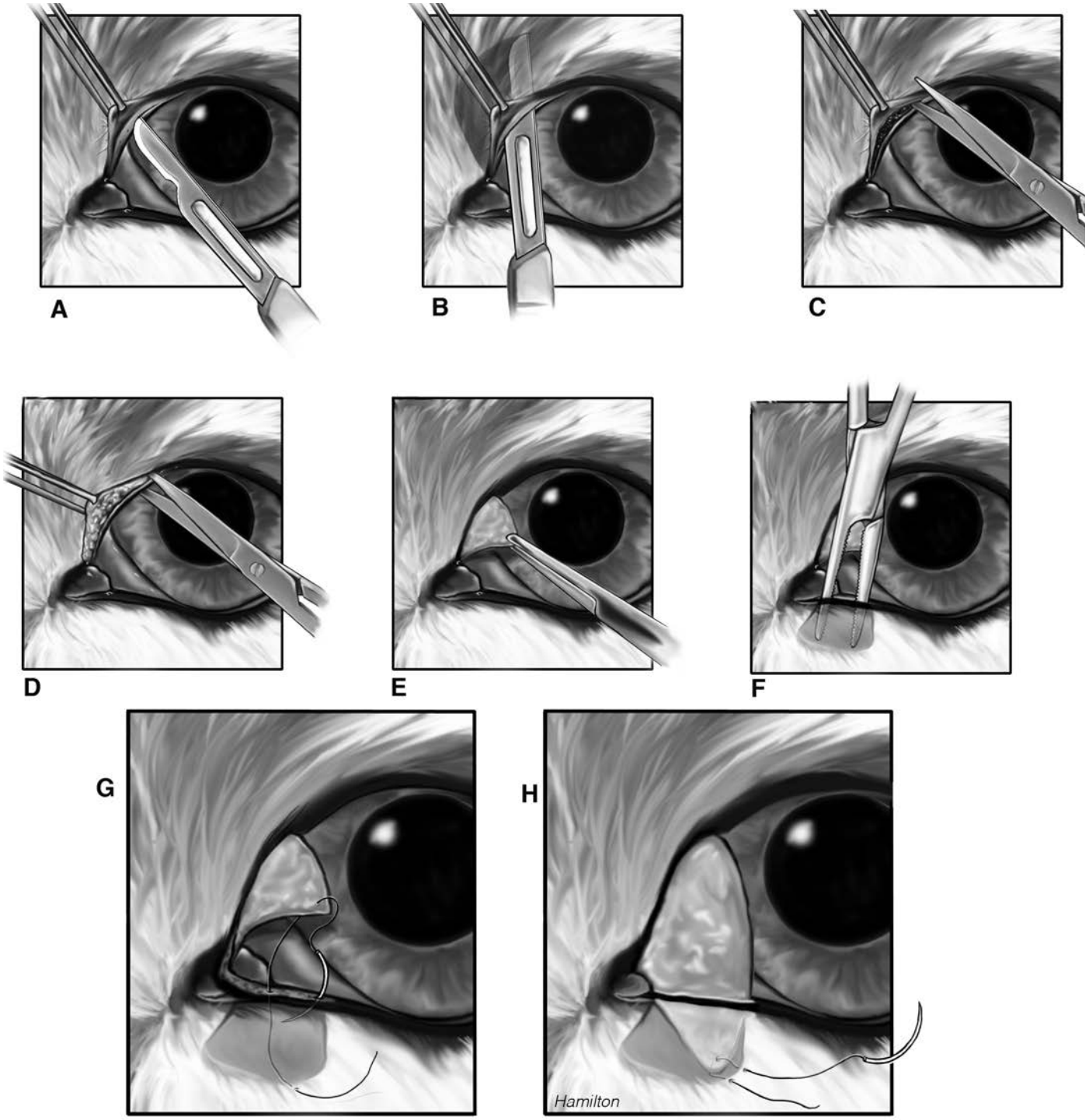


Figure 12-11. Medial canthoplasty technique (Roberts and Jensen "pocket-flap" technique). **A.** With the lid tensed laterally, the eyelid is split at the margin using a scalpel. Both upper and lower lids are split. **B.** The lid splitting is carried to a depth of approximately one centimeter. **C.** Using a small scissor, a strip of lid margin approximately 2 mm wide is excised from the edges of the lid splitting back medially to the medial canthus. The upper and lower lid excisions join at the medial canthus. **D.** A scissor is used to cut the innermost tarsal plate/conjunctival tissue of the upper lid perpendicular to the lid margin to a depth of one centimeter. **E.** The triangular flap of tissue is scarified on the conjunctival surface to the point of hemorrhaging. **F.** To anchor the upper lid flap of tissue into the lower lid pocket, suture is passed through the lower lid skin at the level of the depth of the pocket, into the pocket, and out the split lid margin. A mosquito hemostat passed into the ventral pocket and partially opened makes passage of the needle easier. **G.** The suture is passed through the tip of the flap tissue, and the needle is re-directed back into the ventral pocket and then out through the skin at the depth of the pocket. **H.** The suture is tied as the flap is worked into the deepest recess of the pocket. If non-absorbable silk has been used, the surgeon may choose to place the suture through a stent as described in the temporary tarsorrhaphy procedure. If absorbable suture has been used, the surgeon may choose to bury the suture and knot beneath the skin. **I.** The skin edges are closed with fine suture in two layers as described previously for the eyelid laceration closure.

The eyelid is grasped in the center with tissue forceps and tensed laterally. A #15 Bard-Parker scalpel (or #64 Beaver blade) is used to split the medial aspects of both eyelids (Figure 12-11A) to a depth of approximately 1-1.5 cm to create dorsal and ventral "pockets" (Figure 12-11B). The dissection plane is such that the superficial portion includes the skin, orbicularis muscle and the deep portion is the tarsal plate and conjunctiva. If a simple medial canthoplasty is being performed for medial entropion correction, the dissection extends from the medial canthus laterally to a point 1-2 mm from the nasolacrimal punctae. If the surgery is intended to reduce the size of the palpebral fissure, the dissection can be extended beyond the punctae. It is important to keep the plane of dissection external to the nasolacrimal punctae and their ducts if the dissection extends lateral to the punctae. Using a small tenotomy scissor, the upper and lower eyelid margins are excised from the lateral-most extent of the dissection back to the medial canthus (Figure 12-11C). A strip no more than 2 mm wide should be excised. Next, the tenotomy scissor is passed such that one blade is within the dorsal "pocket" and one blade is within the dorsal cul-de-sac (Figure 12-11D). The tarsal plate-conjunctival tissue is cut perpendicular to the lid margin for a distance of approximately 1-1.5 cm, thus creating a "flap" of tissue based at the medial canthus-upper eyelid (Figure 12-11E). The conjunctival surface of the "flap" is scarified with a scalpel to produce slight hemorrhaging. A small needle armed with 5-0 braided silk or synthetic absorbable suture (Vicryl) is passed through the lower eyelid skin into the ventral-most fornix of the ventral "pocket" and out through the eyelid margin opening (Figure 12-11F). The 5-0-suture needle pierces the tip of the dorsal "flap", and the needle is then passed back down into the deep fornix of the ventral "pocket" (Figure 12-11G) and then out through the skin (Figure 1-11H). When the suture is pulled tight ventrally, this will anchor the "flap" within the deep recess of the ventral "pocket". If absorbable suture is used, a small, partial thickness skin incision is made prior to tying the suture, and the suture knot is buried under the skin surface. If nonabsorbable suture (e.g. silk) is used, the external suture is knotted over a stent in the same manner as that described for temporary tarsorrhaphy. This inhibits the suture cutting into the skin and eases removal of the suture once the wound is healed. The edges of the skin margin of the lids can be closed in two layers similar to closure of a lid laceration (Figure 12-3).

The surgeon should realize that this technique sacrifices the upper nasolacrimal duct. If the dissection extends laterally beyond the ventral nasolacrimal punctum, the inferior duct, although patent, will not likely be functional and epiphora will result. If the dissection extends laterally beyond the punctae, the dorsal "flap" may incorporate Meibomian gland tissue. In this case, excision of glandular tissue prior to burying the "flap" within the "pocket" will prevent cyst formation at a later date due to buried glandular tissue. If the lacrimal caruncle on the palpebral surface of the third eyelid is large with long hairs growing from its surface, the surgeon may wish to excise this tissue and allow for healing by second intention to prevent future frictional irritation of the cornea by the lacrimal caruncle hairs.

Surgery of the Conjunctiva and Cornea

Jamie J. Schorling

Introduction

Conjunctival and corneal surgical procedures are performed to obtain tissue for diagnostic purposes or to reestablish the cornea's anatomic and functional integrity. Important goals for the surgeon include the maintenance of corneal clarity and curvature to preserve adequate optical function. Multiple variables determine the best course of surgical therapy for individual cases, with the primary goal of attaining the best visual outcome for the patient. Prior to proceeding with most corneal and conjunctival procedures, it is ideal to consult with and consider referral to a veterinary ophthalmologist. Consultation with an ophthalmologist will assist in attaining the best possible clinical outcome for the patient.

Anatomy

Surgery of the conjunctiva and cornea requires a working knowledge of the anatomy and physiology of these structures. This knowledge will aid the surgeon in appropriate tissue handling, thereby decreasing surgical trauma and increasing surgical success. The conjunctiva is composed of stratified epithelium overlying a thin layer of loose connective tissue. The palpebral conjunctiva begins at the internal margin of the eyelids and extends posteriorly, reflecting back onto the globe at the level of the fornix, where it becomes the bulbar conjunctiva. The bulbar conjunctiva lies loosely on the surface of the eye until reaching the perilimbal region, where the conjunctiva, underlying denser connective tissue called Tenon's capsule, and sclera become more tightly united. The conjunctival epithelium becomes continuous with the corneal epithelium at the limbus. Lymphatic follicles, goblet cells, blood vessels, and sensory nerves are located in the connective tissue layer of the conjunctiva. Lymphatics drain toward the eyelid commissures, and subsequently to the submaxillary lymph node medially and the parotid lymph node laterally. Goblet cells are individual glandular structures responsible for production of the inner mucin layer of the tear film. Increased densities of goblet cells are noted in the lower nasal and middle fornices and palpebral conjunctiva. The conjunctival vasculature is supplied by the anterior ciliary arteries, which are branches of the external ophthalmic artery, and most of the conjunctival venous drainage is provided by the deep facial vein. Sensory innervation is supplied by the ciliary nerves from the ophthalmic branch of the trigeminal nerve. The conjunctiva is the most exposed mucous membrane of the body and functions to prevent corneal desiccation, facilitate mobility of the lids and globe, and provide a structural and physiological barrier against opportunistic and pathogenic microbial organisms and foreign materials.

The cornea is the anterior fifth of the outer fibrous tunic of the globe, the remainder of which is provided by the sclera. In the dog, the cornea measures 15 mm horizontally and 14 mm vertically, while the cat cornea is slightly larger measuring 17 mm

horizontally and 16 mm vertically. Corneal cross-sectional anatomy consists of five layers, with a thickness of approximately 400 to 800 µm in the dog and 470 to 830 µm in the cat. The outermost layer is the epithelium, comprised of five to seven stratified squamous cells, which are in a constant state of renewal every seven to ten days. A basement membrane lies beneath the epithelium, followed by corneal stroma, which provides approximately 90% of the corneal thickness. Descemet's membrane is the acellular basement membrane of the corneal endothelium, which is a single layer of cells adjacent to the aqueous humor of the anterior chamber.

The cornea functions to protect and support the intraocular contents and to transmit and refract light. To accomplish these functions, the cornea is avascular, has low cellularity, and maintains a relative state of dehydration by a pumping mechanism in the endothelium and lipophilicity of the epithelial and endothelial layers. The corneal layers are thus nourished by the precorneal tear film, aqueous humor, and perilimbal vasculature. The corneal stroma is transparent and consists of parallel bundles of collagen comprising lamellae that span the entire corneal diameter and lie in layered sheets to provide most of the stromal volume. Low numbers of specialized fibroblasts called keratocytes, and leukocytes along with extracellular matrix comprise the remainder of the stroma. The corneal curvature and structural composition in the dog allows for approximately 40 to 42 diopters of refraction, and represents the most powerful refractive surface of the eye.

Instrumentation and Surgical Preparation

Surgical success improves with the appropriate use of specific ophthalmic surgical instruments. A comprehensive review of ophthalmic surgical instrumentation is beyond the scope of this chapter, however a discussion of required equipment is provided. Most surgical procedures involving the conjunctiva and cornea are performed more accurately using magnification. An operating microscope is ideal, although head loupe magnification of 2.5 to 4.5x with appropriate lighting is adequate for many cases.

Ophthalmic surgical instruments are more delicate and have finer tips than general surgical instruments, and specialized care is required to maintain instruments in the best condition. Surgical trays that keep instruments separate and protect the tips should be utilized, and gas sterilization is ideal to maintain instrument life. In contrast to instruments used in general surgery, many ophthalmic instruments have rounded handles and should be held like writing instruments. Many instruments also have spring handles instead of the more traditional finger rings for opening and closing blades. These qualities help minimize hand and arm movements, allowing finger movements to predominate, which provides finer surgical control.

Instruments required for conjunctival and corneal surgeries include tissue forceps, scissors, scalpel handles and blades, and needle holders that accommodate small needles and fine suture. Tissue forceps have three basic designs with regard to the teeth and appositional surfaces. Colibri-style and Castroviejo forceps have protuberant teeth, which aid in grasping and stabilizing tissues without crushing force. Colibri-style forceps are curved, which allow manipulation of tissue while keeping the handle of the instrument out of the magnified surgical field. Bishop-Harmon and similar forceps have teeth at right angles to each other and the handle. These forceps stabilize cut edges, where both sides of the tissue may be gently grasped. The third type of forceps has no teeth, only smooth appositional platforms. These instruments are indicated for tying fine suture material (eg. 6-0 and smaller). They should not be used to grasp tissues, as adequate fixation may only be obtained with crushing force resulting in possible damage to the tissue and instrument. Some Castroviejo and Colibri-style forceps incorporate a tying platform for suture behind the teeth. If the tying platform on these instruments is used, care is taken to avoid grasping and damaging suture with the forceps teeth.

Ophthalmic surgical scissors that are frequently utilized include blunt and sharp tipped tenotomy scissors. Blunt tips are usually preferred, as they are less likely to penetrate delicate tissues. Stevens tenotomy scissors, with ring finger holds, and Wescott scissors, with spring handles are our preference.

The scalpels and handles that are typically used in corneal surgery are Beaver brand. The handles are rounded and should be held like a pencil, and the blades are designed in various shapes. A #64 Beaver blade has a curved tip and cutting surfaces on the tip and on one side of the blade. This blade is used for performing corneal grooves as well as undermining keratectomy sites. Another instrument that may be used for keratectomies is a Martinez corneal dissector, which has a slightly curved semi-sharp blade allowing for dissection between parallel lamellae.

Needle holders have fine curved or straight tips, with either locking or non-locking handles. Most surgeons use slightly curved locking needle holders for corneal and conjunctival procedures. Needles should be positioned in the holders so that the shaft of the needle is perpendicular to the tips of the holders. Spatulated needles with swaged on suture are preferred to minimize disruption of corneal layers. Size 6-0 suture or smaller should be used with ophthalmic needle holders, as larger needles may damage the instrument. In general, 7-0 or 8-0 multifilament absorbable suture material is utilized for conjunctival and corneal procedures in small animals.

Proper patient preparation and positioning are essential for conjunctival and corneal procedures. Most cases require general anesthesia, though some may be performed with topical anesthetic and sedation or short acting anesthetic agents. Anesthetic risk and general patient health are vital considerations, and preoperative evaluation should include a complete physical examination as well as appropriate bloodwork. Excess hair should be carefully trimmed or clipped from the face, and unless infection is suspected and cultures are desired, any discharge or debris should be cleaned from the eye. Surgical scrub solutions should not be applied to the eye, and many antiseptic solutions are irritating to the conjunctival and corneal tissues. Dilute povidone solution (1:10 to 1:50 of the 10% stock solution) is non-toxic and may be gently applied to the eye by

lavage and then removed by rinsing with sterile saline. A cotton-tipped applicator soaked in dilute povidone-iodine is used to clean the cul-de-sacs. In preparation for most conjunctival and corneal procedures, the patient is placed in dorsal recumbency, with the head positioned so that it is stable and the cornea of the eye to be operated is parallel to the table. An eyelid speculum provides increased exposure of the eye and aids visualization of the surgical field, or alternatively, suture may be passed through the skin of the eyelid, parallel to the margin, to aid in retraction of the lids. Hemorrhage should be carefully controlled with dilute (approximately 1:10,000) epinephrine and sterile cotton tip applicators or cellulose sponges. It is essential that the cornea be kept moistened throughout the surgical procedure and is accomplished by dripping saline onto the eye every twenty to thirty seconds. In addition to an eyelid speculum, stay sutures may be placed to stabilize the globe and expose the areas of surgical interest. Stay sutures are placed using 5-0 or 6-0 non-absorbable suture, with the needle passed partial thickness through the sclera and parallel along the limbus. To avoid penetrating the globe, the needle should be nearly parallel to the surface of the sclera is it is passed through the tissue. Tags should be tied and left long to allow manipulation without obstructing the visual field (Figure 12-12). Caution is used to avoid traumatizing the cornea when the stay sutures are manipulated. In general, the globe is stabilized by grasping the tissue near the area of interest, thereby minimizing globe rotation. Tension on the globe caused by tissue retraction is not appropriate, and tension that causes deformation of the globe is dangerous to the health of the eye.

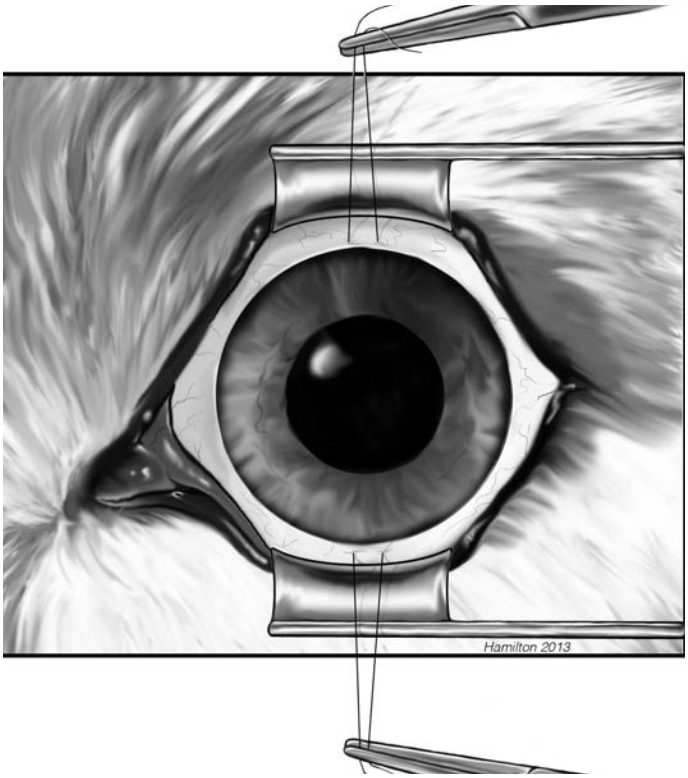


Figure 12-12. The eyelid speculum is placed through the central portions of the upper and lower lid margins to aid visualization. Stay sutures are placed parallel and posterior to the limbus with 5-0 or 6-0 suture material, allowing adequate manipulation and fixation of the globe.

Surgical Techniques

Lacerations

Conjunctival and corneal lacerations are traumatic injuries that often require very different approaches. Preliminary evaluation of conjunctival lacerations should allow the surgeon to localize the wound and assess the extent of the injury. Local swelling, hemorrhage, and patient discomfort may obscure the injury and general anesthesia may be required to explore the wound. The sclera, nasolacrimal system, cornea, and intraocular structures should be assessed for evidence of trauma. The patient is positioned in dorsal recumbency and magnification used to accurately assess the injury. An eyelid speculum or stay sutures are placed to increase exposure. If warranted, the nasolacrimal ducts should be cannulated and flushed to ensure patency. A 22 to 24-gauge intravenous catheter with the stylette removed may be used to cannulate the ducts, and the lids may be stabilized with Bishop-Harmon forceps. Instruments that will assist in wound exploration include Colibri or Castroveijo forceps to grasp the tissues and rotate the globe. Gentle and thorough flushing should be performed with sterile saline. Necrotic tissue should be carefully excised and hemorrhage should be controlled. The wound is systematically explored and evaluated for corneal and scleral injury, trauma to the extraocular muscles and periorbital tissues, and the presence of foreign material. Evidence of extensive trauma increases the short and long term chances of vision-threatening complications, such as endophthalmitis, intraocular hemorrhage, or retinal detachment. A description of surgical repair of extensive globe or orbital trauma is beyond the scope of this chapter, and referral to a veterinary ophthalmologist should be considered. If the wound is obviously contaminated, culture samples should be obtained. A conjunctival wound that is smaller than one centimeter, or one with copious drainage is allowed to heal by second intention. If the wound is larger than one centimeter, closure with 6-0 absorbable suture in a simple continuous pattern is appropriate. Care is taken to avoid suture tags or knots contacting the corneal surface.

Corneal lacerations are assessed differently than conjunctival lacerations. An important to determine the depth of the injury as early as possible. Full or partial thickness lacerations should be differentiated by evaluating for prolapse of intraocular contents, collapse of the anterior chamber, presence of blood or fibrin in the anterior chamber, or a positive Seidel test (apply fluorescein dye to the eye, and look for drainage of aqueous humor from the laceration). If a lens capsule rupture has occurred, lens removal may be required to save the eye from severe lens-induced uveitis. If the laceration is near the limbus, the conjunctiva and underlying sclera should be examined for injury. Assessing for the presence of vision, or of a consensual pupillary light reflex can determine the prognosis for vision prior to proceeding with surgery. In some cases of severe intraocular trauma, the owner and veterinarian must decide whether to attempt to save an avisual globe or consider a salvage procedure, such as enucleation or intraocular prosthesis. For these reasons, referral to a veterinary ophthalmologist is encouraged in cases of full-thickness corneal laceration.

Full thickness corneal lacerations require surgical repair. The

patient is anesthetized and carefully prepared with minimal neck restraint or manipulation of the globe. The patient is positioned in dorsal recumbency and use of an operating microscope is preferred. Prolapsed uveal tissue is either replaced with the aid of a viscoelastic agent and gentle separation of adhesions or excised if the prolapsed tissue is severely desiccated. Fine tipped Colibri forceps are used for corneal and iridal manipulations. Manipulation of iris tissue may cause significant hemorrhage, which must be controlled to avoid serious damage to the eye. Use of 1:10,000 dilute epinephrine will decrease hemorrhage and careful use of a fine-tipped cautery is sometimes necessary. Viscoelastic agents are used to maintain the formation of the anterior chamber while the corneal wound is assessed and repaired. Prior to completion of closure of a full thickness laceration, most of the viscoelastic agent should be flushed from the anterior chamber and replaced with a balanced salt solution.

Corneal tissue does not stretch, so the edges of corneal lacerations, whether full or partial thickness, should not be debrided or excised. Superficial lacerations may heal without surgical repair by application of prophylactic topical antimicrobial ointment. Many lacerations are deep and irregular, requiring placement of interrupted sutures to appose the edges. Sutures should be placed at approximately 75-90% corneal depth using 7-0 or 8-0 absorbable braided suture. In placing corneal sutures, the needle should be directed perpendicular to the corneal surface, approximately one millimeter from the wound edge, depending on the nature of the laceration. As the needle is advanced, the needle holders are rotated and repositioned to allow adequate suture depth and have the needle exit at approximately the same distance on the opposite side of the wound. The suture is tied, using a tying platform, usually with two or three throws on the first knot, so the wound edges are apposed and not crushed. The first suture should be placed near the middle of the laceration, with subsequent sutures placed to divide the remaining length of the wound until closure is complete. Spacing between sutures is usually one millimeter, but adjustments may be necessary for irregular lacerations. Post-operative care is described in the final section of the chapter, and the eye should be reevaluated in five days.

Conjunctival and Corneal Biopsy

The most common indication for conjunctival and corneal biopsies is to identify the cause of abnormal tissue proliferations or chronic inflammatory processes that are not responsive to medical management. Incisional biopsies for sampling small and freely moveable or pedunculated conjunctival lesions may be performed with topical anesthetic and sedation or short acting anesthesia. Unless culture is desired, the eye should be aseptically prepared with dilute povidone iodine solution. Adequate exposure often necessitates placement of an eyelid speculum. A drop of dilute epinephrine or 2.5-10% ophthalmic phenylephrine placed in the eye prior to biopsy will decrease hemorrhage. Incisional biopsies are obtained by stabilizing and placing gentle tension on affected tissue with Colibri or Castroveijo forceps. Stevens or Wescott scissors are used to incise the lesion towards its base, and the excised tissue should be placed in a cassette in ten percent buffered formalin and submitted for histologic evaluation. Conjunctival incisions of less than one centimeter in length do not require primary closure and will heal by second intention. Defects that are larger than one centimeter should be closed with 6-0 absorbable suture in a continuous pattern. Care should be taken to avoid allowing suture or knots to contact the corneal surface. Post-operative care is summarized in the final section of the chapter, and the patient should be rechecked in five to seven days.

If the tissue of interest is expansive or seems firmly adhered to the underlying sclera, there should be suspicion of possible intraocular involvement and more extensive disease. Though an incisional biopsy is still an appropriate initial approach, referral should be considered for ocular ultrasound and additional surgical options. If the lesion is near the limbus, or if it involves the cornea, a superficial keratectomy may be required, as described in a later section of this chapter.

Keratotomy

The primary indications for keratotomies are spontaneous chronic corneal epithelial defects (SCCEDs) that occur in middle-aged to older dogs. These lesions are also known as indolent ulcers, indolent erosions, and boxer ulcers. Ophthalmic examination typically reveals a chronic (weeks in duration), superficial, variably painful, non-infected, and non-progressive erosion or ulceration with a characteristic lip of loose epithelium surrounding the border of the defect. Many patients are reported to have sustained an ocular injury, but the lesion does not heal with topical therapy in an appropriate length of time. Diagnosis is made by clinical signs with the aid of fluorescein staining to evaluate for wicking of stain beneath the poorly adherent corneal epithelium at the edge of the lesion. No specific treatment has been shown to be effective in all cases, but successful therapy has included debridement, striate or punctate keratotomies, corneal gluing, third eyelid flaps, contact lens application, and superficial keratectomies. Most SCCEDs will heal with debridement and keratotomy, but approximately 20 to 30% of animals will require additional surgical procedures and referral to a veterinary ophthalmologist should be considered. To perform debridement of the defect, topical anesthesia is applied, and the patient manually restrained or sedated. Rarely, patients may require short-acting general anesthesia. A dry cotton tipped applicator is swabbed from the center of the lesion peripherally, peeling away loose epithelium in the process. Once the cotton swab is wet with tears, it is less effective and should be exchanged for a dry swab. Epithelium that is poorly adhered to the abnormal underlying stroma is debrided easily with this technique. Debridement is considered complete when a margin of more adherent corneal epithelium is encountered during swab application. The resultant defect will in many cases be considerably larger than the original lesion. For best results in healing, a punctate or striate keratotomy is performed following debridement. Striate (grid) keratotomy is technically easier to perform, with a lower risk of globe injury than punctate keratotomy. Patient restraint may be manual, or sedation or short acting anesthesia may be used. Loupe magnification for the surgeon is ideal. Topical anesthetic is applied, and a 25-gauge needle is held at an approximate 45° angle to the corneal surface with the bevel directed away from

the cornea. The surgeon's hand should rest on the table or on the patient's muzzle. The tip of the needle is then used to lightly scratch the corneal surface, and the pressure applied should be enough to cause a very faint needle mark in the corneal tissue. The scratches extend from normal epithelium across the defect and back into normal epithelium. The resultant grid consists of faint scratches approximately one millimeter apart, crossing in various directions over the lesion. The owner should be warned that the animal will show increased ocular discomfort for several days following the procedure. If successful, complete corneal healing should occur within two to three weeks. These patients should be treated to prevent infection and control inflammation, as described in the Post-Operative Care section, and they should be rechecked in three to seven days to ensure there is no evidence of infection or ulcer deepening.

Superficial Keratectomy

Corneal and limbal proliferations of abnormal tissue and SCCEDs are the most common indication for superficial keratectomies. Keratectomy is also indicated in the preparation of the cornea to receive a conjunctival flap or graft. Ideally, referral to a veterinary ophthalmologist should be considered, as the benefits of an operating microscope and advanced microsurgical skills will increase the success of surgery. The depth of the lesion should be considered prior to surgery, so that surgical planning may include a conjunctival flap if the lesion extends deeper than 30% of corneal thickness. If the lesion to be excised is deeper than approximately 75% of the cornea or if it is full thickness, more advanced or adjunctive surgical procedures may be required, necessitating referral to an ophthalmologist.

The patient is anesthetized, prepared for surgery and positioned in dorsal recumbency. An eyelid speculum and stay sutures are placed as needed to increase exposure of the eye. Topical dilute epinephrine (1:10,000) is used to control hemorrhage. A #64 Beaver blade is used to create a square or circular corneal groove surrounding the lesion. The groove should extend into slightly deeper corneal stroma than the deepest aspect of the lesion (Figure 12-13A). If the lesion is close to the limbus, the groove is made in a semicircular fashion around the lesion and adjacent to the limbal margin. Fine tipped Colibri or Castroviejo forceps are used to grasp the grooved edge of the cornea, and either a #64 Beaver blade or a Martinez corneal dissector is used to undermine the abnormal tissue. If a blade is used, it is held so that the blade is nearly parallel to the corneal surface and small circular motions used to undermine the lesion. A Martinez corneal dissector is held so that the dissecting blade is parallel to the corneal surface, and a sweeping motion is used to advance the instrument (Figure 12-13B). If the limbus is involved, the dissecting instrument is carefully advanced under the limbal tissue approximately two millimeters, using care to remain parallel to the ocular surface. Diseased conjunctiva that is adjacent to a limbal lesion is elevated using regular Colibris forceps and excised using tenotomy scissors. The conjunctiva at the margin of the lesion is tented and a small incision is made. The scissors are then advanced to bluntly undermine the conjunctiva prior to extending the incision, eventually elevating the entire affected region so that the only remaining conjunctival tissue attachments are at the limbus. Curved tenotomy scissors and forceps are then used to incise along the limbus and remove the affected corneal and conjunctival tissue *en bloc*.

The resulting corneal defect if it is less than 30% of corneal thickness does not require a conjunctival flap. If the limbus is involved, a conjunctival advancement, or hood flap may be performed to protect the limbal region and close the orbit. Keratectomy beds > 30% corneal thickness require a graft or flap to re-establish the structural integrity of the cornea, and some of these techniques

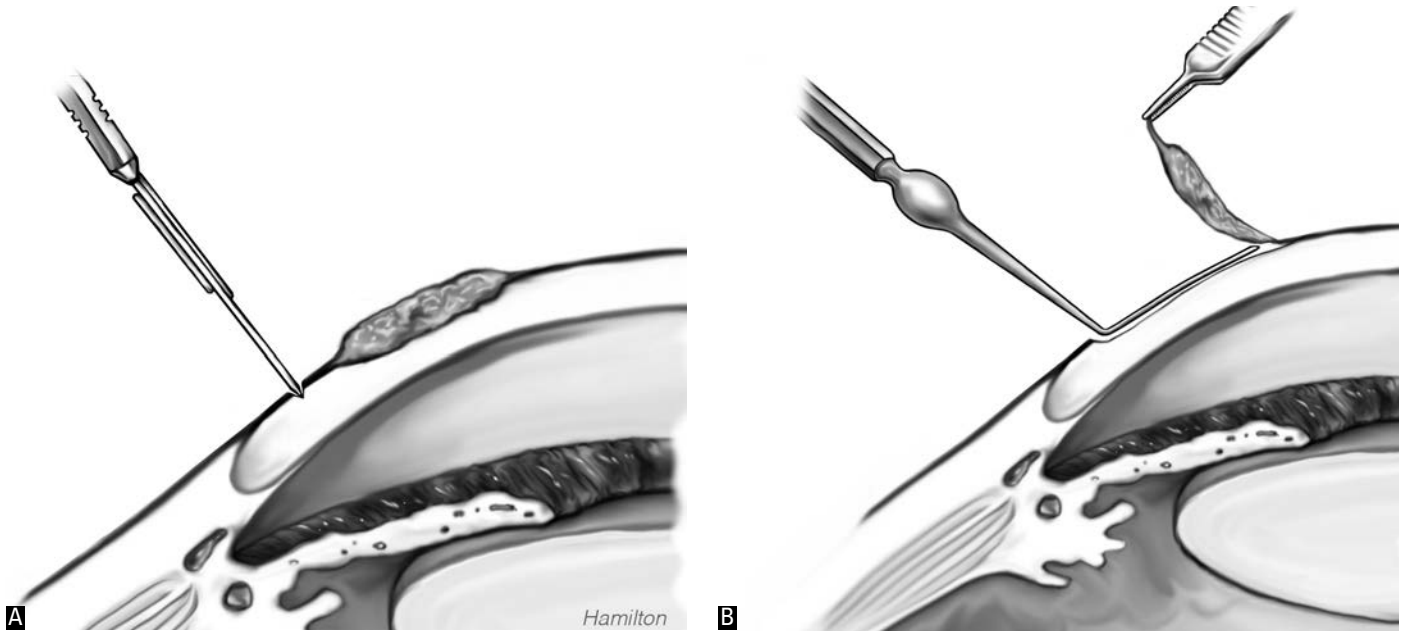


Figure 12-13 A. The cross-sectional view of the cornea demonstrates use of a Beaver blade to groove the cornea to a depth beneath the lesion. The blade is perpendicular to the corneal surface and is advanced to surround the lesion. **B.** The cross-sectional view of the cornea shows a Martinez corneal dissector advanced with a sweeping motion beneath a corneal lesion, with the blade of the dissector aligned with the corneal curvature.

are described in the following section. Post-operative medications are described in the final section of the chapter, and these patients should be rechecked in three to five days.

Conjunctival Flaps and Grafts

Conjunctival flaps and grafts differ in that flaps are attached to the tissue of origin with an intact blood supply, whereas grafts are completely severed from the donor site and must be revascularized from the recipient site to survive. The most common indication for conjunctival flap construction is to repair a loss of corneal integrity caused by keratomalacia, surgical wounds, and traumatic injuries. Corneal sequestra are an additional indication in cats. If corneal tissue is lost, as with keratomalacia, and a corneal perforation has resulted, tissue replacement with keratoplasty procedures may be indicated in addition to conjunctival flap techniques, necessitating referral to a veterinary ophthalmologist. The inciting cause and severity of corneal disease dictates which of the techniques described here are appropriate for use in individual patients. The benefits of conjunctival flaps include provision of physical support to weakened corneal tissue, a direct blood supply to naturally avascular tissue, and a source of cellular components to accelerate healing. Overall, the success rate of conjunctival flap procedures is approximately 90%, however, failure of adhesion, excessive tension resulting in flap dehiscence, flap necrosis, continued leakage of a ruptured globe, and refractory keratomalacia, are examples of complications that may occur following conjunctival flap surgery. In most cases, referral to a veterinary ophthalmologist should be considered, as surgical experience and technique are factors in establishing a successful outcome.

Conjunctival Pedicle Flap

Conjunctival rotating pedicle flaps are the most common type of flap performed by veterinary ophthalmologists. The patient is anesthetized, prepared routinely for ophthalmic surgery and positioned in dorsal recumbency. Use of an operating microscope is recommended for best results. An eyelid speculum and stay sutures should be placed to aid in exposure of the surgical field. The corneal recipient bed is prepared using fine tipped Colibri forceps for stabilization, and the cornea is grooved around the perimeter of the lesion with a #64 Beaver blade. The groove may be rounded or squared, depending on surgeon preference, and the affected stroma within the confines of the groove is removed by a superficial keratectomy. If a keratectomy is not performed, a surgical blade, cellulose sponges, and fine corneal scissors are used to freshen the edges of the corneal defect. The width or diameter of the defect is approximated, and a correspondingly sized or larger piece of conjunctival tissue is obtained for the flap. The donor conjunctival site is typically the dorsolateral bulbar conjunctiva, due to the ease of access and relatively loose adhesions to the underlying connective tissue. However, if the lesion is markedly closer to the ventral limbus, a ventrally based flap may be more appropriate. The base of the flap, which will remain attached to the donor tissue, should be located such that the flap is vertically oriented when positioned over the corneal defect; this reduces friction and drag caused by eyelid motion. In designing a flap, the surgeon plans the width of the flap base to be approximately one millimeter wider than its distal margin. The free or distal margin of the flap is designated by drawing an imaginary horizontal line across the cornea from the ventral aspect of the corneal lesion to the donor bulbar conjunctiva (Figure 12-14A). Due to curvature of the globe, the resultant conjunctival flap will be slightly longer than necessary; however, it is easier to trim away excess tissue than it is to supplement a flap that is too small. Hemorrhage is controlled by use of dilute epinephrine (1:10,000) cellulose sponges, and cotton tipped applicators. The conjunctival tissue is tented gently using regular Colibri or Castroviejo forceps, and a small incision is made using blunt tipped tenotomy scissors approximately two millimeters posterior to the limbus. Conjunctival tissue is undermined by blunt dissection with tenotomy scissors prior to enlarging the incision, and the elevated tissue should be thin, allowing visualization of the scissor blades through the conjunctiva (Figure 12-14B). Care must be taken during dissection to avoid closing the scissor blades until they are completely withdrawn from tissue, as inadvertently cutting small holes in the flap will weaken its integrity. The incision is extended to the predetermined distal point of the flap, staying as close to the limbus as possible. The distal flap margin is then incised by directing the scissors posterior and cutting perpendicular to the initial incision. This incision is approximately one millimeter greater than the horizontal width of the corneal lesion. The third conjunctival incision is parallel to the initial perilimbal incision, with the scissors directed toward the base of the flap. This third incision should be parallel to but shorter than the initial incision to maintain vascular supply to the flap.

As the flap is rotated, the surgeon must ensure that the non-epithelialized surface of the conjunctiva is placed in contact with the corneal recipient site. Placement of the flap with the conjunctival epithelial surface in contact with the corneal defect will result in failure. The donor tissue is positioned over the corneal defect, and should lie where placed without continued traction or tension. If there is tension on the flap, the conjunctival tissue is further undermined to release residual remnants of the white connective tissue, Tenon's capsule. The flap is initially sutured with 7-0 to 9-0 multifilament absorbable suture using simple interrupted sutures placed at the corners of the corneal defect. Needle bites should include approximately one millimeter of flap tissue, and the needle should then enter the cornea at the base of the lesion, along the edge of the defect. The needle should then exit the normal corneal tissue one to two millimeters from the wound margin. The needle is passed cautiously so as to not penetrate the anterior chamber. If inadvertent penetration into the anterior chamber occurs, the suture is completely removed and placed in a different location. The perforation site will heal spontaneously, though some uveitis may occur. Ideally, the suture should penetrate to a depth that approximates 75-90% of the corneal thickness, though slightly shallower suture bites are acceptable for conjunctival flaps. Suture should be tied with two to three throws on the first knot, and the knot should be tied so as to appose but not crush tissue. Additional interrupted sutures are placed by dividing the distance between the initial sutures in half, then in half again, until sutures are spaced approximately one millimeter apart around the three exposed sides of the flap. The fourth side of the corneal lesion covered by the flap of conjunctival tissue close to the limbus is not sutured, as this would compromise vascular supply to the flap. A simple

continuous suture pattern may be used to suture the three sides of the flap rather than interrupted sutures. After corneal suturing, two anchoring sutures are placed from the base of the flap to the limbus on each side. These sutures help to decrease flap tension on the corneal recipient site. Closure of the conjunctival donor site is unnecessary, but may be performed with a simple continuous pattern of 7-0 to 8-0 multifilament absorbable suture. Figure 12-14C demonstrates the appearance of the flap sutured to the corneal surface. The patient should be treated as described in the Post-Operative Care section, and a recheck examination should be scheduled in five to seven days.

Five to eight weeks after surgery and following complete healing of the corneal wound the vascular supply to the flap may be severed to improve the cosmetic appearance of the eye. Ideally, corneal vasculature should reach the surgical site prior to incising the flap. Incising the flap is performed with manual restraint or with a combination of light patient sedation and ocular topical anesthesia. A drop of dilute epinephrine or 2.5 to 10% ophthalmic phenylephrine will help to control hemorrhage. The bridge portion of the flap, which is not attached to the cornea, is gently elevated with Castroviejo forceps, and a blunt tipped scissor blade is inserted between the flap and the corneal surface. As the scissor blades are closed the flap is cut and the free margin retracts toward the limbus. The remaining tag of tissue is then trimmed near the limbal attachments. Complications of this procedure include necrosis of the remaining island graft, iatrogenic corneal ulceration from the scissors, and mild

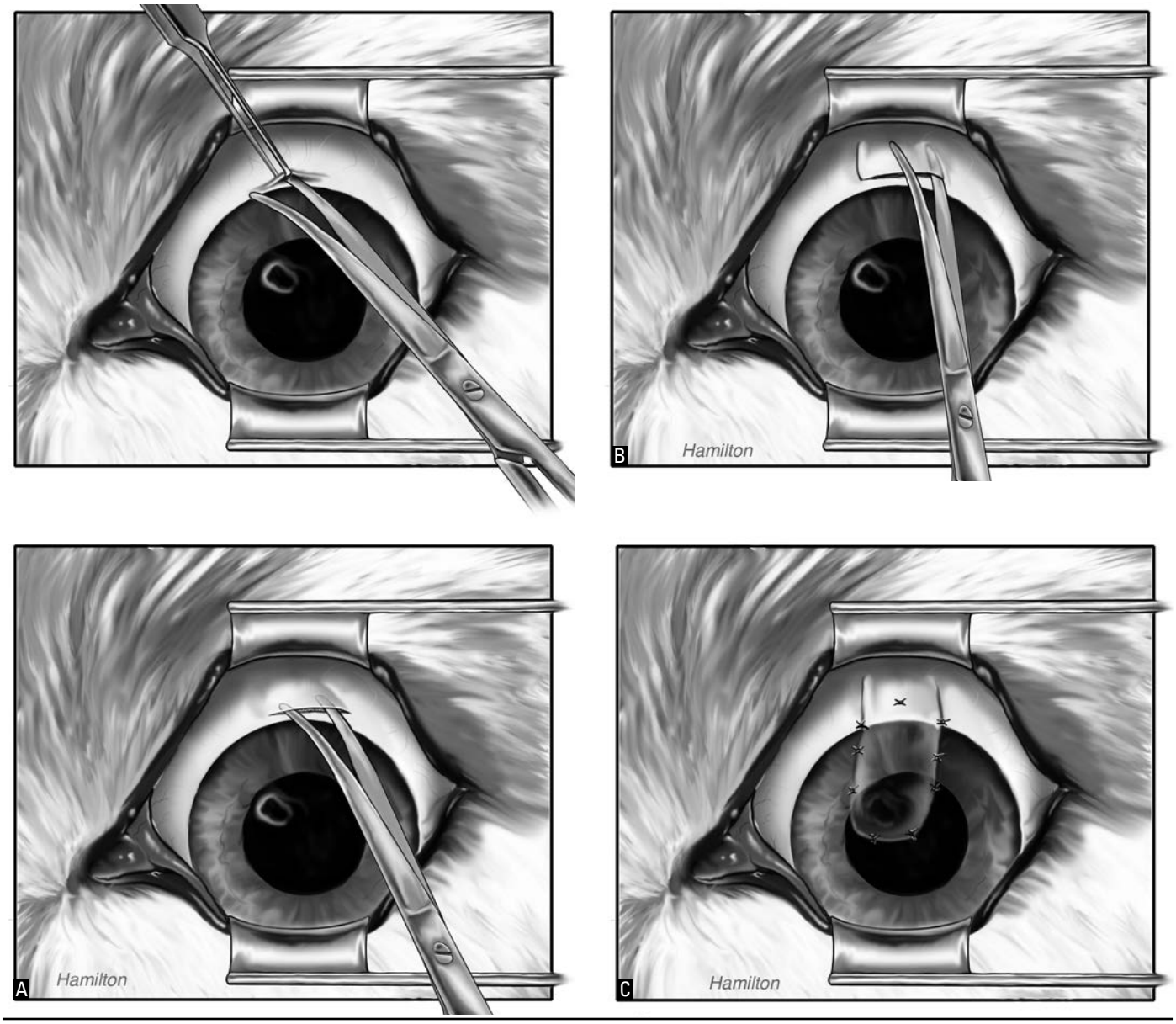


Figure 12-14. A. In elevation of a conjunctival flap, the conjunctiva is gently tented with Colibri style forceps and tenotomy scissors are used to incise the conjunctiva and bluntly dissect the thin conjunctival tissue from the underlying Tenon's capsule. **B.** Once the thin conjunctival tissue is elevated and undermined, tenotomy scissors are used to incise along the ventral extent of the flap, perpendicular to the limbus. An incision is then made parallel to the limbus and towards the flap base resulting in a flap approximately 1mm greater than the width of the corneal lesion. **C.** The conjunctival flap has been rotated into place and sutured along the three free margins to the corneal defect. Anchoring sutures are also placed where the flap traverses the limbus.

ocular discomfort for 2 to 3 days while the conjunctival incisions heal. Patients should be treated for five to seven days with prophylactic topical antimicrobials, and rechecked in two to three weeks.

Conjunctival Bridge Flap

The indications for performing conjunctival bridge flaps are similar to those for pedicle flaps. However, some ophthalmic surgeons feel that bridge flaps are more appropriate for exophthalmic breeds, providing for increased protection of the corneal surface during healing. The technique is similar to that described for pedicle flaps, with the exceptions described here. There is no distal or free margin to bridge flaps. The parallel conjunctival incisions extend 180° around the bulbar conjunctiva, leaving attachments dorsally and ventrally. The freed central portion of the flap is then placed onto the surface of the cornea, so that the lesion is completely covered (Figure 12-15). Only the medial and lateral edges of the corneal lesion are sutured to the corresponding edges of the conjunctival flap. Suturing the dorsal and ventral aspects of the flap would compromise vascular supply. Anchoring sutures are placed from the edges of the flap through the limbal tissues, both dorsally and ventrally. Postoperative management is similar to that for pedicle flaps, and these flaps are often severed after complete corneal healing occurs (5 to 8 weeks postoperatively) to release the nonadherent dorsal and ventral aspects of the tissue bridge.

Conjunctival Hood Flap

Conjunctival hood, or advancement flaps are indicated for perilimbal lesions of the cornea (Figure 12-16). The corneal recipient bed is prepared as described for rotating pedicle flaps. A perilimbal conjunctival incision is made by tenting the tissue with Colibri-style forceps and incising it with tenotomy scissors. The conjunctiva is then undermined in a direction radiating outward from the initial incision, extending posteriorly toward the fornix.

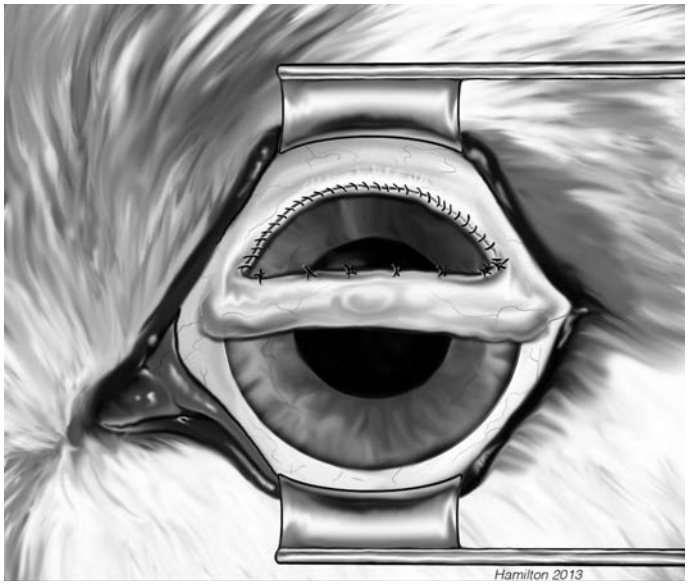


Figure 12-15. Placement of a conjunctival bridge flap with sutures on the medial and lateral aspects of the corneal lesion. Anchoring sutures are placed where the flap traverses the limbus dorsally and ventrally.

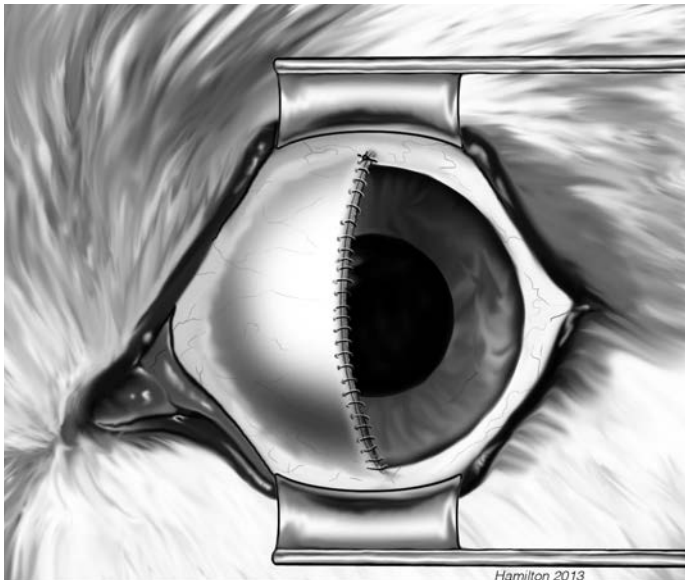


Figure 12-16. A conjunctival hood flap is advanced and sutured over a perilimbal corneal lesion.

The perilimbal incision is then extended to a distance one to two millimeters beyond the corneal lesion. The conjunctival tissue is advanced over the corneal defect. Interrupted sutures using 6-0 to 7-0 multifilament absorbable suture are placed from the edges of the advanced conjunctiva through the limbus so that the conjunctival hood completely covers the corneal lesion without tension. The conjunctiva is sutured to the edge of the corneal defect with absorbable multifilament 7-0 to 8-0 suture material. Postoperative management techniques are similar to those described for pedicle flaps.

360° Conjunctival Flap

The 360° conjunctival flap causes severe visual compromise and is considered a salvage procedure when most of the corneal surface has been severely damaged. The procedure is technically easier to perform than other conjunctival flaps, as no corneal sutures are needed. A perilimbal conjunctival incision is performed for 360°, and the conjunctival tissue is undermined posteriorly. The tissue is advanced over the cornea, and the cut edges of the conjunctiva are sutured in a simple interrupted or continuous pattern with 7-0 multifilament absorbable suture. Patient care postsurgically is described later.

Conjunctival Graft

Conjunctival grafts are performed by completely excising a portion of conjunctival tissue and then suturing the free tissue graft to a corneal defect. The graft provides structural support to the cornea, however the benefits of an intact vascular supply and cell-mediated healing provided by a flap are absent as the graft has no vascular supply. Indications for performance of a conjunctival graft are limited to chronic, inactive lesions that involve greater than 75% of corneal stromal loss. Corneal vascularization should be present at or near the edge of the corneal defect. Preparation of the corneal recipient bed is described earlier with conjunctival pedicle flap construction. The conjunctival donor graft is usually harvested from the dorsal or lateral

bulbar or tarsal conjunctiva. The conjunctiva is incised with tenotomy scissors and undermined. The final donor graft should approximate the shape of the recipient bed, and should be approximately two millimeters larger in diameter. The conjunctival graft is carefully placed onto the corneal defect with the non-epithelialized surface in contact with the cornea. The suture material and suturing technique is similar to that described for conjunctival flaps. Initially, the four corners or quadrants of the graft are sutured to the cornea. Additional sutures should be placed so that the distances between the previously placed sutures are divided equally. Post-operative management is similar to that described for conjunctival pedicle flaps.

Post-Operative Care

Post-operative care is similar for many patients following corneal or conjunctival surgery. Frequent recheck examinations are recommended in most cases to monitor for progress or possible postoperative complications. Broad spectrum topical antimicrobials are indicated to prevent post-operative infection and should be applied three times daily. More specific and aggressive therapy may be required in cases where established infection is recognized by culture and microbial sensitivity, and application frequency should be increased to every two to four hours in some cases. Autologous serum has antiproteolytic properties that inhibit corneal melting and supplies various growth factors that may assist in early post-operative healing, however, care must be taken to avoid microbial contamination of serum. The frequency of topical application varies from three to eight times daily, depending on the case. In cases of corneal melting, additional anti-proteolytic effect may be obtained using systemic doxycycline (5 mg/kg PO BID). Systemic antimicrobials are also indicated in cases of full thickness corneal defects or infected wounds. Secondary uveitis is treated with topical atropine applied once or twice daily for its mydriatic and cycloplegic effects. Systemic antiinflammatories, such as nonsteroidal anti-inflammatory drugs are indicated to decrease post-operative discomfort and inflammation. In many cases, a temporary tarsorrhaphy, will help to protect the eye during the initial postoperative period. An Elizabethan collar should be used to prevent self trauma, and exercise should be restricted during the initial two to three weeks of post-operative healing.

Suggested Readings

Gelatt KN, Gelatt JP: Surgery of the cornea and sclera In Gelatt KN, ed.: Small Animal Ophthalmic Surgery. Woburn: Butterworth-Heinemann, 2001, p 180.

Gilger BC, Whitley RD: Surgery of the cornea and sclera In Gelatt KN, ed.: Veterinary Ophthalmology (ed 3). Philadelphia: Lippincott Williams and Wilkins, 1999, p 675.

Herring IP: Corneal surgery: instrumentation, patient considerations, and surgical principles. Clin Tech Small Anim Pract 18:152, 2003.

Hollingsworth SR: Corneal surgical techniques. Clin Tech Small Anim Pract 18:161, 2003.

Slatter D: Cornea and sclera In Slatter D, ed.: Fundamentals of Veterinary Ophthalmology (ed 3). Philadelphia: Saunders, 2001, p 293.

Imbrication Technique for Prolapsed Third Eyelid Gland Repair

Stacy E. Andrew

Introduction

Prolapse of the gland of the third eyelid (also known as "cherry eye") is a common occurrence in dogs less than 1 year of age. A breed predisposition has been noted in Boston terriers, Cocker spaniels, Bulldogs, and other brachycephalic breeds. Presenting complaints include ocular discharge, conjunctivitis and unacceptable cosmetic appearance due to protrusion of the gland above the third eyelid.

Because of its importance in tear production, replacement of the prolapsed third eyelid (TE) gland to its normal anatomic location is strongly recommended rather than excision of the gland. While numerous surgical techniques have been described for gland replacement, the two most frequently utilized procedures will be described in this chapter. The first technique is creation of a conjunctival pocket which is tried first in all cases. The second technique fixes the gland to orbital periosteum and is used for recurrent gland prolapses or with the pocket technique if the gland is chronically prolapsed and extremely hypertrophied.

Pocket Technique (Morgan Method)

Instrumentation Required

Small Bishop-Harmon forceps with 0.3 mm wide tips, 2 curved mosquito forceps or towel clamps, tenotomy scissors (Stevens or Westcott), an eyelid speculum (Castroviejo or Barraquer), needle holder (Castroviejo or Barraquer), and absorbable 6-0 suture material (polyglactin 910 or polyglycolic acid).

Surgical Procedure

The patient is placed under general anesthesia and positioned in sternal recumbency. The third eyelid surfaces as well as the periocular haired lid surfaces are swabbed three times with dilute (1:50) povidone-iodine solution. The affected eye is draped with either a sterile, disposable drape or with towels. An eyelid speculum is placed to retract the upper and lower eyelids. The leading edge of the TE is grasped with either mosquito forceps or towel clamps placed near the medial and lateral attachments of the TE to the globe. The clamps are used to maneuver the TE by retracting the lid forward and slightly dorsal such that the bulbar aspect of the TE is exposed.

A curvilinear incision is made in the conjunctiva with tenotomy scissors parallel to the base of the TE gland closest to the fornix (Figure 12-17A). The conjunctiva is best handled with small (0.3 mm) Bishop Harmon forceps. A second incision is made 2 to 3 mm from the free margin of the TE parallel to the gland (Figure 12-17B). The length of the incision corresponds to the length of the exposed gland, but usually approaches 1 cm. The incisions should not converge at either end. It is necessary to leave an

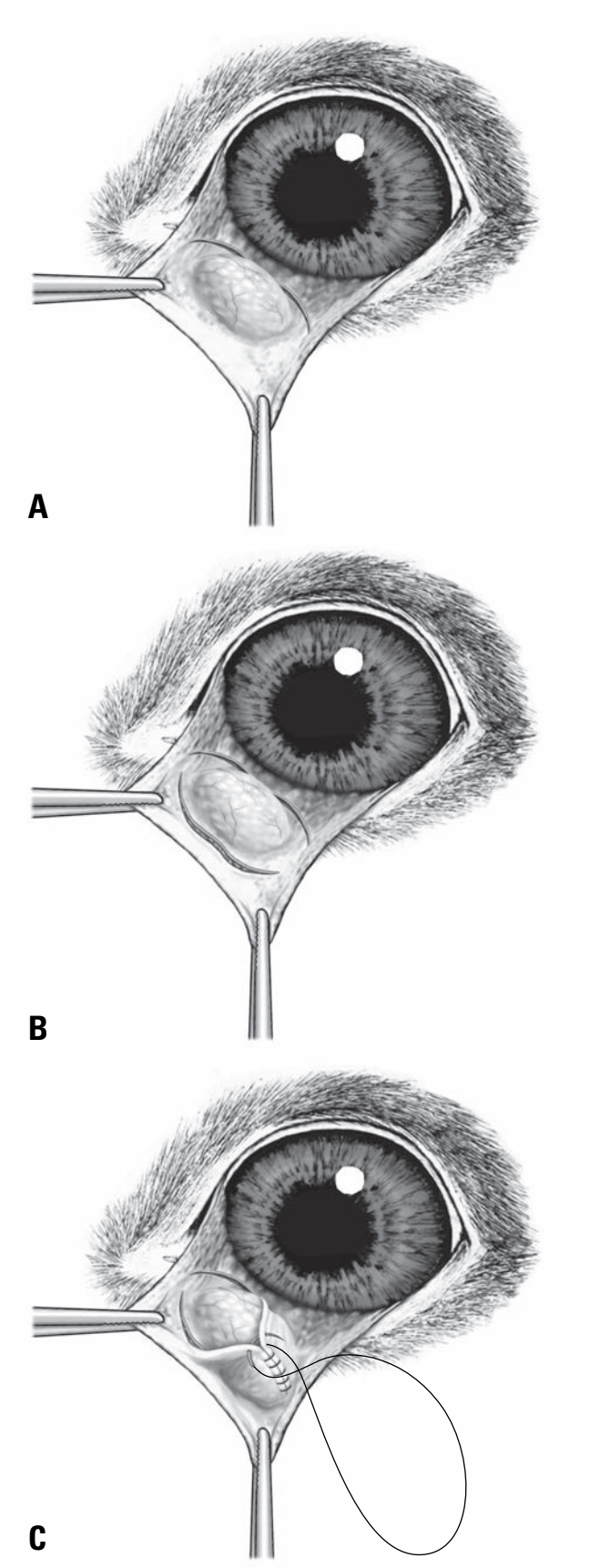


Figure 12-17. A. A curvilinear incision is made in the conjunctiva with tenotomy scissors parallel to the base of the TE gland closest to the fornix. **B.** A second incision is made 2 to 3 mm from the free margin of the TE parallel to the gland. **C.** The incisions are closed so that the third eyelid conjunctiva covers the gland.

area at both ends of the gland that is not incised to allow secretions from the gland to exit onto the ocular surface and not cause cyst formation.

The incisions are then closed so that the third eyelid conjunctiva covers the gland. (Figure 12-17C). A knot is tied on the anterior or palpebral surface of the third eyelid and the needle passed through the lid to the posterior or bulbar side near one end of the incision. The incisions are closed in a simple continuous pattern with 6-0 polyglactin 910 or polyglycolic acid. At the far end of the incision, the needle is again passed through the third eyelid and the knot is tied on the palpebral TE surface. This prevents the suture knots from causing corneal irritation or ulceration.

Postoperative Care

Animals are discharged and owners instructed to apply triple antibiotic ophthalmic ointment 3 times daily for 5 days. The TE gland will likely remain swollen for 2 to 3 days postoperatively, sometimes up to 7 to 10 days, and then return to more normal conformation. An Elizabethan collar may be necessary if the animal shows any tendency to traumatize the eye (s).

Orbital Tacking (Stanley Modification of the Kaswan Technique)

Instrumentation Required

Bard Parker blade (#11 or #15), small Bishop-Harmon forceps with 0.3 mm wide tips, 2 curved mosquito forceps or towel clamps, tenotomy scissors (Stevens or Westcott), eyelid speculum (Castroviejo or Barraquer), Derf needle holder, and 3-0 nylon on a cutting needle, 6-0 polyglactin 910, needle holder (Castroviejo or Barraquer).

Surgical Procedure

The patient is placed under general anesthesia and positioned in sternal recumbency. The hair ventral to the eye and over the zygomatic arch is clipped. The third eyelid surfaces as well as the clipped site are swabbed three times with dilute (1:50) povidone-iodine solution. The affected eye is then draped with either a sterile, disposable drape or with towels. A 5 mm long skin incision is made with a #11 or #15 Bard Parker blade, parallel to and just ventral to the periorbital rim (Figure 12-18A). An eyelid speculum is placed to retract the upper and lower eyelids. A second incision is made in the center of the ventral conjunctival fornix with tenotomy scissors on the anterior or palpebral side of the third eyelid (Figure 12-18B).

Using nylon suture, the needle is inserted through the skin incision and a portion of periosteum from the ventral orbital rim is engaged. The needle is then directed to exit the incision in the conjunctival fornix. The leading edge of the TE is grasped with either mosquito forceps or towel clamps placed near the medial and lateral attachments of the TE to the globe. The bulbar surface of the TE is then exposed by retracting the TE forward and slightly dorsal.

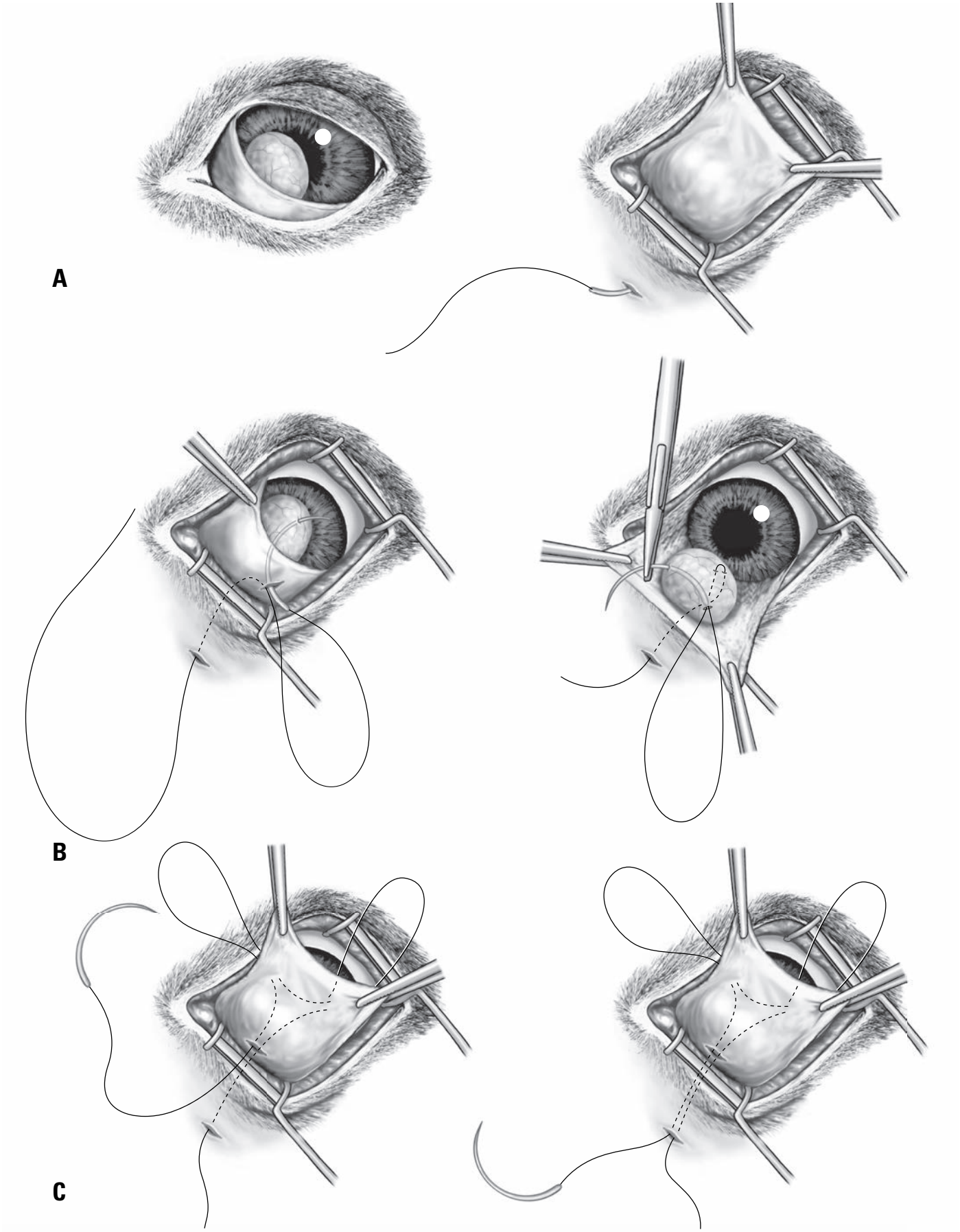


Figure 12-18. Orbital Tacking Technique. **A.** A 5 mm skin incision is made parallel to and just ventral to the periorbital rim. **B.** A second incision is made in the center of the ventral conjunctival fornix on the anterior or palpebral side of the third eyelid. **C.** Suture material anchors the gland to the periosteum.

Suture material is used to penetrate the gland in multiple directions to anchor it to the periosteum. The needle is inserted through the gland toward the leading edge of the TE and then back through the exit hole to cross horizontally or parallel to the leading edge (Figure 12-18C). The needle is passed back through the exit hole and directed towards the ventral fornix so that it emerges from the initial conjunctival incision. All suture should be covered with conjunctiva. The TE is then reflected back to its normal position and the suture needle is passed back beneath the skin to engage the orbital periosteum a second time. The nylon is tied in a secure knot being careful not to place too much tension on the suture and restrict the movement of the third eyelid. The conjunctival incision may be left open or closed with 6-0 polyglactin 910. Similarly, the skin incision may be left open or closed with nylon.

Postoperative Care

Animals are discharged and owners are instructed to apply triple antibiotic ophthalmic ointment 3 times daily for 5 days. An Elizabethan collar should be applied if the animal shows any tendency to traumatize the eye or surgical site. This technique may result in some TE immobilization which is usually not clinically significant.

Enucleation and Orbital Exenteration

Ian P. Herring

Some ophthalmic diseases or their consequences necessitate enucleation or orbital exenteration. Generally, enucleation refers to removal of the globe, whereas exenteration refers to removal of the globe and all orbital contents. The indications for enucleation and exenteration are different and are discussed in this chapter.

Pre-Operative Preparation and Surgical Positioning

Preoperative preparation of the surgical site is similar for enucleation and exenteration. Clipping the eyelids and liberal clipping of the periocular facial skin is recommended. Surgical scrubs are generally not used on or around the eye ,and although less important when the eye is to be removed, precautions to prevent surgical scrub contact with the contralateral eye are warranted. Dilute povidone-iodine solution (1:10 to 1:50 dilution of a stock 10% solution) is an effective topical antiseptic for surgical preparation and can be safely applied to the eyelids and corneoconjunctival surface. Perioperative intravenous antibiotic administration is also recommended.Surgical positioning is largely a matter of surgeon preference. I generally place dogs in lateral recumbency and rotate the head so that the palpebral fissure is near horizontal.

Enucleation

Indications for enucleation include most causes of a blind and painful eye. Specific diseases that often lead to enucleation in small animals include end-stage uncontrolled glaucoma, septic endophthalmitis, irreparable globe perforation and irreparable globe proptosis. Dogs with chronic glaucomatous eyes are good candidates for implantation of an intrascleral prosthesis, a surgical alternative that should be considered. Intraocular neoplasms constitute an additional indication for enucleation. However, depending upon the specific neoplasm, age of the animal and presence of secondary ocular complications, the necessity of and preferred timing for enucleation is variable. Many intraocular neoplasms follow a benign course with regard to metastasis (e.g. canine anterior uveal melanoma), whereas others commonly metastasize (e.g. feline diffuse iris melanoma). Additionally, some intraocular neoplasms are amenable to surgical resection or treatment by laser ablation. Consultation with and referral to a veterinary ophthalmologist is encouraged with cases of ocular neoplasia.

The two most commonly utilized methods for enucleation in dogs and cats, transconjunctival and transpalpebral will be described. The tissues removed with both approaches are the same and the approach utilized is often a matter of surgeon preference. However, there are specific clinical indications for utilizing the transpalpebral method. The transpalpebral method is indicated in cases where sepsis or neoplasia involves the corneoconjunctival surface, as the closed conjunctival sac formed with this approach serves to prevent orbital contamination during surgery. I prefer the transconjunctival approach in most cases due to improved visualization and less operative hemorrhage than with the transpalpebral technique. With either approach, a minimum of traction should be applied to the globe during surgery. Excessive globe traction or orbital pressure may stimulate an oculocardiac reflex, which causes bradycardia and is occasionally fatal. Additionally, excessive traction may result in trauma to the optic chiasm or contralateral optic nerve, causing vision loss or blindness in the contralateral eye. The latter complication is a particular concern in cats.

Transconjunctival Approach

Preoperative preparation involves periocular hair clipping and aseptic preparation of the eyelids and ocular surface utilizing dilute (1:10-1:50) povidone-iodine solution. Placement of an eyelid speculum improves visualization. Additionally, a lateral canthotomy is often helpful in cats, dogs with tight eyelid apertures and chronic glaucoma cases where severe buphthalmos encumbers globe removal through an intact eyelid opening (Figure 12-19).

Utilizing curved scissors, a 360° incision is made through the conjunctiva and Tenon's capsule to expose the sclera (Figure 12-20). Placement of this circumferential incision 2-3 mm posterior to the limbus and leaving a small rim of conjunctiva adherent to the eye is useful, as the surgeon can grasp this tissue to fixate the eye during subsequent globe manipulations. Next, the scleral insertions of the rectus and oblique extraocular muscles are identified and transected (Figure 12-21). Muscles can be identified easily by placing one blade of a curved scissor on the posterior surface of the globe and sweeping it anteriorly. The scissor blade will slip underneath the muscle belly and as it is drawn anteriorly will

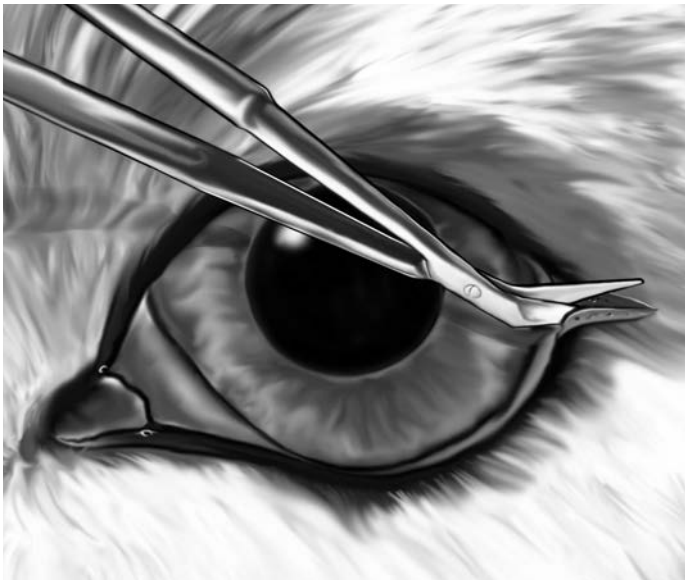


Figure 12-19. Lateral canthotomy improves surgical exposure.

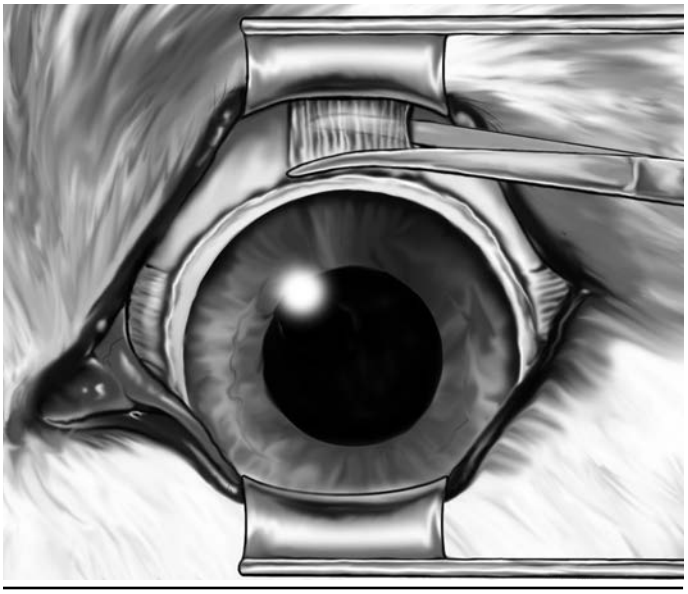


Figure 12-21. Extraocular muscles are identified using the scissor blade in an anterior sweeping motion and are transected at their scleral insertions.

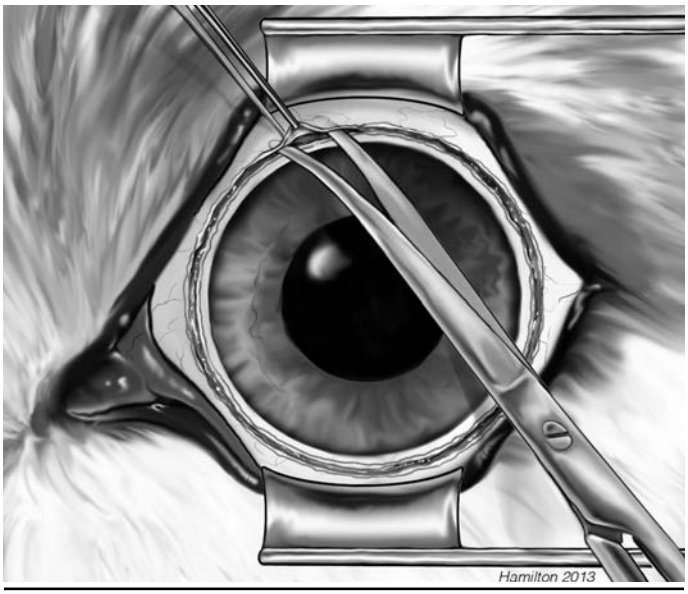


Figure 12-20. Circumferential conjunctival incision placed 2-3 mm posterior to the limbus exposes the sclera and provides a rim of conjunctival tissue attached to the globe to facilitate manipulation.

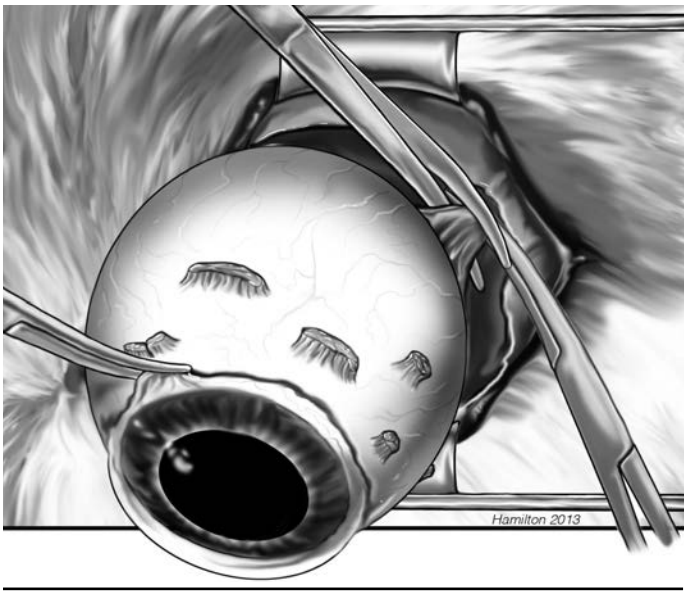


Figure 12-22. The optic nerve bundle is severed, with or without prior placement of a hemostatic clamp.

stop at the muscle's scleral insertion, at which point the scissors are closed to transect the muscle tendon. Muscle transection is performed at the level of scleral insertion rather than mid-body to reduce hemorrhage. The retractor bulbi muscles are then severed by sliding curved, blunt-tipped scissors posteriorly along the scleral surface and gently cutting the muscles at their scleral insertions. After all extraocular muscles have been severed, the globe should rotate rather freely. A curved hemostat is used to clamp the optic nerve and associated vasculature prior to transecting these structures between the clamp and globe using curved scissors (Figure 12-22). The clamp may be left in place for several minutes during subsequent steps of the surgery to maintain hemostasis. Although seldom necessary, absorbable suture can be used to ligate the optic nerve and associated vasculature prior to removing the hemostat. Again, traction on the optic nerve should be minimized. Some surgeons advocate not using a hemostatic clamp at all by simply transecting the optic nerve and achieving hemostasis with gauze packed into the orbit for several minutes following globe removal.

After the globe is removed, the nictitating membrane (3rd eyelid) and its associated gland are excised, followed by removal of the remaining conjunctival tissue.(Figures 13-23 and 13-24) The lacrimal gland can be identified in the dorsolateral region of the orbit and excised, although cyst formation seems rare even when the gland is left in situ. Finally, the margins of the eyelids are removed using Mayo scissors. Excision of the eyelid margins must incorporate the meibomian glands which requires removal of

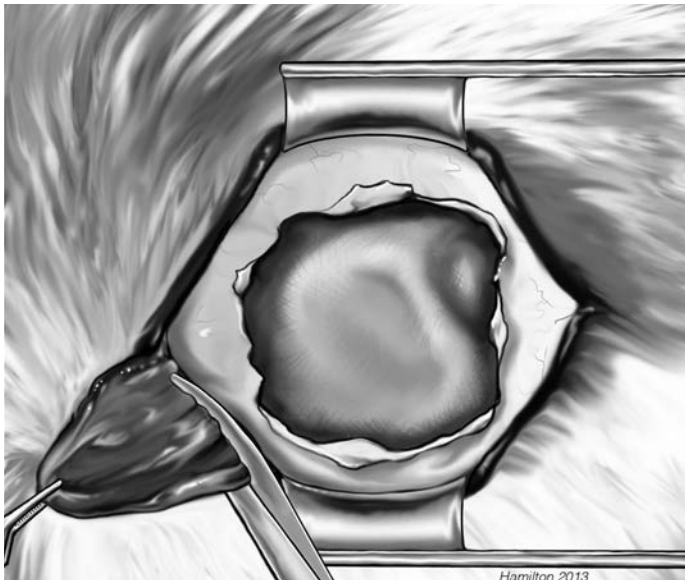


Figure 12-23. The nictitating membrane and associated gland are excised.

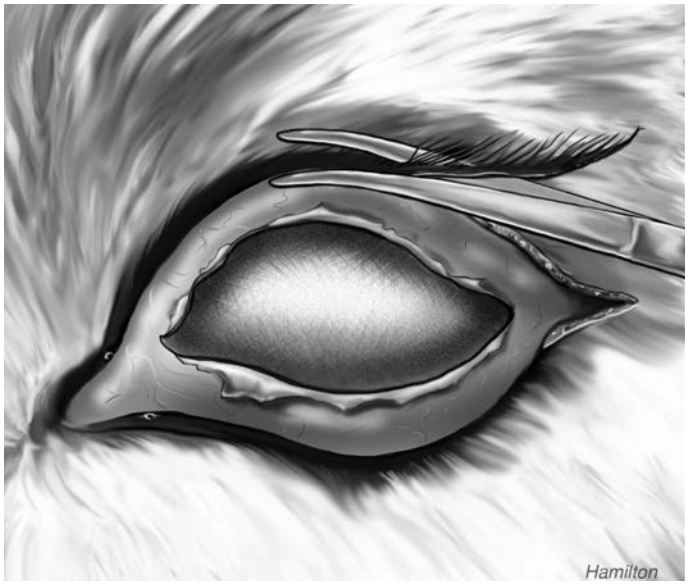


Figure 12-24. Removal of the eyelid margins should incorporate the meibomian glands, necessitating removal of approximately 4-5 mm of eyelid margin tissue.

approximately 4 mm of marginal eyelid tissue (Figure 12-25). Due to the presence of secretory structures, failure to excise the lacrimal or meibomian glands may lead to intraorbital cyst formation and dehiscence of the surgical closure.

Prior to wound closure, the orbit is flushed copiously with isotonic sterile irrigating solution. A silicone prosthetic sphere can be placed which improves post-operative cosmesis by preventing the sunken appearance associated with the anophthalmic orbit. Closure involves apposition of the deep orbital fascia using 3-0 to 5-0 absorbable suture in a simple continuous pattern. If a silicone sphere is placed, the deep orbital fascia is sutured over the sphere. Subcutaneous closure is performed using 4-0 to 5-0 absorbable suture in a continuous pattern. The skin is closed with 4-0 to 5-0 non-absorbable suture material in a simple interrupted pattern.

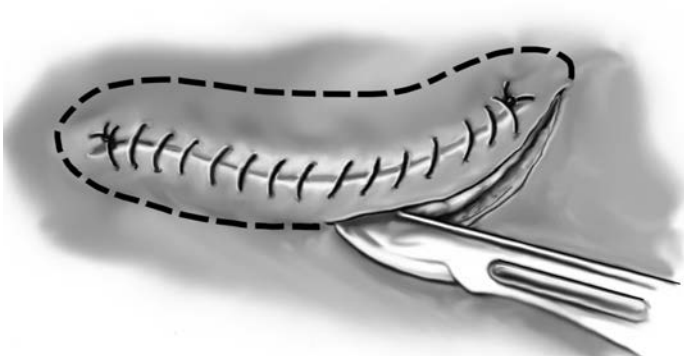


Figure 12-25. Following suture closure of the eyelids for transpalpebral enucleation an elliptical skin incision is performed, incorporating the meibomian glands of the eyelids.

As an alternative to placement of a silicone prosthetic sphere, 3-0 to 4-0 non-absorbable suture can be used to span the rostral orbital opening to prevent post-operative sinking of the skin. This suture is anchored in orbital periosteum and run back and forth across the orbital opening to form a tight meshwork of suture. This is performed after closure of the deep orbital fascia and prior to skin closure.

Transpalpebral Approach

Presurgical preparation of the surgical site is identical to that described for the transconjunctival approach. The eyelids are apposed and sutured shut using 3-0 nylon in a continuous pattern. An elliptical skin incision is made with a scalpel paralleling and 4-6 mm from the eyelid margins, converging at the medial and lateral canthus (Figure 12-26). The medial and lateral canthal tendons must be severed completely before progress can be made in dissecting down to the sclera. Although not required, Allis tissue forceps can be placed on the apposed eyelid margins to aid in subsequent globe manipulations. A combination of blunt and sharp dissection using Metzenbaum scissors is used to

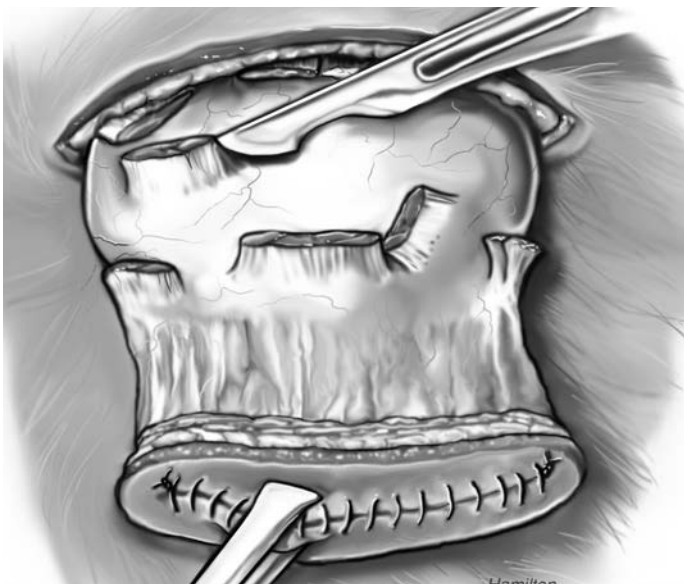


Figure 12-26. After penetrating the orbital septum, dissection to the sclera reveals extraocular muscles, which are transected at their insertions.

approach the conjunctiva. Care must be taken not to penetrate the conjunctival surface or the aseptic advantage of the transpalpebral technique is lost. If the conjunctiva is inadvertently incised in cases of ocular surface neoplasia or sepsis, the hole in the conjunctiva should be closed before continuing with dissection. Dissection to the scleral surface just posterior to the limbus allows identification of the rectus and oblique extraocular muscles, which are transected at their scleral insertions. The retractor bulbi musculature is then transected at or near their scleral insertions. The optic nerve is then transected after liagation of the nerve and its vasculature with absorbable suture. Depending on the extent of dissection in the dorsolateral aspect of the orbit, the orbital lacrimal gland may or may not be incorporated in the tissues removed. This can be confirmed by careful palpation in the dorsolateral region of the orbit. After the orbit is irrigated copiously with sterile isotonic solution, surgical closure is performed as described for the transconjunctival approach.

Exenteration

Exenteration refers to the surgical removal of the eyelids, globe and all orbital contents including the conjunctiva, extraocular muscles, orbital lacrimal gland, nictitating membrane and associated gland, orbital connective tissue and orbital fat. The most common indications for exenteration include extrascleral extension of intraocular neoplasms and primary orbital neoplasms that are not surgically resectable without concurrent removal of the globe. However, if orbital neoplasms have invaded the bony structures of the orbit or extended beyond the confines of the orbit, exenteration would be palliative and more aggressive surgical procedures such as orbitectomy should be considered. Rarely, medically uncontrollable orbital infection may necessitate exenteration.

Exenteration is generally performed in a manner similar to transpalpebral enucleation, with wider excision margins to incorporate removal of the orbital contents, including the globe, extraocular muscles, nictitating membrane and gland, orbital lacrimal gland and orbital fat. Occasionally, removal of periosteum is indicated, as when neoplastic disease abuts this tissue. The eyelids are sutured shut with 3-0 monofilament suture in a continuous pattern. A surgical blade is used to perform an elliptical skin incision outside of the eyelid margins as for transpalpebral enucleation. This incision may be carried further from the eyelid margins, as necessary, to ensure removal of diseased tissue. However, sufficient skin must be left to allow skin closure without tension on the suture line. Following completion of the skin incision, subcutaneous dissection is continued to the bony margin of the orbit, where the orbital septum is incised. Bands of connective tissue that attach the medial and lateral canthus to the orbital wall, the medial and lateral canthal ligaments, must be sharply incised. The goal of the remainder of the surgery is to continue dissection towards the orbital apex, staying outside of the extraocular muscle cone. Blunt dissection is continued with Metzenbaum scissors and should follow the bony wall of the orbit dorsally and medially proceeding towards the orbital apex. The origin of the ventral oblique muscle is encountered ventromedially and is incised. Dorsolaterally, dissection should proceed underneath the orbital ligament, using care not to transect this structure. Ventral dissection should avoid trauma to or excision of the zygomatic salivary gland, unless it is involved in the disease process, in which case it should also be removed. When dissection to the orbital apex is complete, a curved hemostat is placed around the optic nerve and extraocular muscle cone near the posterior wall of the orbit and these structures are transected with curved Metzenbaum scissors near the clamp. A ligature using absorbable suture is placed around the optic nerve and vasculature posterior to the clamp. The orbit is then irrigated with sterile isotonic solution prior to wound closure.

Two layer wound closure is performed as described for enucleation. Since more extensive orbital tissue removal occurs with exenteration, the sunken appearance of the orbit will be greater than occurs with enucleation. Post-operative cosmesis can be improved by the use of non-absorbable suture material to bridge the anterior opening to the orbit prior to skin closure, as described under transconjunctival enucleation closure. Silicone sphere implants can also be used, but the likelihood of dehiscence and sphere extrusion may be increased due to the lack of deep orbital connective tissue to close over the sphere prior to skin closure. If exenteration is performed due to uncontrollable orbital infection, both methods for improving cosmesis are contraindicated.

Post-operative Care

Postoperative considerations include provision of analgesia, prevention of infection and prevention of self-trauma. The use of opiate analgesics in the early post-operative period followed by oral non-steroidal anti-inflammatory medications for a period of 7 days is recommended. An Elizabethan collar may be used to prevent self-trauma of skin sutures. Dogs are more likely than cats to require an Elizabethan collar. Owners should be advised to keep the incision clean to help prevent localized infection. Systemic antibiotics are generally not required beyond the perioperative period, unless pre-existing sepsis is present.

Complications

Operative complications of enucleation and exenteration include hemorrhage and the previously described complications of oculocardiac reflex stimulation and potential damage to the optic chiasm due to excessive globe or optic nerve traction. Postoperative orbital swelling is common and sometimes severe if related to hemorrhage confined to the orbital space. Although not considered a complication, it is also common to note serosaguinous discharge from the ipsilateral nares for a few days post-operatively as fluid passes through the severed nasolacrimal canaliculus to the nasal ostium. Orbital emphysema is occasionally encountered following enucleation, particularly in brachycephalic dogs, presumably due to air being forced up the nasolacrimal duct and accumulating in the closed orbit. Orbital infection, seroma and cyst formation are rare. Cyst formation is more likely to occur when secretory tissues (e.g. nictitans gland, lacrimal gland) are left in the orbital space. When orbital silicone spheres are placed to improve post-operative cosmesis, sphere extrusion is a potential complication that can be minimized by ensuring that adequate deep orbital fascia covers the sphere

prior to skin closure. This complication is more common in cats than dogs.

Suggested Readings

Ramsey D.T., Fox D.B.: Surgery of the orbit. Vet. Clin. North Am. Small Anim. Pract. 27:1215, 1997.

Slatter D., Basher T.: Orbit. In Textbook of Small Animal Surgery. 3rd Ed. Edited by D.H. Slatter. Philadelphia, Saunders, 2003.

Chapter 13

Ear

Pinna

Suture Technique for Repair of Aural Hematoma

Paul E. Cechner

Aural hematomas occur most frequently in dogs with pendulous ears and occasionally in dogs with erect ears and in cats. Hematomas are most apparent in the concave surface of the ear. The etiology is not clear, but the most accepted theory is that the lesion is self-inflicted from head shaking, scratching, and rubbing the ear.

The auricular cartilage is pierced by many foramina, a configuration that permits passage of numerous vessels from the great auricular artery. Shearing forces from trauma are believed to tear some of the vessels. Blood accumulates between the skin and the layers of cartilage of the pinna. Bleeding continues until the internal pressure equals the pressure of the feeder arteries. The underlying causes for irritation to the ear should include all the external factors and diseases that predispose an animal to otitis externa, including immune-mediated diseases, food, and inhalant hypersensitivities.

Treatment Considerations

Hematomas should be treated immediately after diagnosis. Untreated hematomas usually cause various cosmetic alterations resulting from fibrous contracture. Some ears have a cauliflower-like appearance, which is a permanent alteration. Identification and treatment of the underlying cause are critical to long-term management of patients with aural hematoma.

Suture Technique

In my experience, incisional drainage combined with suturing has consistently been the most successful treatment for aural hematomas. The pinna is surgically prepared on both sides. Hematomas have been opened using longitudinal, S-shaped, and cruciate incisions, depending on the surgeon's preference. I prefer the longitudinal incision, and it is not necessary to remove additional skin to widen the incision.

The fibrin clot is removed, and the cavity is curetted and flushed with saline. Horizontal mattress sutures are placed in rows parallel to the skin incision (Figure 13-1). The first row of sutures are placed at the outer edge of the hematoma cavity with each new row placed toward the skin incision. The spacing of sutures varies with the size and shape of the pinna and the size and location of the hematoma.

Mattress sutures are 5 to 10 mm wide, 5 to 10 mm apart in each row, and 5 to 10 mm between each row, and the last row of sutures is 2 to 5 mm from the skin incision. Usually, 2 to 5 rows of

sutures are placed on each side of the incision. To promote wound drainage, the skin incision is not sutured. The same procedure is recommended for cats; however, the suture spacing is 2 to 4 mm apart. The sutures should not be placed perpendicular to the skin incision in either species (Figure 13-2).

The sutures penetrate the full thickness of the pinna and are tied on the convex surface of the ear (Figure 13-3). When placing the sutures, the surgeon should avoid the three main great auricular branches, which are visible on the convex surface of the pinna. Suture tension is subjective. As a guideline, sutures should be placed with just enough tension to permit insertion of the needle holder tips to the level of the hinge.

Various suture materials have been used. My preference is 2-0, 3-0, or 4-0 nylon or polypropylene swaged onto a straight cutting needle. The use of stents or suturing through material, such as radiographic film, is usually not necessary if sutures are placed properly.



Figure 13-1. Correct placement of sutures after removal of an aural hematoma.

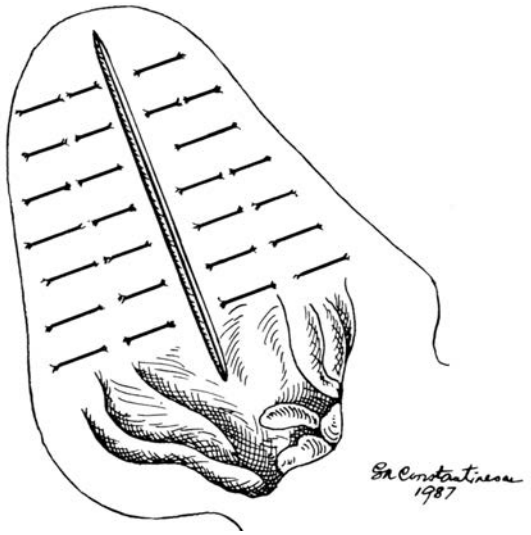


Figure 13-2. Incorrect placement of sutures after removal of an aural hematoma. Placement of sutures with tranverse orientation may decrease blood supply to the cartilage and skin of the pinna.

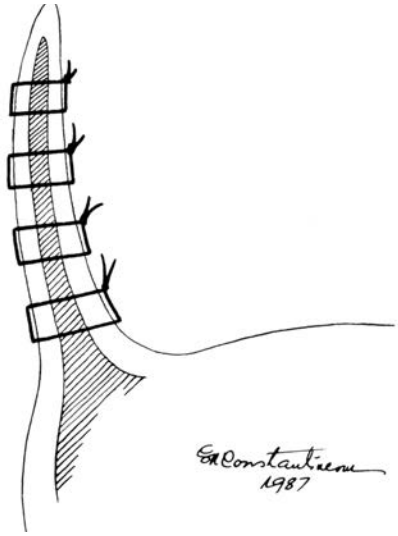


Figure 13-3. After removal of an aural hematoma, sutures are placed through the full thickness of the ear and tied on the convex surface. See Figure 13-1 for correct placement of sutures.

Postoperative Care

A light protective bandage is applied to protect and immobilize the ear. Pendulous ears are bandaged over the head or neck. Erect ears are bandaged to maintain a normal erect position. Ear bandages should not occlude the opening of the vertical canal. The bandage is changed in 3 days and is removed in 7 days. The sutures are removed in 3 weeks. An Elizabethan collar is recommended to prevent scratching of the unband-aged ear.

Complications

The most common complications of aural hematomas are cosmetic alterations and recurrence. Necrosis of the pinna has been reported from improper suture placement. Cosmetic alterations are usually the result of delayed treatment, improper suture placement, and excessive suture tension.

Aural hematomas can recur at the same site, but they are more likely to recur adjacent to the original hematoma. Recurrence of a hematoma is likely when inadequate numbers of sutures are used or inappropriately placed or when the underlying causes of the hematoma are not identified and treated appropriately. Necrosis of the pinna can be prevented by avoiding the ascending branches of the great auricular artery through the use of suture placement parallel, rather than perpendicular, to the incision.

Client Education

Communication with the animal's owner regarding all aspects of aural hematomas and their management will help to avoid misunderstandings, especially if complications occur. Owners should also understand that to treat the underlying causes properly, further investigation and expense will be required.

Suggested Readings

Angarano DW. Diseases of the pinna: Vet Clin North Am 1988; 18:1.

Dubielzig RR, Wilson JW, Seireg AA. Pathogenesis of canine aural

hematomas. J Am Vet Med Assoc 1984,185:873.

Harvey CE. Ear canal disease in the dog: medical and surgical management. J Am Vet Med Assoc 1980:177:136.

Henderson RA, Home RD. The pinna. In: Slatter DH, ed. Textbook of small animal surgery. 2nd ed. Philadelphia: WB Saunders, 1993.

McKeever PJ. Otitis externa. Compend Contin Educ Pract Vet 1996:18:759.

McCarthy RJ. Surgery of head and neck. In: Lipowitz AL, Caywood DD, Newton CD, et al, eds. Complications in small animal surgery. Baltimore: Williams & Wilkins, 1996.

Sutureless Technique for Repair of Aural Hematoma

M. Joseph Bojrab and Gheorghe M. Constantinescu

One disadvantage of suture techniques for repair of aural hematomas is the possibility that the treated ear may thicken, wrinkle, and resemble a cauliflower. These unwanted changes do not occur with the sutureless technique described in this section.

After the pinna has been clipped, thoroughly cleaned, and prepared, an elliptic incision is made on the concave surface over the swelling. The incisions should expose the hematoma cavity from end to end. The cavity is thoroughly curetted and copiously irrigated. The ear is firmly taped so the incision is exposed (Figures 13-4 and 13-5), and the pinna is then reflected over a large roll of cast padding and is taped in place (Figure 13-6). A nonstick Telfa surgical dressing covered by a Tendersorb Wet Pruf (Ken Vet Animal Care Group, 100 Elm Street, Walpole, MA 02081) pad is applied to the incision surface and is changed as needed. Sutures are not used.

The ear is left firmly immobilized for 3 weeks. Healing is by second intention. The elimination of sutures helps to keep the pinna flat and prevents thickening, wrinkling, and cauliflowering.

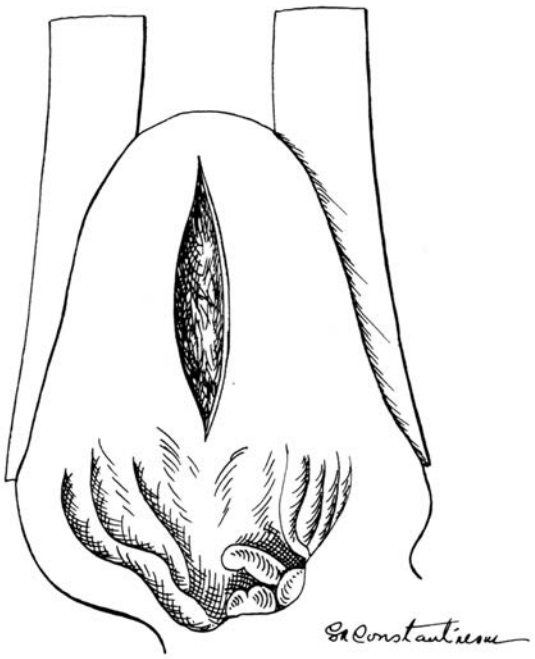


Figure 13-4. Short pieces of tape are placed on the rostral and caudal borders of the convex side of the pinna. The tape extends beyond the ear border. The elliptic incision into the hematoma cavity is shown.

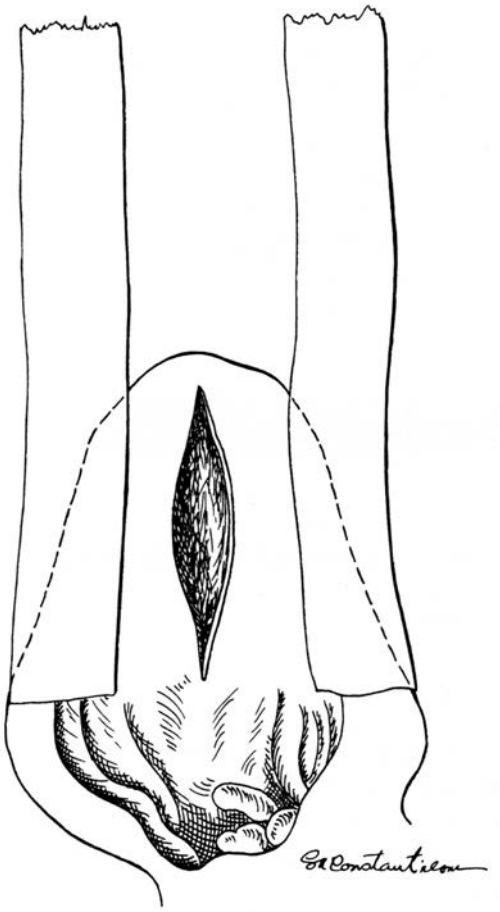


Figure 13-5. Long pieces of tape are placed on the concave side of the rostral and caudal borders of the pinna. These tapes also extend beyond the ear border and contact the tape on the opposite side.

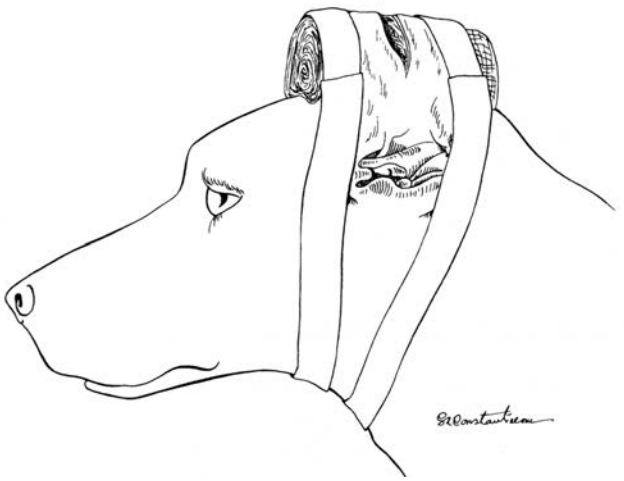


Figure 13-6. The pinna is then reflected up over a large roll of cast padding, and the tape is brought around the neck, to secure the ear in place.

External Ear

Treatment of Otitis Externa

M. Joseph Bojrab and Gheorghe M. Constantinescu

Otitis externa is an inflammation of the epithelium of the external ear canal characterized by an increased production of ceruminous and sebaceous material, desquamation of epithelium, pruritus, and pain. The condition is caused by one or more etiologic agents including parasites, bacteria, and fungi. In addition, allergy and trauma may play a role in otitis externa. The conformation of the ear canal and that of the pinna can predispose to development of acute and chronic otitis externa. For example, the high incidence of the disease in poodles and cocker spaniels indicates that the pendulous pinna and hair-filled external ear canal predispose to otitis externa. The high relative humidity of the external ear canal, in addition to the warmth, darkness, and enclosed nature of the ear canal of some breeds of dogs, provides an excellent environment for the growth of infective agents. Chronic otitis externa can permanently change the size and character of the external ear canal. The epithelium becomes thickened and fibrous and can become ulcerated. The ear canal can become stenotic if the epithelium becomes excessively scarred or undergoes metaplastic proliferation.

Diagnosis and Medical Treatment

A complete otoscopic examination of each ear, including visualization of the tympanum, is imperative for proper diagnosis and assessment of otitis externa. The initial treatment of this disease consists of irrigating and cleansing the external ear canal. Additional treatment consists of the use of ceruminolytic agents and, depending on the origin of the otitis, antibiotics (aqueous solutions) locally or parenterally, antifungal agents or parasiticides locally, and pH alteration. Bandaging the ears over the top of the animal's head allows better ventilation of the ear canal.

Culture and sensitivity tests in cases of severe or repeated occurrences of acute otitis externa may obviate a future ear canal operation by identifying the bacterial etiologic agent and thus the antibiotic that should effectively eliminate that agent. Chronic otitis externa must be treated more vigorously. Instillation of "swimmer's solution" (three parts 70% isopropyl alcohol and one part white vinegar) is useful for long-term treatment; it provides a cleaning-drying action and lowers the pH of the ear canal.

Surgical Treatment (Lateral Ear Canal Resection)

Indications

When otitis externa becomes unresponsive to medical therapy, a lateral ear canal operation is indicated. Lateral ear canal resection is also indicated for frequent recurrence of otitis externa, for chronic otitis externa resulting from inadequate treatment or lack of treatment, for external ear canal thickening that does not concurrently obstruct the horizontal portion of the external ear canal, and for exposure and removal of small tumors or polyps.

The purpose of lateral ear canal resection is to provide environmental alteration by means of ventilation so moisture, humidity, and temperature are decreased. Lateral ear canal resection also provides drainage for exudates and moisture in the ear canal.

Surgical Technique

The patient is placed in lateral recumbency and is draped so the pinna and external ear canal region are left exposed and all anatomic relationships are identifiable (Figure 13-7). The veterinary surgeon initially is positioned ventral to the patient. A probe is inserted into the ventral ear canal to determine the canal's depth. Two skin incisions are extended ventrally, parallel to each other, from the intertragic notch and the trago-helicene notch. These vertical incisions should be 1.5 times the length of the vertical ear canal. A transverse incision is made joining the vertical incisions ventrally (Figure 13-8). The skin is reflected to its dorsal attachment on the dorsal rim of the vertical ear canal. An incision is made through the subcutaneous tissue of the lateral surface of the cartilaginous vertical canal. With scissors, the subcutaneous tissue is reflected rostrally and caudally off the vertical ear canal (Figure 13-9). In similar fashion, the parotid salivary gland is reflected ventrally. The lateral aspect of the vertical ear canal should be exposed at this point.

The next portion of the surgical procedure is best performed from the dorsal aspect of the head. With scissors, two incisions are made in the cartilaginous vertical canal, one along the rostrolateral aspect of the canal and one along its caudolateral aspect. For the incisions to be made properly, the pinna and the skin flap must be pulled dorsally and the vertical portion of the ear canal visualized. One blade of the scissors is placed into the vertical canal (Figure 13-10), which is then incised from the tragohelicene notch ventrally approximately half the length of the vertical ear canal. Both the rostral and caudal ear incisions should be alternately extended until the floor of the horizontal ear canal limits further advancement of the scissors. The lateral wall of the vertical ear canal is now reflected ventrally (Figure 13-11).

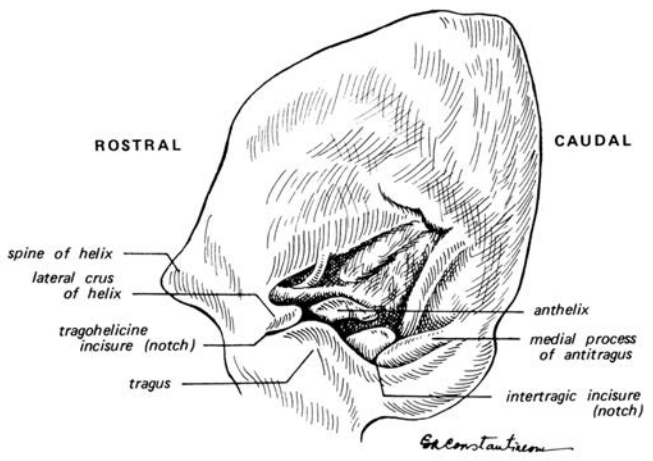


Figure 13-7. Anatomic relationships of the ear.

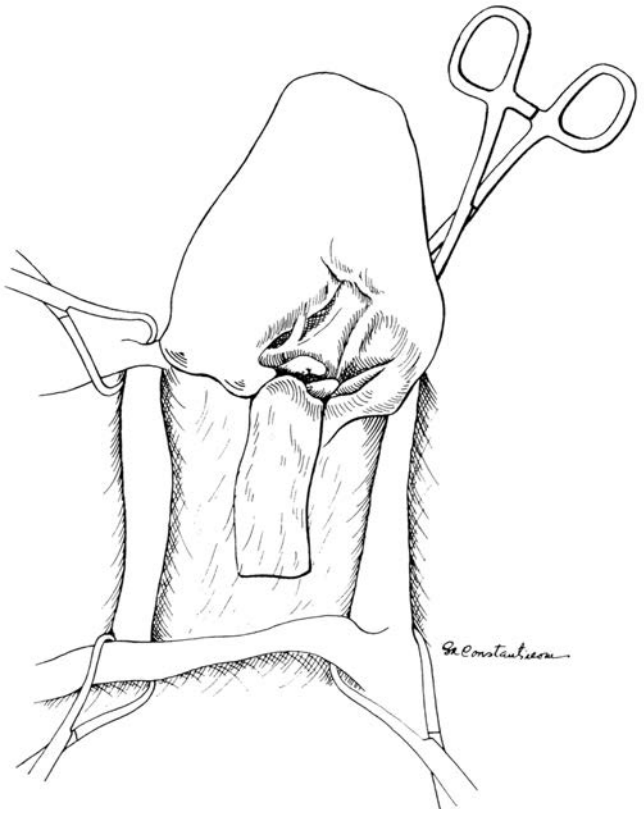


Figure 13-8. The skin incisions are made to extend 1.5 times the length of the vertical canal.

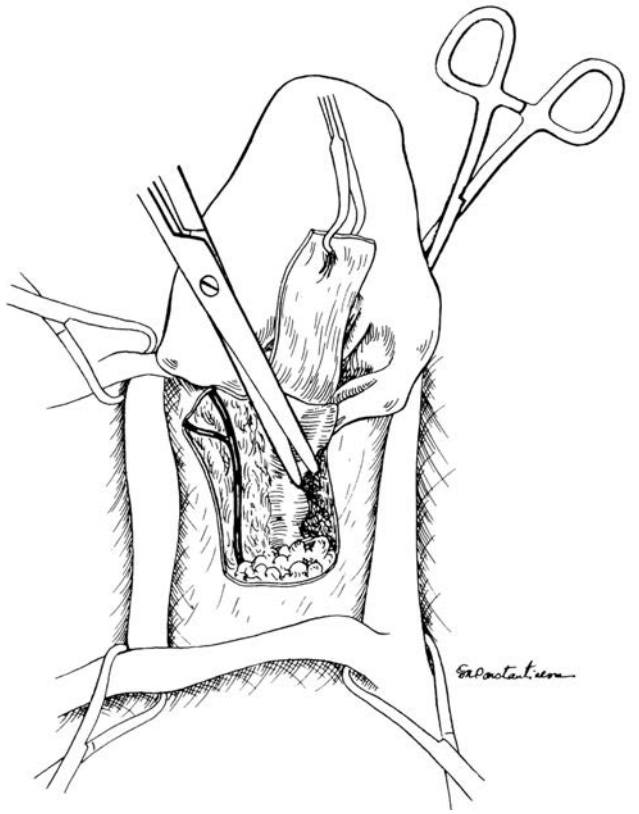


Figure 13-9. The subcutaneous tissue and parotid salivary gland are reflected, exposing the cartilaginous canal.

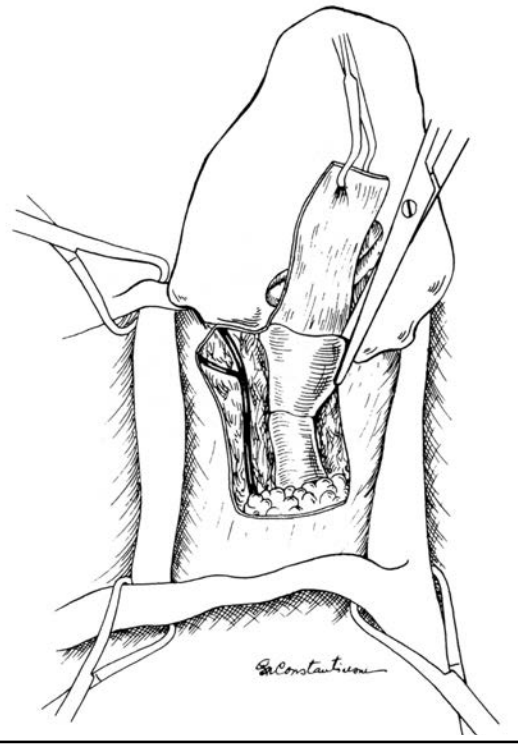


Figure 13-10. After the subcutaneous tissue is reflected, the vertical ear canal is exposed and is ready for cutting with scissors.

If the incisions have been made properly, the lateral wall will have a base of attachment equal to the width of the floor of the horizontal ear canal. Next, the skin flap and all but the proximal 2 cm of the lateral wall are removed. This section is used as the "drain board" flap.

The lateral flap is pulled ventrally. Size 3-0 nonabsorbable, preferably swaged-on suture material is used to suture the lateral ear canal flap and the remaining vertical ear canal to the adjacent skin in a simple interrupted pattern (Figure 13-12). The first suture is placed through the rostroventral edge of the epithelium and cartilage of the "drain board." This suture is angled rostroventrally and is sutured to the skin. Similarly, the second suture is placed through the caudoventral edge of the flap and is sutured caudoventrally to the skin. The skin is adjusted before placement of this suture, so no redundant skin persists between these two sutures. The next two sutures should anchor the skin to the rostral and caudal walls of the opening of the horizontal ear canal. Additional interrupted sutures are placed to join the lateral ear canal flap to the skin and the edges of the vertical ear canal to the skin in cosmetic fashion.

The ear is placed approximately in its normal position, and the ear canal is checked for possible obstruction to drainage and ventilation by the anthelicene tubercle or proliferative ridges of tissue. If these tissues cause obstruction, they should be excised, and the resultant wound should be allowed to heal by second intention.

After all incisions have been closed, the pinna needs to be anchored over the head of the dog to provide ventilation and to prevent damage from head shaking. A porous bandage may be

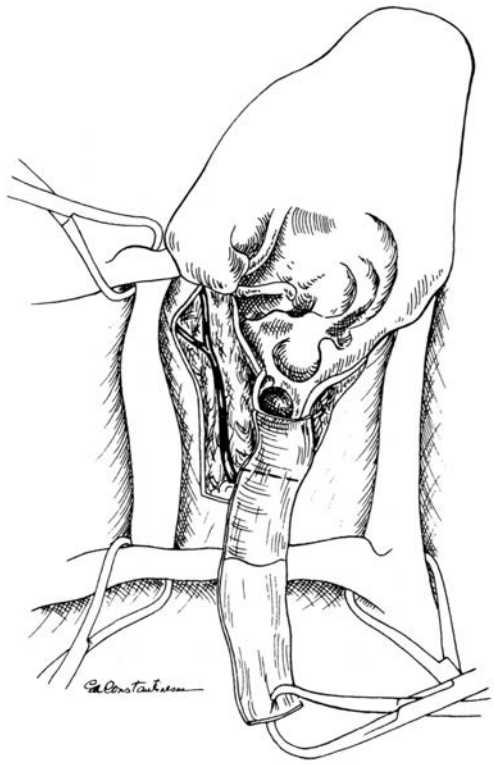


Figure 13-11. The lateral wall of the vertical ear canal is reflected ventrally. The broken line indicates where the lateral cartilage flap is incised.



Figure 13-12. The skin edges are sutured to the cartilage edges, creating a ventral "drain board."

placed over the surgical site to protect it from scratching. Paw pads may be fashioned, or the patient's legs may be hobbled as additional measures to protect the ear from self-trauma.

Postoperative Care

Postoperative care includes treatment with appropriate systemic antibiotics and management of self-trauma and ear movement. Coping with the prolonged healing time may be difficult. Healing time averages 10 to 14 days; if the suture line breaks down, healing may take longer. If lateral ear resection fails to control otitis externa, ear canal ablation needs to be considered. This procedure is discussed in the next section of this chapter.

Editor's Note: To be effective, lateral ear canal resection must be performed early in animals with recurring otitis externa. If chronic tissue change such as skin hyperplasia/hypertrophy occurs as a result of chronic otitis, the efficacy of lateral ear canal resection is poor. Lateral ear canal resection should not be expected to cure otitis but rather acts as an adjunctive procedure improving ventilation and drainage to make ongoing medical therapy more effective.

Suggested Readings

Bojrab MJ, Dallman MJ. Lateral ear canal resection. In: Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.

Coffey DJ. Observations on the surgical treatment of otitis externa in the dog. J Small Anim Pract 1970; 11:265.

Fraser G. Factors predisposing to canine internal otitis. Vet Rec 1961;73:55.

Fraser G, Withers AR, Spruell JSA. Otitis externa in the dog. J Small Anim Pract 1961;2:32.

Fraser G. et al. Canine ear disease. J Small Anim Pract 1970;10:725.

Grono LR. Studies of the microclimate of the external auditory canal in the dog. Parts I, II, and III. Res Vet Sci 1970;! 1:307.

Grono LR. Otitis externa. In: Kirk RW, ed. Current veterinary therapy. Vol. 7. Philadelphia: WB Saunders, 1980.

Ott RL. Ears. In: Archibald J, ed. Canine surgery. 2nd ed. Santa Barbara, CA: American Veterinary Publications, 1974.

Singleton WB. Aural resection in the dog. In: Jones BV, ed. Advances in small animal practices. Vol. 2. Oxford: Pergamon Press, 1960.

Zepp CP. Surgical correction of diseases of the ear in the dog and cat. Vet Rec 1949;61:643.

Gregory CR, Vasseur PB. Clinical results of lateral ear resection in dogs. J Am Vet Med Assoc 182: 1087, 1983.

Modified Ablation Technique

M. Joseph Bojrab and Gheorghe M. Constantinescu

An alternative surgical technique for chronic otitis externa has been used when the entire vertical canal is grossly distorted or filled with hyperplastic mucosa.

This technique combines the advantages of ablation (removal of the chronically infected vertical canal) with those of lateral ear

canal resection (maintenance of drainage and hearing).

The preparation of the patient (Figure 13-13), skin incision, and vertical canal isolation are the same as described for lateral ear canal resection in the previous section of this chapter. Isolation of the vertical canal is continued medially until the entire canal is isolated (Figure 13-14). The auricular cartilage and skin are cut just dorsal to the opening of the vertical canal at the base of the pinna (Figure 13-15). This method allows complete mobilization of the vertical canal, which remains attached ventrally to the horizontal canal. The vertical canal is cut approximately 2 cm dorsal to the horizontal canal (Figure 13-16) and is discarded. The remaining vertical canal is incised both rostrally and caudally down to the horizontal canal (See Figure 13-16, inset), thus creating two rectangular flaps, a dorsal flap and a ventral flap (Figure 13-17). The ventral flap is sutured as described in the previous section of this chapter on treatment of otitis externa. The dorsal flap is sutured as depicted in Figure 13-17.

Aftercare consists of bandaging the patient's ear over the head for 1 week and administering systemic antibiotics as determined by culture and sensitivity tests.



Figure 13-13. Skin incisions for this modified ablation technique.

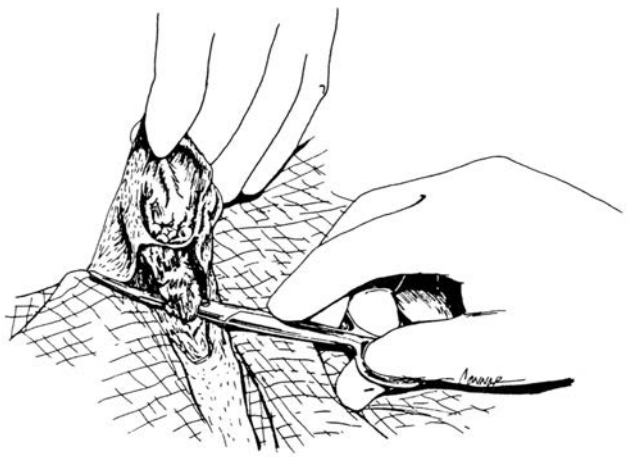


Figure 13-14. Isolation of the vertical ear canal.

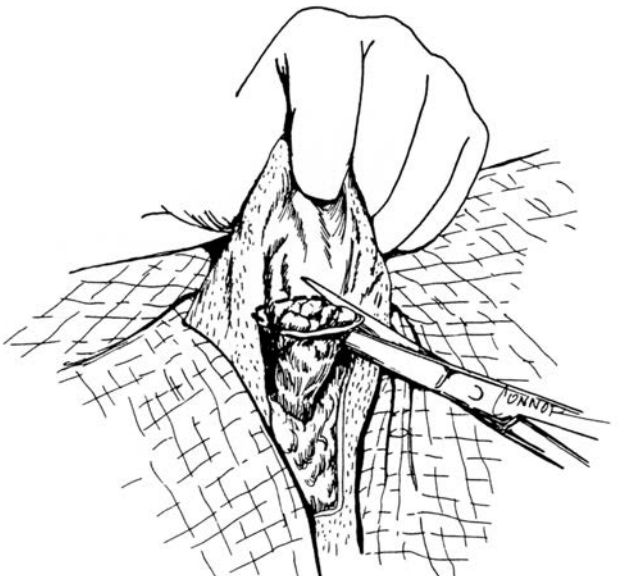


Figure 13-15. The auricular cartilage and skin are cut dorsal to the opening of the vertical canal.

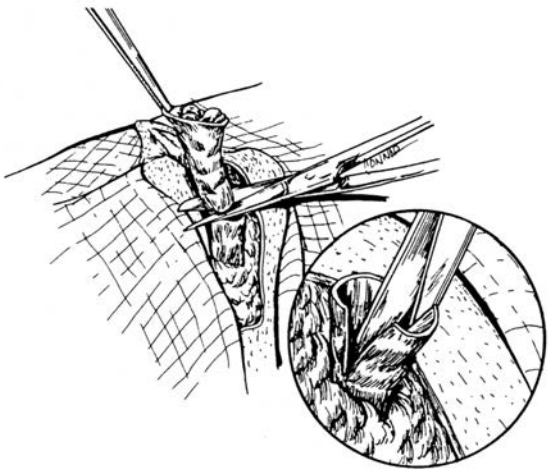


Figure 13-16. The vertical canal is cut dorsal to the horizontal canal. Inset, incision of the remaining vertical canal, rostrally and caudally, down to the horizontal canal.

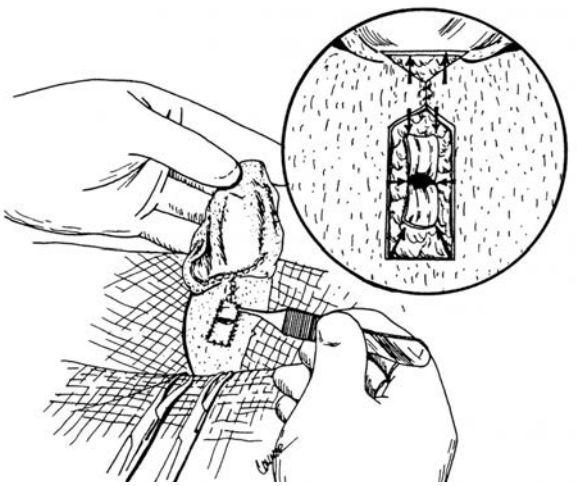


Figure 13-17. Suturing of the dorsal and ventral rectangular flaps.

Total Ear Canal Ablation and Subtotal Bulla Osteotomy

Daniel D. Smeak

Introduction

Otitis externa is an insidious disease that is not usually debilitating, and the associated clinical signs are generally controlled until medical therapy is withdrawn. When multiple attempts at medical treatment fail, ear disease invariably progresses, and more extensive surgery is indicated to permanently relieve the clinical signs. Owners must understand that the frequency and severity of intra- and postoperative complications increase in proportion to the degree of surgery required. Thus, for the most part, early surgical intervention should be strongly advised when appropriate medical treatment for otitis externa fails or the condition becomes recurrent.[1] As the ear tissue damage becomes irreversible from chronic infection, drainage procedures fail and removal of the entire horizontal and vertical ear canal is required. This salvage procedure is known as total ear canal ablation (TECA).[2]

Secondary middle ear infection frequently develops in dogs with end-stage otitis externa.[3] Consequently, variable results and high complication rates have been reported when TECA is preformed without a means of middle ear exposure and debridement (bulla osteotomy and curettage). Because TECA eliminates a primary pathway for exudate drainage, the external canal, recurrent deep infection occurs unless the middle ear is adequately evacuated. Inadequate removal of the secretory epithelium within the bulla or short osseous ear canal is responsible for such long-standing complications as persistent fistulation and abscessation.[1,4] For these reasons, most surgeons routinely combine lateral bulla osteotomy (LBO) through the same approach used for TECA. These combined procedures are described in this chapter.

Indications

TECA is most often performed for irreversible inflammatory ear canal disease in dogs. Other less common indications include severe ear canal trauma, neoplasia, and certain congenital malformations obstructing horizontal ear canal drainage. Irreversible inflammatory ear canal disease is present when one or a combination of the following is observed: hyperplasia of the epithelium occluding the horizontal ear canal, collapse or stenosis of the horizontal ear canal caused by infection within the cartilage or bone, or severely calcified periauricular tissue noted by palpation or observed on skull radiographs.

Many dogs that present to the veterinarian for surgical treatment of inflammatory ear disease have one or more irreversible conditions or indications for TECA. If medically unmanageable otitis externa is related to an ongoing generalized skin condition such as atopy or hypothyroidism, treatment of the primary dermatological disorder often helps control the ear disease. Concurrent skin disorders are very common in dogs with otitis externa. Almost 80% of dogs undergoing TECA in one report had one or more primary dermatological diseases including seborrhea, pyoderma, hypothyroidism, and atopy.[5] When the related primary skin condition has been thoroughly diagnosed and appropriately treated but continues to be unresponsive, I prefer TECA for treatment of persistent otitis externa instead of surgical drainage procedures such as lateral ear canal resection. As the skin disorder progresses, so will the ear disease in most circumstances, and a lateral ear resection or vertical ear canal ablation will subsequently fail due to progressive inflammatory changes in the remaining canal. Similarly, if owners are incapable or unwilling to treat the skin or chronic ear disease appropriately, TECA may be indicated **before** irreversible changes exist.

Although TECA combined with LBO is indicated for a number of conditions in the dog, it is less commonly performed on cats. Irreversible, proliferative inflammatory changes resulting from long standing otitis externa do not appear to form as readily in cats as they do in dogs. Cats with otic tumors, such as ceruminous adenocarcinoma or basal cell carcinoma, diffuse polypoid disease, or those sustaining severe trauma to the ear canal are potential candidates for TECA.[6] TECA is not usually required for cats affected with otitis media or inflammatory middle ear polyps, since the external ear canal is usually not severely affected, and exposure to the source of the clinical problem is best achieved with a ventral approach (ventral bulla osteotomy).

Owner Education

The owner must be made fully aware of the purpose of TECA as well as the possible sequelae before contemplating surgery. The surgeon should remind owners that the principle aim of TECA is to make their pet more comfortable by removing the source of pain and chronic infection. Elimination of further ear cleaning duties and the malodorous discharge are added benefits. Before surgery, however, owners seem to be concerned most about the appearance of their pet and whether their animal will be deaf after surgery. Generally, the appearance of floppy-eared dogs following TECA is unchanged. In erect-eared dogs, the extent of auricular and pinna cartilage removed determines whether the ear will stand following surgery. Removal of extensive proliferative tissue well up into the pinna will cause the erect ear to fall owing to lack of support at the ear base. The ear will remain somewhat erect if more than the proximal third of the vertical canal cartilage is preserved in dogs and cats. A simple modification of the TECA skin incision to create a single pedicle advancement flap has been found to maintain normal ear carriage in cats.[7] The surgeon should not limit the amount of canal resection because of pressure from owners who want preservation of ear carriage at all costs. Continued irritation and pain can be expected if proliferative ear canal tissue remains following TECA.

Because TECA obliterates the external auditus, most owners are skeptical about their pet's future hearing ability. Although the possibility of causing complete deafness remains, TECA combined with LBO should not be expected to affect hearing appreciably in most cases. Although air conducted sound may not be detected by brain evoked auditory testing after TECA, the ability to hear bone conducted sound is apparently preserved.[8,9] I warn owners that the quality of sound their dog can discern may

change after surgery, but some hearing ability usually can be expected. Most complaints about hearing difficulty after TECA stem from inadequate owner evaluation or awareness of the pet's hearing condition beforehand. The surgeon should try to make the owner aware of their dog's hearing deficits before surgery to minimize this misunderstanding. Owners must be prepared for serious and potentially long-standing problems resulting from TECA. If nystagmus, circling, or loss of balance are present before surgery, exacerbation of these signs is common afterwards in the author's experience. These signs usually improve if middle ear infection is eliminated but they may persist indefinitely. Transient, or more rarely, permanent facial nerve dysfunction may occur causing drooling from ipsilateral lip paralysis. Hemifacial spasm or facial nerve deficits that are present before surgery may indicate that the facial nerve is invaded by neoplasia or, more likely, that it is embedded in the horizontal canal or serious secondary middle ear infection is present. More dissection and retraction of the nerve may be required to free it up during TECA; this greatly increases the risk of iatrogenic facial nerve damage. Ocular problems from a diminished eye-blink response may be disastrous, particularly in exophthalmic dog breeds or those with inadequate tear production. Unresolved middle ear infection or any retained secretory tissue can cause recurrent abscessation and fistulation which may create conditions far worse for the owner and their pet than the presenting otitis externa problem.[4] Proper preparation of owners for these potential problems by counseling before surgery is recommended.

Preoperative Considerations

A complete preoperative workup is essential to determine the extent and nature of the disease process and to predict possible surgical complications. Following routine physical examination, the external ear is inspected and palpated. A sharp pain response elicited during deep palpation of the ear canal usually indicates middle ear infection. Thickened and firm (calcified) ear canal tissue is a manifestation of irreversible inflammatory change. Evidence of a head tilt without other signs of inner ear disease (nystgmus, circling, loss of balance) usually indicates severe pain in the ear on the lower side. Neoplasia should be highly suspected if the ear drainage appears mostly as blood versus the more typical thick, foul-smelling exudate of an inflammatory otitis externa.

A complete neurologic examination should be performed to evaluate for facial nerve dysfunction (hemifacial spasm, poor palpebral reflex, lip droop) and inner ear involvement, especially in patients with chronic otitis externa. During preoperative workup, approximately 15% of patients with end-stage otitis are found to have partial or total facial nerve deficits.[1] It is important to identify patients with concurrent otitis media because they more often develop complications such as cellulitis, persistent fistulation, or abscessation following TECA.[4] In addition, their postoperative care is more demanding and costly. Any hearing deficits or other neurologic problems should be clearly noted in the medical record and brought to the owner's attention **before** TECA; otherwise, the owner may blame the surgeon if these deficits are noticed after surgery.

If the ear problem is a possible manifestation of a systemic skin disorder, a complete dermatologic examination should be performed and appropriate tests should also be completed. Postoperative head shaking and self-inflicted irritation to the remaining ear tissues may persist if the primary skin condition is neglected or inappropriately treated. This can be seen as a failure of the surgical procedure from the owner's point of view.

The remaining preoperative workup is best performed while the patient is anesthetized. Thorough ear cleaning must be accomplished to allow maximal visualization of the canal during otoscopic examination. Otoscopic examination of **both** canals is indicated, even if one side superficially appears normal or if the condition of both ears is severely proliferative. Attention is directed at locating tumors or polyps, as these are not infrequent in older patients with long standing otitis externa. Otitis media is present if the tympanic membrane is not found and the tympanic bulla is filled with debris. Samples of suspicious tissues are submitted to help diagnose occult neoplasia, which may drastically change the prognosis as well as the owner's wish to allow surgery on their pet. If neoplasia is suspected, local lymph nodes are examined and fine needle aspirates are evaluated cytologically for tumor staging. Chest radiographs are evaluated for evidence of metastatic disease or other occult thoracic problems. Rather than culturing the exudate at otoscopic examination, a more reliable result may be obtained if deep wound tissue and middle ear exudate are sampled at the time of surgery.

Skull radiographs help confirm the extent and severity of the ear canal pathology and may alert the clinician that otitis media or neoplasia is present. The ventrodorsal skull view may be used to help determine the horizontal canal patency and its diameter, and whether the canal walls have undergone irreversible change. Open mouth plain radiographic views of the bulla are best to evaluate for subtle middle ear change.[10] Oblique lateral views may help demonstrate lytic neoplastic changes of the petrous temporal bone.

Radiography should not be regarded as a highly sensitive tool for the diagnosis of otitis media.[11] Positive radiographic signs such as thickening and calcification of the bulla indicate the presence of middle ear pathology, but false negative radiographs are common. The presence of predominately lytic changes in the rostroventral aspect of the bulla on oblique lateral views most often is a result of chronic inflammation in my experience. Conversely, evidence of bone lysis in other areas, particularly in the petrous temporal bone, suggests a neoplastic process. In summary, despite the lack of sensitivity, radiographic evaluation is recommended to evaluate for the presence of neoplastic invasion of bone, particularly when otoscopic examination of deep structures is not possible. Normal appearing skull radiographs do not rule out otitis media or neoplasia. CT imaging is a more sensitive modality to identify neoplastic and middle ear disease.

Surgical Anatomy

The surgeon must be aware of certain important structures before surgery (Figures 13-18 and 13-19). Branches of the great auricular and superficial temporal vessels should be avoided

when incising through and dissecting medial to the vertical ear canal cartilage. The V-shaped parotid gland overlays the lateral and ventral areas of the ear canal, and it may be damaged if not retracted during horizontal ear canal exposure. Deep to the parotid gland are the facial nerve, internal maxillary vein, and branches of the external carotid artery. These structures are difficult to identify and preserve when dissecting deeply around the horizontal ear canal and tympanic bulla. The facial nerve emerges from the stylomastoid foramen, located just caudal to the ossesous portion of the ear canal, and travels rostroventrally directly under the horizontal ear canal. Additionally, the terminal branches of the facial nerve and auriculotemporal branch of the mandibular portion of the trigeminal nerve should be avoided rostral to the ear canal. Careful retraction of tissues and hemostasis, meticulous dissection, and staying close to the external ear canal cartilage and osseous bulla will reduce the risk of iatrogenic damage to many of the structures.

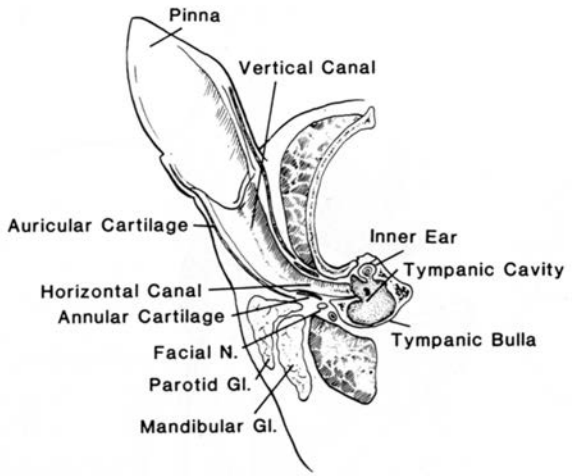


Figure 13-18. Transverse section of the head showing ear canal, middle ear, and inner ear structures.

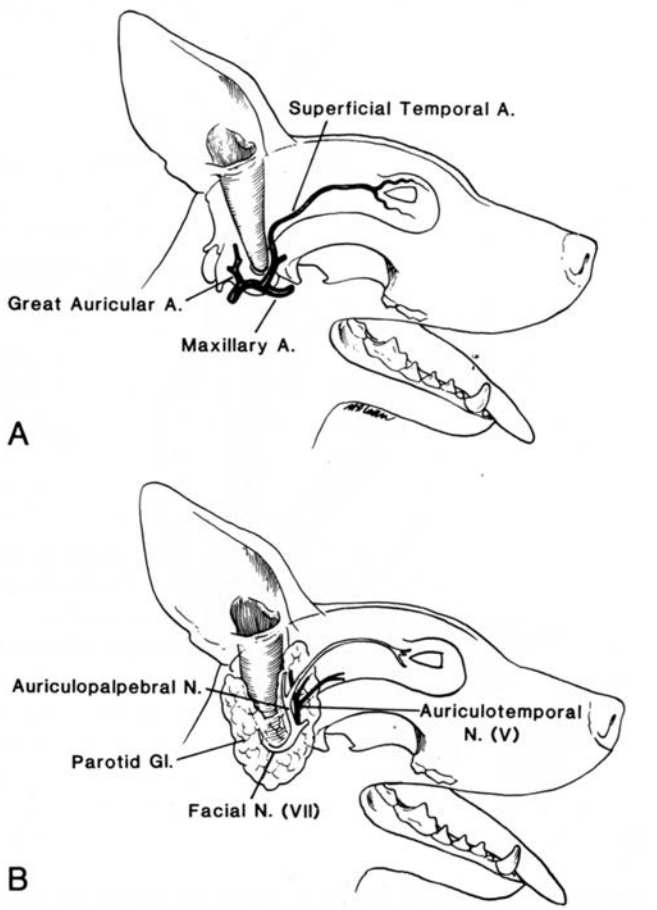


Figure 13-19. A. Location of branches of the external carotid artery in relation to the ear canal. **B.** Location of the facial *(VII)* and auriculotemporal *(V)* nerves in relation to the ear canal.

The external carotid artery and maxillary vein lie immediately ventral to the tympanic cavity and these must be safely retracted away from the tips of the ronguers during removal of the ventral aspect of the bulla (Figure 13-20). Sharp dissection and curettage of the rostral aspect of the osseous ear canal should be avoided to reduce the risk of retroarticular vein damage (Figure 13-21). During evacuation of debris and epithelium from the tympanic cavity, curettage should be avoided in the rostrodorsal and

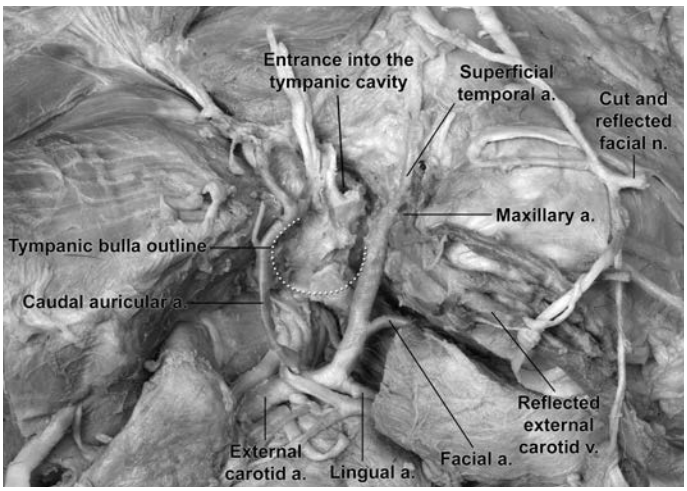


Figure 13-20. Lateral view of dissected head showing entrance into the tympanic cavity after the annular cartilage and entire cartilaginous external ear canal has been excised from the rim of the osseous EAM. Note the close approximation of the facial nerve (cut and reflected upward), and maxillary artery to the rim of the EAM.

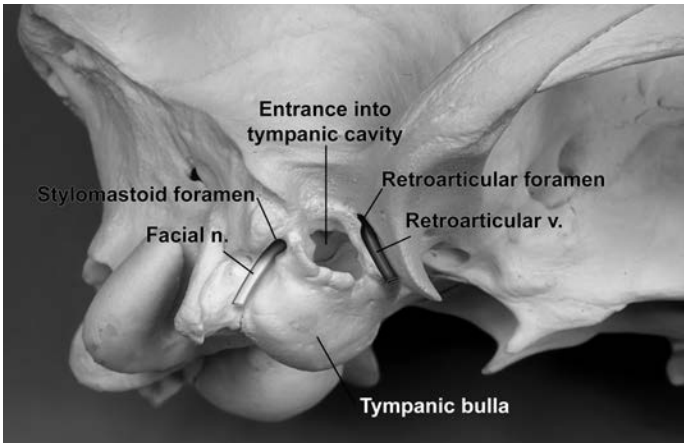


Figure 13-21. Close-up oblique ventrolateral view of important deep structures surrounding the tympanic bulla of the skull. The retroarticular vein is located just rostral to the entrance into the osseous ear canal and tympanic bulla. A distinct bony rim separates the osseous EAM from the stylomastoid foramen where the facial nerve exits the skull.

medial aspect of the bulla to preserve the ossicles and sensitive inner ear structures. The internal carotid artery can be damaged if the thin bone wall between the carotid canal and tympanic cavity has been eroded by chronic infection or neoplasia, or it may be disturbed by excessive medial pressure during curettage of the medial bulla wall (Figure 13-22).

Surgical Technique

Total Ear Canal Ablation

The ear canal is difficult to prepare aseptically, and contamination is inevitable during surgery. Therefore, a broad spectrum, bactericidal, intravenous antibiotic is given before and during surgery so that adequate blood levels are maintained in tissues during dissection. Alternatively, administration of antibiotics may be delayed until cultures of the osseous bulla are obtained during surgery. In either case, antibiotics are continued until the results of the intraoperative culture and susceptibility are available. The surgeon should use these susceptibility results to choose the appropriate drug for long-term therapy.

After anesthesia is induced, ample surrounding skin, the ear canal, and pinna are routinely prepared for aseptic surgery. The patient is placed in lateral recumbency with the head elevated by a towel to a level parallel with the chest wall. Figure 13-23 illustrates the TECA and LBO procedure. A T-shaped skin incision is made; the horizontal incision is parallel and just below the upper edge of the tragus between the tragohelicine and intertragic notch (Figure 13-23A). The vertical incision is created perpendicular from the midpoint of the horizontal incision to a point just ventral to the horizontal canal. The surgeon undermines and retracts the two resulting skin flaps, and exposes the lateral aspect of the vertical canal from the surrounding loose connective tissue (Figure13-23B). With curved Metzenbaum scissors, bluntly dissect around the proximal and medial portion of the vertical canal staying as close as possible to the cartilage. Starting from the caudal aspect, cut through the medial vertical canal wall with serrated Mayo scissors and continue cutting rostrally until the ends of the original horizontal skin incision connect (Figure 14-23C). One must avoid inadvertent damage to the branches of the great auricular vessels that travel in a dorsal direction just deep to the medial canal wall. Damage to these branches can lead to a vascular necrosis of pinna skin, particularly in the area of the posterior incisure and cornu of the antitragus. Starting at the dorsal and rostral aspect, free the remaining vertical canal of tissue connections and continue to dissect dorsally close to the horizontal canal cartilage down to the rim of the boney external auditory meatus. (Figure 13-23D). Damage to the facial nerve and parotid gland is avoided by carefully retracting these structures away from the dissection plane at the **ventral** and **caudal** aspect of the horizontal canal. These aforementioned areas are approached last, so that soft tissues can be retracted sufficiently to allow maximal exposure during dissection. Occasionally, the facial nerve is entrapped and is hidden from view within extensively thickened and calcified horizontal canal tissue. In such cases, I first search for peripheral small facial nerve branches (internal auricular nerves) that perforate the cartilage on the caudal and more superficial aspect of the horizontal canal; these branches lead to the seventh nerve trunk. Alternately, one may palpate for a small sharp protuberance (ridge) which is the rim separating the caudal osseous ear canal from the stylomastoid foramen (origin of the facial nerve). Once this area is located, one follows the most proximal portion of the nerve as it courses directly lateral from the foramen. Entrapment is generally found as the nerve exits the foramen and begins its rostral course. Carefully dissect the remaining nerve from the canal. To avoid iatrogenic nerve trauma, one should always incise the horizontal canal attachment to the external auditory meatus away from the course of the facial nerve. Branches of the superficial temporal vessels originating from the retroarticular vein (retroarticular foramen) may be encountered during dissection of the rostral aspect of

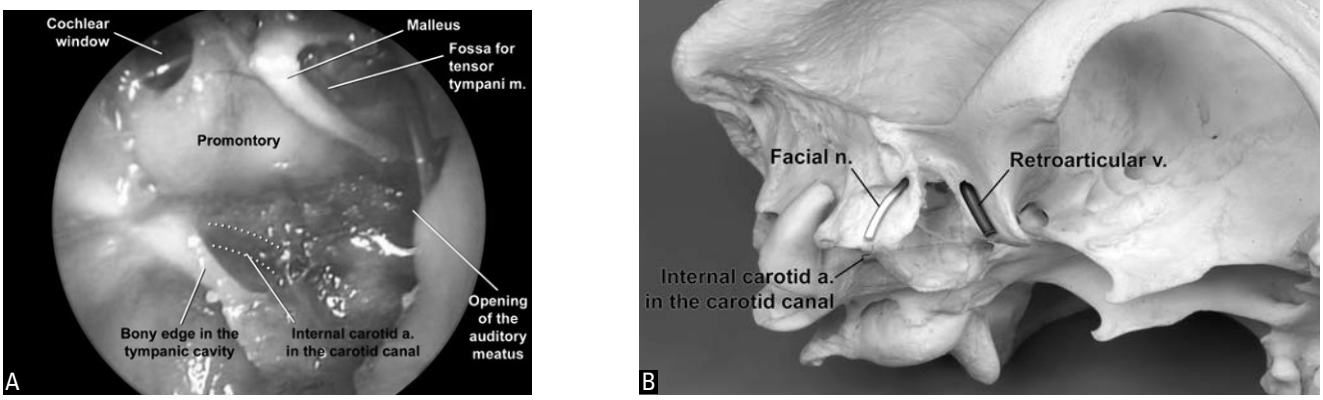


Figure 13-22. A. Oblique ventrolateral view of important structures within rostrodorsal compartment of the tympanic cavity. The arch-shaped malleus is located in the rostrodorsal aspect of the cavity, referred to as the epitympanic recess. The opening of the auditory tube is in the most rostral aspect of the cavity, an area often lined with ingrown secretory epithelium from the external ear canal. This epithelium must be completely excised during the LBO. Note the promontory and cochlear window, which house the inner ear structures. A portion of the large fundic compartment of the tympanic cavity is exposed caudally. **B.** Oblique ventrolateral view of the skull after the lateral wall of the tympanic bulla is removed. The internal carotid artery, a major blood supply to the brain, is illustrated. The internal carotid artery enters the caudal carotid foramen in the petro-occipital fissure and transverses in the carotid canal. The medial wall of the tympanic bulla forms the lateral wall of the carotid canal.

the canal from bone. Electrocoagulation or bone wax may be required to stop excessive hemorrhage. The entire canal should be removed and submitted for histologic examination. Rongeurs are usually required to excise remaining calcified attachments until the entire circumference of the external auditory meatus is seen as a white glistening edge.

In severely affected ears, a greenish-brown epithelial pouch (similar to the shape of a "sock") is present within the external auditory meatus and tympanic cavity extending lateral and ventral to the tympanic bulla (Figure 13-23E). Removal of all secretory tissue is critical to the success of the surgery since chronic fistulization will occur if secretions form within this enclosed area. Grasp the dorsal aspect of the pouch and with traction, "tease out" the pouch in one piece if possible with a Freer elevator. A curette should be used to remove **any** remaining secretory tissue that is adherent to the walls of the boney meatus. This tissue is submitted for culture and susceptibility testing.

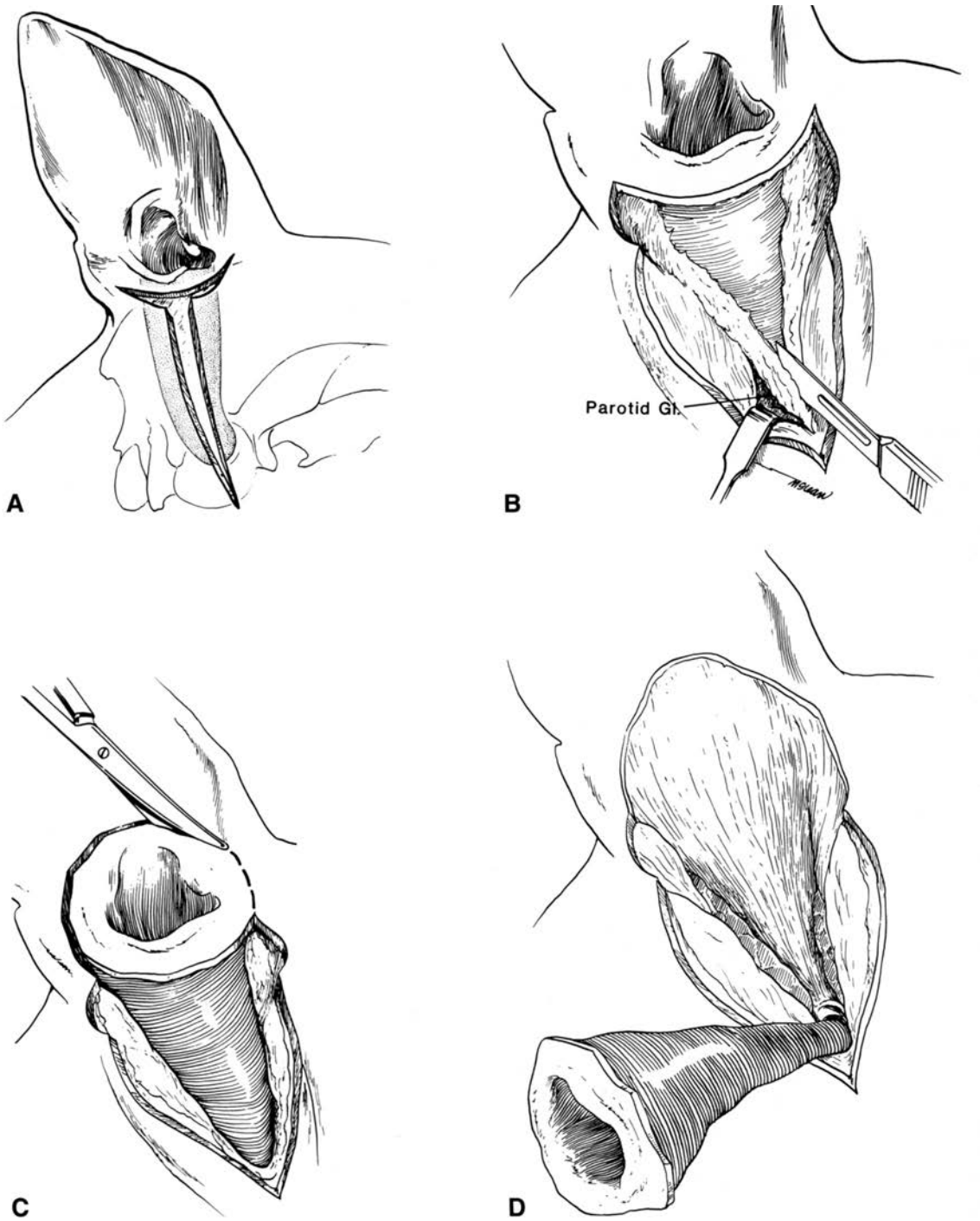
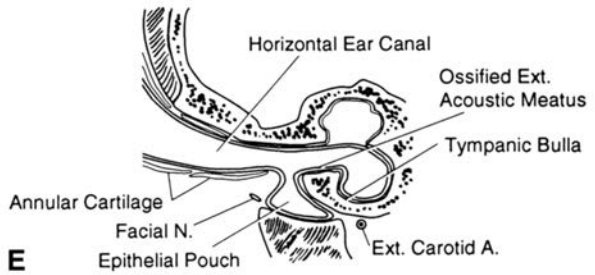
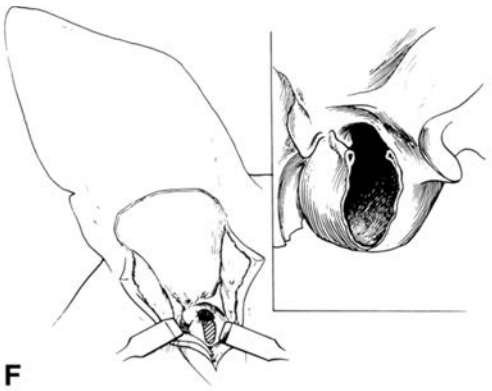


Figure 13-23. Summary of surgical technique of TECA and lateral bulla osteotomy. **A.** T-shaped incision to expose the vertical ear canal. **B.** Loose connective tissue is reflected from the vertical ear canal. The parotid gland is ventrally retracted to avoid damage during dissection of the ventral portion of the vertical ear canal. **C.** The dorsomedial aspect of the vertical cavity is sharply incised with scissors connecting the ends of the original horizontal skin incision. **D.** The vertical and horizontal ear canals are isolated from surrounding soft tissues by blunt and sharp dissection.





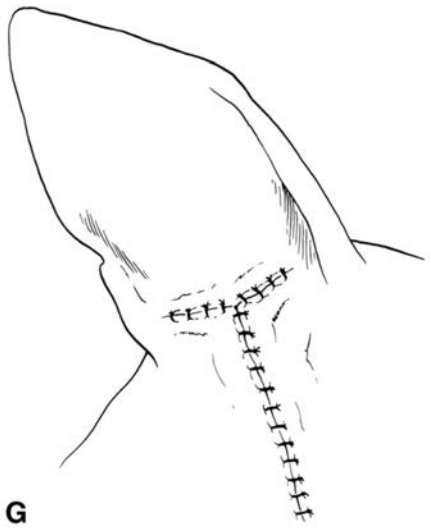


Figure 13-23 (continued) E. A pouch of secretory epithelium often forms between the tympanic bulla and annular cartilage extending into the external auditory meatus. This should be completely excised. **F.** Lateral view of skull showing aggressive excision of the lateral bulla through exposure of the tympanic cavity. The dotted line indicates the excision margin of the tympanic bulla (Left); Lateral view of the skull with limited excision of the tympanic bulla. Dotted line shows the extent of the bone removed – this limited approach provides poor exposure. **G.** Subcutaneous and skin sutures are placed to form a T-shaped wound.

Lateral Subtotal Bulla Osteotomy[1]

As the surgeon approaches the tympanic bulla, it is important to note that the bulla may be extensively remodeled (expanded) from a mounting cholesteatoma or chronic bulla osteitis. Important neurovascular structures may be more tightly draped around an expanded bulla. This close anatomic relationship greatly increases the risk of iatrogenic damage if the following steps are not carefully completed. The location of the facial nerve is important and retractors should be placed laterally (or more superficially) to spare the nerve (Figure 13-24). The author believes overzealous retraction during attempts at exposing deep structures during LBO is a major cause of temporary postoperative facial nerve dysfunction. Bluntly dissect soft tissue directly from the lateral and ventral aspects of the tympanic bulla with a Freer periosteal elevator. Stray dissection away from the bulla is avoided particularly rostral to the external auditory meatus (EAM) to spare the retroarticular vein and ventral to the bulla (to avoid the carotid artery, maxillary vein, and their branches). Soft tissue is elevated and retracted from the ventral aspect of the bulla using Freer elevators. During the entire LBO procedure, the surgeon is careful to visualize what is caught in the jaws of the ronguers to help avoid inadvertent damage to important surrounding soft tissue. Bone removal is begun with Cleveland or Lempert rongeurs; this choice depends on the thickness of bone and size of the patient. Controlled bites of bone are taken from the floor of the EAM. This will create a notch in the soft tissue lining and ventral bony floor of the EAM. (Figures 13-25 and 13-26). The remaining soft tissue is peeled from the osseous

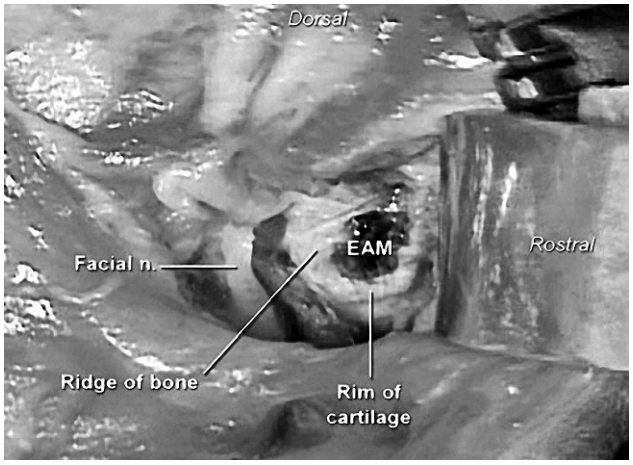


Figure 13-24. Surgeon's lateral view of EAM after the cartilaginous ear canal has been excised. A thin rim of cartilage remains attached at the EAM. Note the location of the facial nerve and stylomastoid foramen. Arrow points to a prominent ridge (a consistent landmark) dividing the EAM from the foramen.

ear canal by starting blunt dissection with Freer elevators at the cut edge of epithelium just adjacent to the notch. Once this dissection is complete, the EAM will appear as a shiny white surface throughout its circumference. The osseous ear canal is usually the thickest part of the tympanic bulla removed during LBO. The surgeon continues bone removal from the ventral osseous ear canal and into the ventral tympanic cavity with bone rongeurs. Samples of tissue and debris are collected and

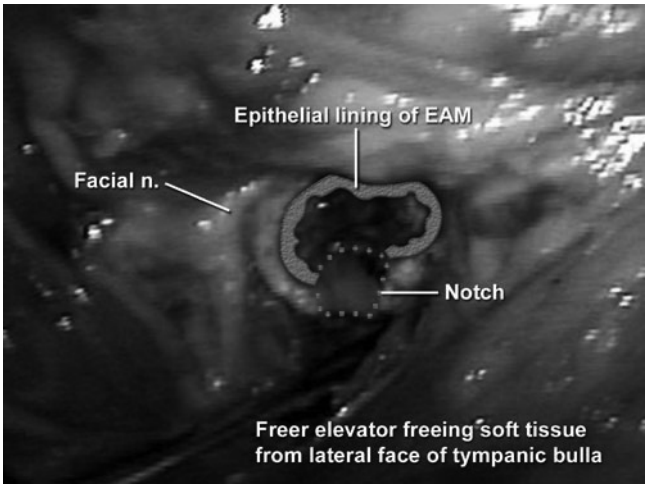


Figure 13-25. Soft tissue has been reflected and retracted away from the lateral face of the tympanic bulla with a Freer elevator. A rongeur is used to create a notch in the ventrolateral floor of the osseous EAM. The maneuver helps free edges of epithelium lining the osseous EAM so the lining can be removed completely in one piece.

submitted for biopsy and culture/susceptibility. The facial nerve trunk is gently elevated from the caudal (vertically oriented) shelf of bone between the stylomastoid foramen and the EAM. Next, this vertical sharp bony ridge is carefully removed with Lempert ronguers (Figure 13-27). This will allow gentle elevation of the facial nerve from the lateral face of the caudolateral tympanic bulla. Keeping the nerve safely retracted with the Freer elevator, one should try to angle Cleveland or Lempert rongeurs into the EAM and remove the bone on the lateral aspect of the caudal tympanic bulla. If this is not possible, I prefer Kerrison rongeurs to begin bone removal ventral to the stylomastoid foramen just caudal to the EAM (Figure 13-28). Bone is very brittle and hard in this area, but once the shelf and bone just caudal to the EAM have been removed, the remaining caudolateral bulla bone is usually thinner and easier to excise, and Lempert rongeurs will suffice for bone removal. One should not attempt to rongeur bone rostrally since structures of the epitympanic recess could be damaged and the retroarticular vein may be torn. The retroarticular vein cannot be exposed readily and usually is not evident to the surgeon unless it is damaged. If brisk hemorrhage is encountered in the rostral aspect of the EAM, a cotton tipped swab should be used to hold direct pressure on the origin of the bleeding area. It should be noted that the retroarticular foramen opens ventrally, not laterally, just rostral to the EAM, so bone wax must be pushed in a dorsomedial direction to fill the foramen and maintain hemostasis. The LBO is completed once most of the lateral and ventral aspects of the tympanic bulla have been removed. This will create a large window to adequately view the tympanic cavity interior (Figure 13-23F).

The interior aspect of the tympanic cavity is carefully inspected after irrigating the area with tepid sterile saline solution. When normal, the bulla is lined with a thin transparent epithelium, which does not need to be disturbed. If the external ear disease is chronic and there are signs of bulla osteitis, the tympanic cavity is usually (either partially or completely) lined with a greenish-brown to dark brown hyperplastic epithelial tissue. In most cases, a small cavity is found just within the rostral tympanic cavity (adjacent to the opening of the auditory tube), in which a "sock" of epithelium (sometimes coined "false middle ear or acquired cholesteatoma") is found.[14,15] In either case, all abnormal epithelium inside the tympanic cavity should be removed (Figure 3-23E). The sock of epithelium is generally easy to remove; the edge of the epithelium is grasped with hemostats, and while placing traction on the tissue, Freer elevators or Daubenspeck curettes are used to separate the attachments and remove the entire undisturbed epithelial cuff. If discolored or abnormal soft tissue clings from the dorsal compartment, it is carefully teased off with fine tipped curved hemostats. The ossicles are usually found tucked in the dorsal epitympanic recess just medial to the bony dorsal rim of the EAM. There is no need to remove the ossicles unless abnormal soft tissue or the tympanum is adhered to them. Curettage is avoided around the thin promontory areas, located dorsomedially that houses the sensitive inner ear structures (Figure 13-29). Excessive downward (medial) force with the curette on the medial surface of the tympanic cavity should be avoided since bone covering the carotid canal (housing the internal

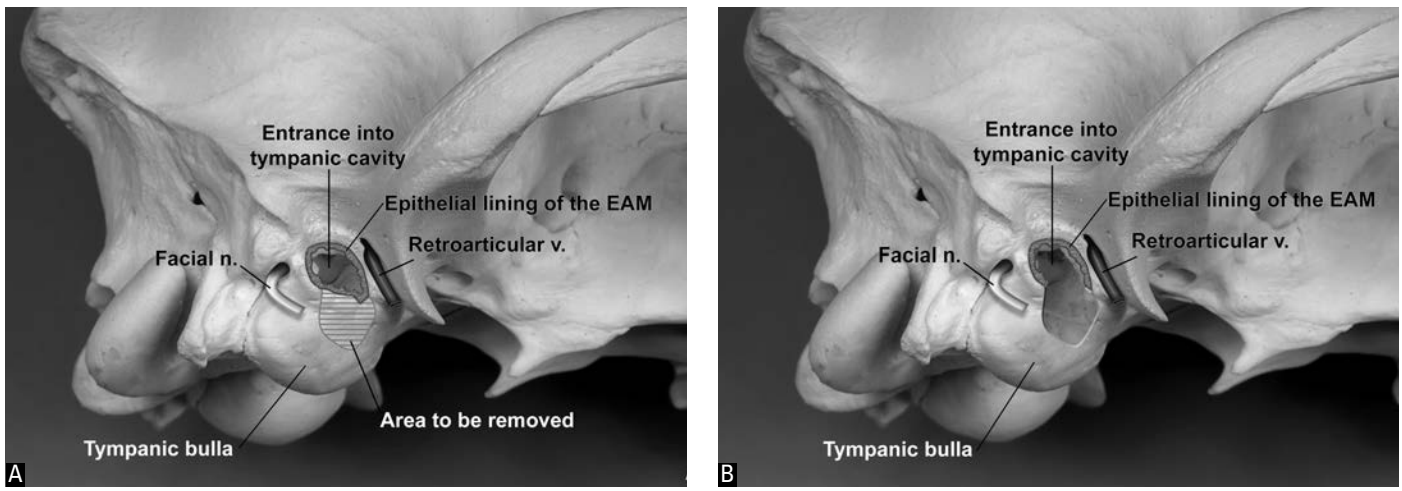


Figure 13-26. Lateral aspect of skull showing epithelial lining of EAM. **A.** The hatched area denotes the notch created in the ventral floor of the osseous ear canal described in Figure 13-25. The epithelial tissue lining of the ear canal is shown as the shaded area. **B.** While grasping the freed edge, the epithelial "cuff" is elevated both rostrally and caudally from the osseous ear canal beginning in the notched area. The ridge of bone separating the EAM from the stylomastoid foramen is now well exposed.

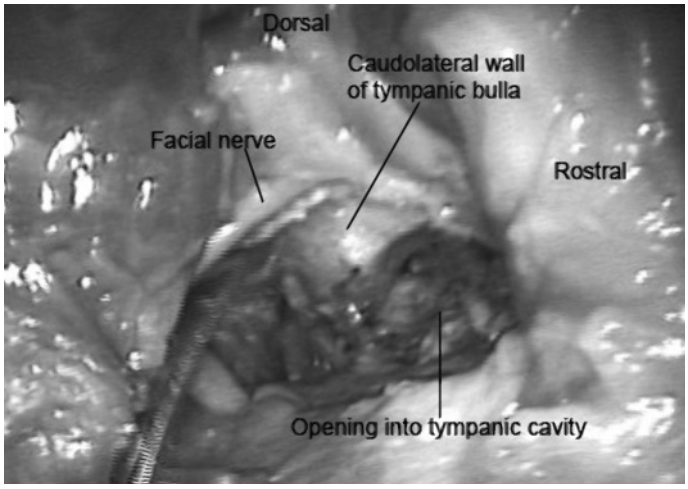


Figure 13-27. While protecting the facial nerve with a Freer elevator, the ridge of bone between the EAM and foramen has been removed with Lempert rongeurs and the facial nerve is isolated and retracted caudally.

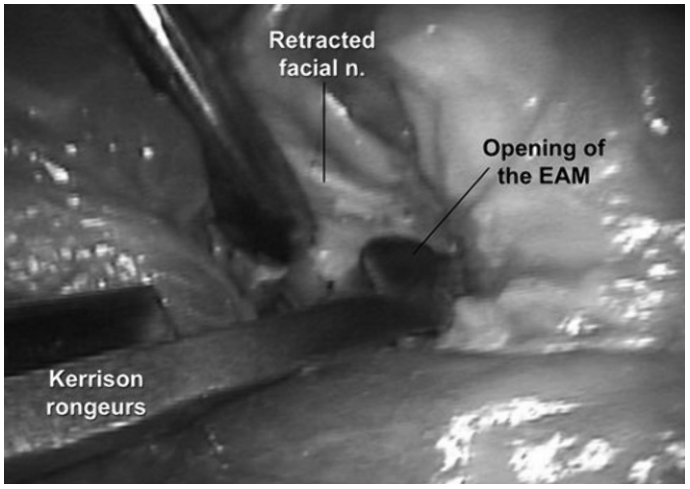


Figure 13-28. A Kerrison rongeurs is used to begin removal of the caudolateral aspect of the tympanic bulla while the facial nerve is protected with the elevator.

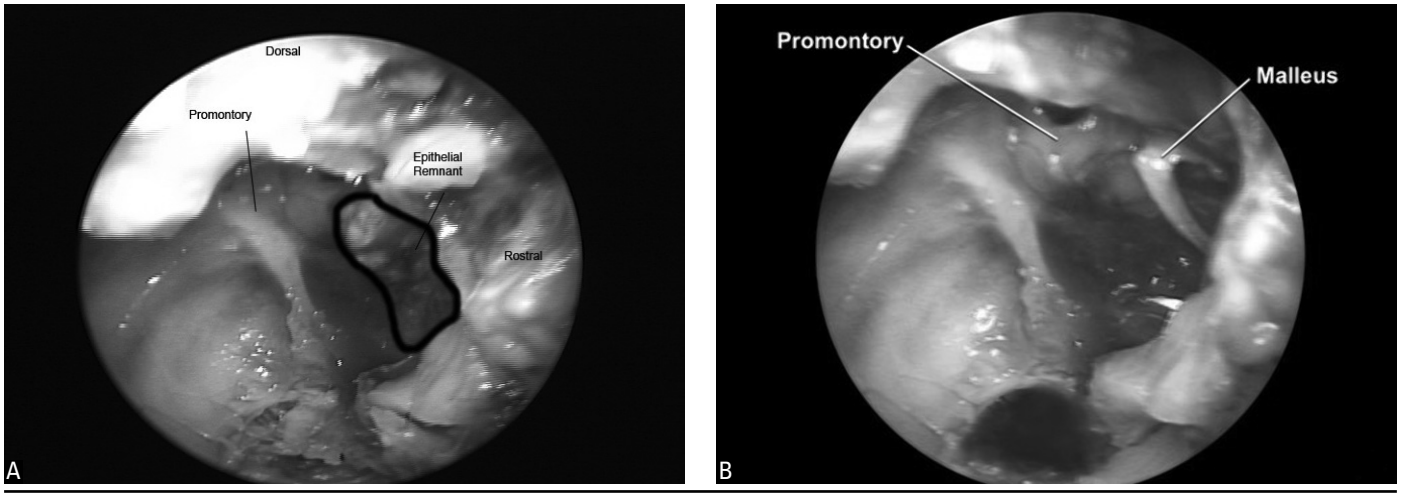


Figure 13-29. Lateral views of tympanic bulla after removing the caudal and lateral aspects of the bulla. **A.** Note the in vivo epithelial remnant (circled) in the rostral compartment of the cavity, which must be removed entirely without damaging the malleus and promontory areas (labeled). **B.** Excellent exposure of the completely evacuated tympanic cavity is achieved with the described subtotal bulla osteotomy technique.

carotid artery) can be penetrated causing profuse hemorrhage. If this occurs, the tympanic cavity is tightly packed with gauze stripping, and one should wait at least 5 minutes until hemostasis is established, and then the packing should be removed slowly to continue the inspection. Daubenspeck or malleable curettes are used to scrape the rostral, ventral and caudal tympanic cavity. Abnormal tissues are submitted for histologic evaluation. The epitympanic recess and the EAM should be carefully inspected for remnants of abnormal epithelium or retained tympanum. The entire tympanic cavity should be irrigated and inspected again and any remaining suspicious tissue and bony fragments are removed. Thorough irrigation of the entire wound, especially the dead space just medial to the base of the pinna is performed with sterile saline.

Ideally, an active suction drain system (Jackson-Pratt) is recommended in those patients with heavy contamination intra-operatively, uncontrolled bleeding, concurrent para-aural abscessation, or when the bulla is difficult to clean out properly. Alternately, if a closed suction system is not available, a passive surgical drain (Penrose drain) may be used. If the tissue surrounding the wound has minimal contamination, inflammation or hemorrhage, and the tympanic cavity is thoroughly evacuated, there is usually no need for wound drainage.[16] Dead space is closed in the subcutaneous tissue with 4-0 monofilament absorbable material. The skin is closed routinely with simple interrupted 4-0 monofilament nonabsorbable material to complete the total ear canal ablation.

Postoperative Care

If a drain is used, a loose, padded head bandage is placed to cover the drain and surgical site until the drain is removed, usually within 48 to 72 hours. Significant pharyngeal swelling can result particularly if TECA and bulla osteotomy are performed bilaterally. In addition, bandages may further reduce pharyngeal airway size and this can cause suffocation in the early postoperative period. These patients should be closely monitored for signs of dyspnea especially during the first 24 hours. An Elizabethan collar is used when needed to reduce self-trauma until sutures are removed in

10 to 14 days. During bandage changing, wounds are examined for evidence of fluid accumulation or ensuing infection. If signs of acute postoperative infection occur, sutures in the vertical portion of the wound are removed and the wound is opened fully to allow adequate drainage. Systemic antibiotics, based on the intraoperative culture and susceptibility results, are administered for a minimum of three weeks. Postoperative treatment for any underlying systemic skin disorder is continued.

Patients undergoing TECA and LBO often show evidence of extreme postoperative pain due to inflammation and nerve stimulation from deep wound dissection and bone removal. The surgeon must be prepared to aggressively manage this pain both preemptively and postoperatively. General postoperative guidelines for management of small animals after TECA and LBO are beyond the scope of this chapter, and are discussed elsewhere. (See Chapter 9) I prefer to give injectable opioid medications and NSAIDS in advance of surgery to reduce the amount of postoperative analgesics required to maintain patient comfort. A fentanyl patch can be applied 24 hours before surgery as another preemptive analgesic option. Postoperatively, injectable opioid analgesics combined with local anesthetic patches or constant local anesthetic infusion are also good options. The patient is released from the hospital and NSAID treatment is continued for 3 to 5 days if indicated.

Complications and Treatment

Many complications have been reported after TECA.[17-21] Most complications related to the surgery (wound infections and seromas) are short-lived and resolve within two weeks if treated appropriately. Extensive bacterial numbers are present in occluded chronically infected ear canals even after proper aseptic preparation of the area. Acute postoperative wound infection is not uncommon after TECA since wound contamination is inevitable. Proper intraoperative wound irrigation, antibiotic administration, and drainage help reduce this problem. Evidence of avascular skin slough at the proximal caudal skin margin and acute cellulitis are managed with open wound management and debridement until the area heals completely. Animals afflicted with inner ear signs before surgery may deteriorate immediately after anesthetic recovery and these signs may persist indefinitely in my experience. Until proven otherwise, inner ear signs that first develop in a patient a week or more after surgery are attributable to a fulminant abscess within the middle ear. Surgically induced Horner's syndrome tends to occur from middle ear curettage during TECA only in the cat. This will usually resolve within several weeks provided middle ear infection has been eradicated.

Many dogs experience slow or incomplete eye blink response and ear or lip droop immediately after surgery owing to paresis of muscles innervated by the facial nerve. Artificial tears or ointments are used prophylactically until the affected eyes regain full function, usually within five days after surgery. If no evidence of eye blink is appreciable by four weeks following surgery, permanent damage can be expected. Overall, about 10% to 15% of dogs have permanent facial nerve damage following TECA.[17] This does not cause significant disability in my experience, provided normal tear flow is present and the eye is not predisposed to exposure keratitis from exophthalmia. In summary, most facial nerve damage is iatrogenic and transient and is most often caused by overzealous retraction during ear canal dissection in my experience. Dissection of an entrapped facial nerve or en bloc resection of neoplasia may cause permanent damage.

Fistulization or skin sinus formation and middle ear infection are considered the most serious complications from TECA since these problems can cause clinical disability worse than the original chronic ear disease. Long-term antibiotic treatment and wound drainage rarely eliminate the problem in my experience. Persistent infection usually requires wound exploration for successful treatment, a costly and difficult procedure.[4] Persistent wound drainage or fistulization forms anytime from one month to over two years after surgery in about 5% to 10% of patients undergoing TECA and LBO for chronic otitis.[4] Persistent infection is most commonly attributed to a remnant of secretory tissue within the external auditory meatus or tympanic cavity. Isolation and removal of retained secretory epithelium with proper drainage of exudates permanently eliminates the problem. Ventral or LBO may be required depending on the suspected source of the persistent infection.[4,22] CT imaging is useful in helping the surgeon decide which approach is best. I, and others, prefer to use the lateral approach through the original incision site if retained horizontal ear canal tissue is the cause of the fistulization.[22] Ventral bulla osteotomy is the preferred route for exploration if the nidus is believed to be located in the middle ear because it avoids dissection through the previous surgery site and allows maximal exposure of the tympanic cavity. Approximately 70%-85% of patients explored for persistent infection will be cured.[4,22] Despite the expense and potential for serious complications following TECA, most owners are satisfied with the procedure and improvement in their dog's demeanor.

References

1. Smeak DD, Kerpsack S: Total ear canal ablation and lateral bulla osteotomy for management of end-stage otitis externa. Seminars in Veterinary Medicine 8:30-41, 1993.

2. Smeak DD: Total ear canal ablation and lateral bulla osteotomy. In Bojrab MJ (ed): Current Techniques in Small Animal Surgery. Williams and Wilkens, Baltimore, 1998, pp 102-9.

3. Cole LK, Kwocka KW, Kowalski JJ, Hillier A: Microbial flora and antimicrobial susceptibility patterns of isolated pathogens from the horizontal ear canal and middle ear in dogs with otitis media. J Am Vet Med Assoc 15:212:534-8, 1998.

4. Smeak DD, Crocker CB, Birchard SJ: Treatment of recurrent otitis media after total ear canal ablation and lateral bulla osteotomy in dogs: nine cases (1986-1994). J Am Vet Med Assoc 209:937-942, 1996.

5. Mason, LK, Harvey CE, Orsher, RJ: Total ear canal ablation combined with lateral bulla osteotomy for end-stage otitis in dogs-results in thirty dogs. Vet Surg 17:263-268, 1988.

6. Bacon NJ, Gilbert, RL, Bostock DE, et al.: Total ear ablation in the cat: indications, morbidity, and long-term survival. J Small Anim Pract 44:430-4, 2003.

7. McNabb AH, Flanders, JA: Cosmetic results of a ventrally based advancement flap for closure of total ear canal ablation in 6 cats: 2002-2003. Vet Srug 33:435-9, 2004.

8. Krahwinkel DJ, Pardo AD, Sims MH, Bubb WJ: Effects of total ablation

of the external acoustic meatus and bulla osteotomy on auditory function in dogs. J Am Vet Med Assoc 202:949-52, 1993.

9. McAnulty JF, Hattel A, Harvey CE: Wound healing and brain stem audtory evoked potentials after experimental total ear canal ablation with lateral tympanic bulla osteotomy in dogs. Vet Surg 24:1-8, 1995.

10. Geary CJ: Radiographic aspects of otitis media. Auburn Vet 21: 71-3, 1965.

11. Remedios AM, Fowler JD, Pharr JW: A comparison of radiographic versus surgical diagnosis of otitis media. J Am Anim Hosp Assoc 27:183-8, 1991.

12. Garosi LS, Dennis R, Schwarz T: Review of diagnostic imaging of ear diseases in the dog and cat. Vet Radiol Ultrasound 44: 137-46. 2003.

13. Smeak DD, Inpanbutr: Lateral approach to subtotal bulla osteotomy in dogs: pertinent anatomy and procedural details. Compend Contin Educ Pract Vet 27:377-385, 2005.

14. Lesinskas, E, Lesinskas R, Vainutiene V: Middle ear cholesteatoma: present-day concepts of etiology and pathogenesis. Medicina (Kaunas) 38: 1066-71, 2002.

15. Davidson EB, Brodie Ha, Breznoch EM: Removal of a Cholesteatoma in a Dog, Using a Caudal Auricular Approach. J Am Vet Med Assoc 211:1549-1553, 1997.

16. Devitt CM, Seim HB, Willer R, McPherro M, Neel, M: Passive drainage versus primary closure after total ear canal ablation-lateral bulla osteotomy in dogs: 59 dogs(1985-1995) Vet Surg 26:210-216, 1997.

17. Smeak DD, Dehoff WD: Total ear canal ablation-clinical results in the dog and cat. Vet Surg 16:161-170.

18. Mason LK, Harvey CE, Orsher RJ: Total ear canal ablation combined with lateral bulla osteotomy for end-stage otitis in dogs-results from thirty dogs. Vet Surg 17: 263-268, 1988.

19. Matthieson DT, Scavelli T: Total ear canal ablation and laeral bulla osteotomy in 38 dogs. J Am Anim Hosp Assoc 26:257-267, 1990.

20. Beckman, SL, Henry WB, Cechner P: Toal ear canal ablation combining osteotmy and curettage in dogs with chronic otitits externa and media. J Am Vet Med Assoc 196:84-90, 1990.

21. Sharp NJH: Chronic otitis externa and otitis media treated by total ear ablation and ventral bulla osteotomy in thirteen dogs. Vet Surg 19:162-166. 1990.

22. Holt D, Brockman, DJ, Sylvestre AM, Sadanaga KK: Lateral exploration of fistuals developing after total ear ablation: 10 cases (1989-1993). J Am Anim Hosp Assoc 32:527-30. 1996.

Ventral Bulla Osteotomy

David Holt

Indications

Ventral bulla osteotomy is indicated in dogs to treat chronic otitis media that has not responded to appropriate medical therapy, benign neoplasia affecting the middle ear, and cholesteatomas. In dogs with chronic otitis media, the surgeon must carefully evaluate the condition of the external ear canal before performing a ventral bulla osteotomy. Dogs with marked otitis externa causing narrowing or stenosis of the external ear canal usually require total ear canal ablation. In these cases, a concurrent lateral rather than ventral bulla osteotomy is performed. Ventral bulla osteotomy has been used to successfully treat recurrent or ongoing otitis media in dogs after total ear canal ablation and lateral bulla osteotomy. In addition, the surgical approach used to expose the ventral aspect of the bulla is very useful when exploring for foreign bodies that have pentrated the caudal pharynx or for evaluating neoplasia that may occur in this area of the head and neck.

Refractory otitis media requiring surgical drainage is less common in cats than in dogs. In cats, the most frequent indication for ventral bulla osteotomy is exploration to remove the middle ear component of aural or nasopharyngeal polyps. Rarely, the ventral approach has also been used in cats to treat benign and malignant masses involving the middle ear.

Bulla Anatomy

The tympanic bulla in dogs is part of the petrous temporal bone and forms a pear-shaped cavity. The larger main portion of the bulla extends ventrally. The smaller epitympanic recess extends dorsally and contains the auditory ossicles, the malleus, incus and stapes, which extend from the tympanic membrane to the vestibular window (Figure 13-30). Medial to the epitympanic recess is a bony eminence, the promontory, which contains the cochlea. The cochlear window is located on the caudolateral aspect of the promontory (Figure 13-31). Curettage of the epitympanic recess and in the area of the promontory should be avoided to prevent iatrogenic damage to the vestibular and cochlear windows. Damage to these structures may cause postoperative otitis interna and balance/equilibrium problems for the dog.

In the cat, the middle ear is divided by an incomplete boney septum into a large ventromedial compartment and a smaller dorsolateral compartment. During ventral bulla osteotomy in cats, the larger ventromedial compartment is invariably entered first. The septum runs obliquely from craniomedial to caudolateral in the rostral one-third of the bulla. Removing this septum and opening the dorsolateral compartment is mandatory during bulla osteotomy for polyps as this compartment contains the opening of the Eustachian (auditory) tube. Once the septum is removed, the complete extent of the oval promontory can be visualized (Figure 13-32). The cochlear window is located in the caudolateral aspect of the promontory. Postganglionic sympathetic nerve fibers from the cranial cervical ganglion enter the bulla caudally and fan out over the promontory where they may be damaged by curettage.

Surgical Technique

The ventral approach to the bulla is similar in cats and dogs. The animal is positioned in dorsal recumbency with a folded towel placed under the neck and tape is used to secure the rostral mandibles to the surgery table. Each bulla lies medial and slightly caudal to the vertical ramus of the mandible in a paramedian position. The bulla is palpable percutaneously in most cats but rarely in dogs. It is helpful to identify the mandibular salivary gland located at the bifurcation of the jugular vein by palpation immediately before surgery. A longitudinal paramedian skin incision is made between the larynx medially and vertical ramus of the mandible laterally, starting just rostral to the larynx and extending 1-5 cm caudal to it, depending on the size of the animal. The platysma muscle is incised longitudinally and the mandibular salivary gland identified. Dissection continues medial to the salivary gland, which must be carefully separated from the linguo-

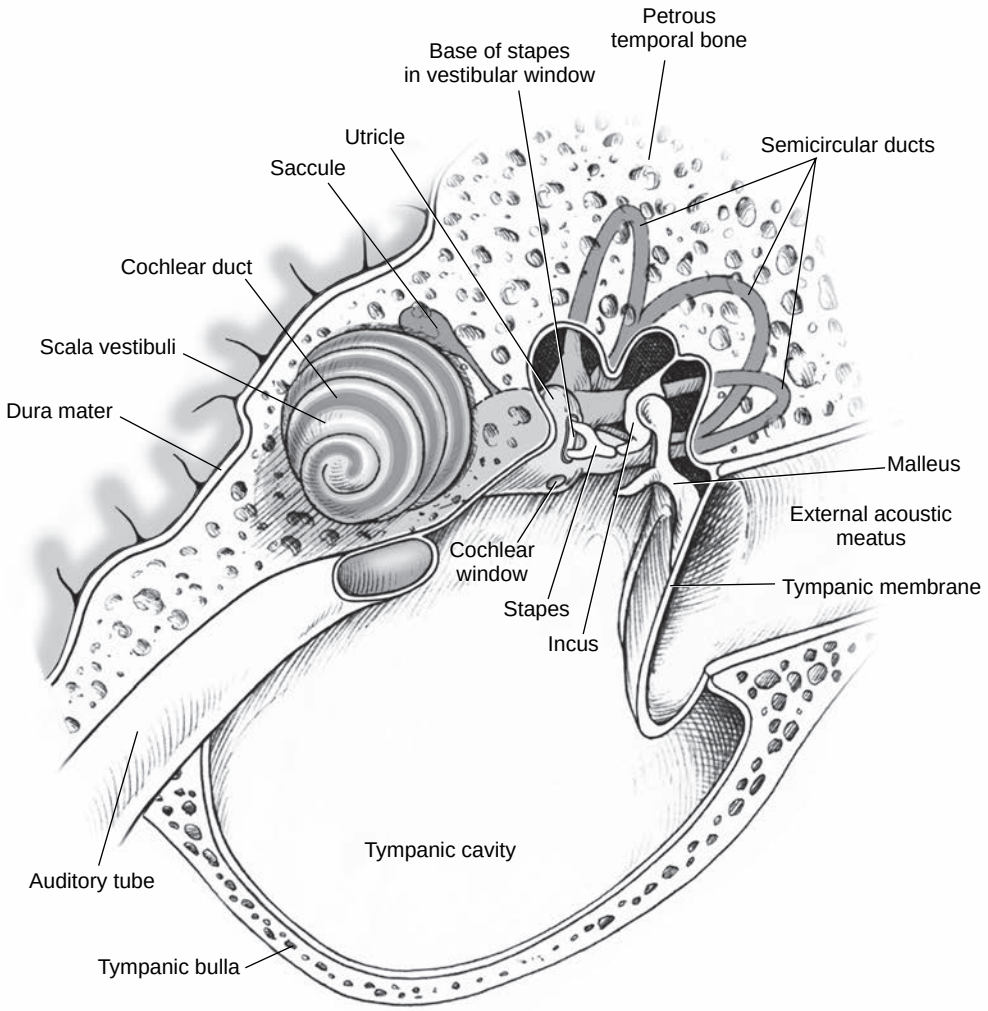


Figure 13-30. The middle ear of the dog illustrating the large ventral bulla cavity and the more dorsal epitympanic recess. The auditory ossicles extend from the typmpanic membrane to the vetibular window.

facial branch of the jugular vein (Figure 13-33). A small venous branch draining from the salivary gland into the linguofacial vein may require ligation and division. The separation between the large digastricus muscle laterally and the myelohyoideus muscle medially is identified. Correct location of this dissection plane is crucial for this approach. If this plane is correctly identified and dissected, the hypoglossal nerve will be visible coursing cranially on the medial aspect of the surgical field. The hypoglossal nerve is gently retracted and protected from injury throughout the procedure. Surgical exposure is maintained by careful placement of hand-held or Gelpi tissue retractors.

At this point, it is important to accurately identify the bulla by palpation. In cats, the large ventral dome of the bulla is easily palpable. In dogs, especially those with chronic otitis media, the bulla is not as apparent on palpation, feeling more flat than domed. To further localize the bulla, the surgeon should gently palpate for the stylohyoid bone coursing dorsally and laterally from the remainder of the hyoid apparatus. The hyoid apparatus in both species is attached to the caudal and lateral aspect of the bulla by the tympanohyoid cartilage, a small extension of the stylohyoid bone. In dogs, the paracondylar process of the occipital bone can often be palpated as a pointed structure protruding ventrally from the skull just caudal to the bulla. As an additional means to confirm the bulla's location, a non-sterile assistant can place an index finger into the mouth and palpate the hamular processes of the pterygoid bones. The assistant moves a finger to the bulla, which lies just caudal and lateral to this process on either side of the skull. The surgeon palpates the assistant's finger to confirm the location of the bulla.

Once the bulla is accurately identified, dissection proceeds dorsally. The bulla lies in a "V" formed by the internal and external branches of the carotid artery. These branches should be identified and carefully dissected or protected in the dog. In dogs, the thin muscular tissue lying immediately ventral to the bulla is bluntly separated parallel with the orientation of its fibers. In cats, the loose areolar tissue covering the bulla is bluntly elevated or dissected. The periosteum of the bulla is incised and elevated from the entire ventral surface of the bulla. The surgeon should take the time to ensure adequate lateral dissection and exposure of the bulla in cats before opening the bulla to facilitate exposure of the dorsolateral bulla compartment. A sharp Steinman pin in a Jacob's chuck is used to make the initial opening into the bulla. Very little dorsal pressure is applied to the chuck to prevent the pin from lurching into the dorsal aspect of

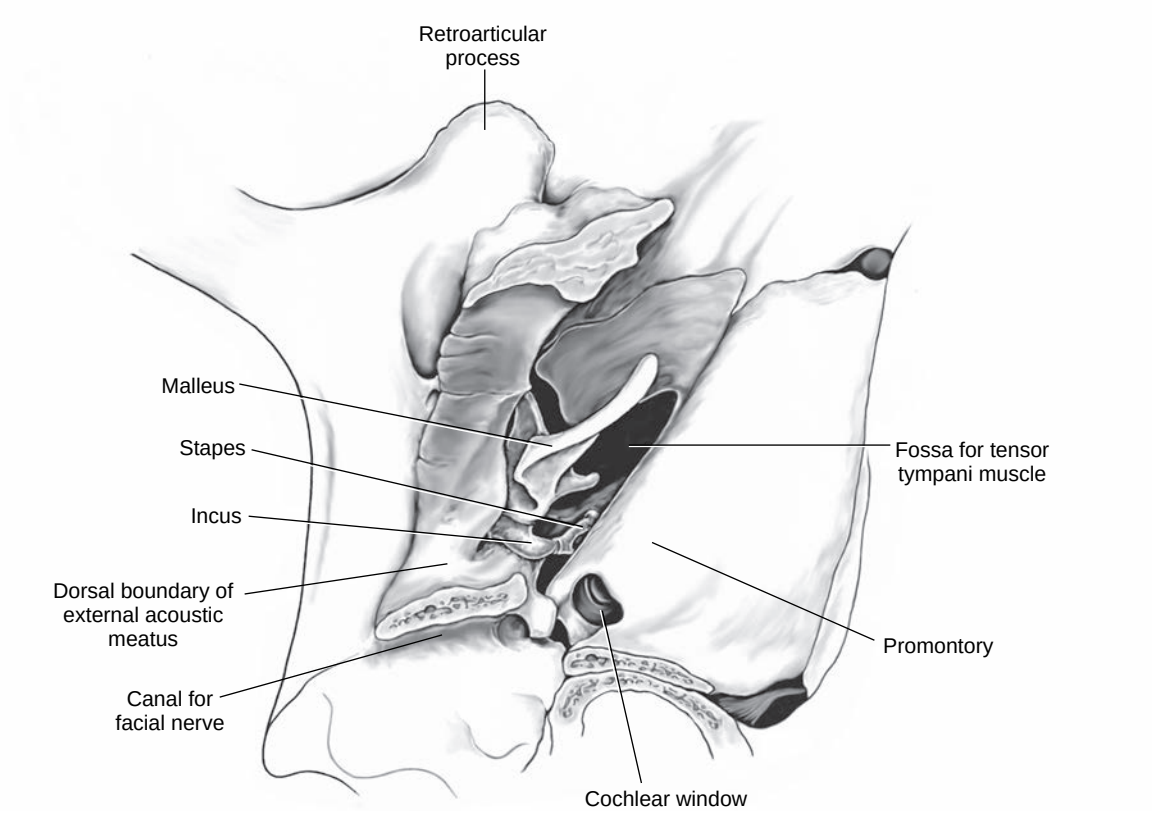


Figure 13-31. The middle ear of the dog with the majority of the tympanic bulla removed. The cochlear window is visible on the caudal aspect of the promontory.

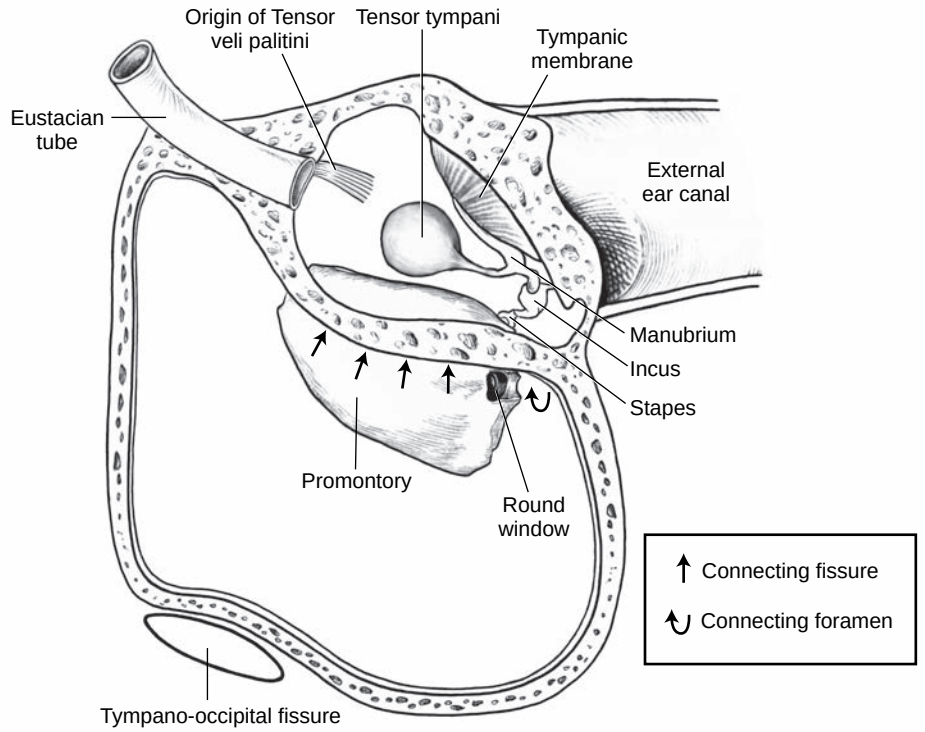


Figure 13-32. The feline bulla with part of the ventral wall removed. The medial compartment , bony septum and lateral compartment are visible. The cochlear (round) window is visible on the caudal aspect of the promontory.

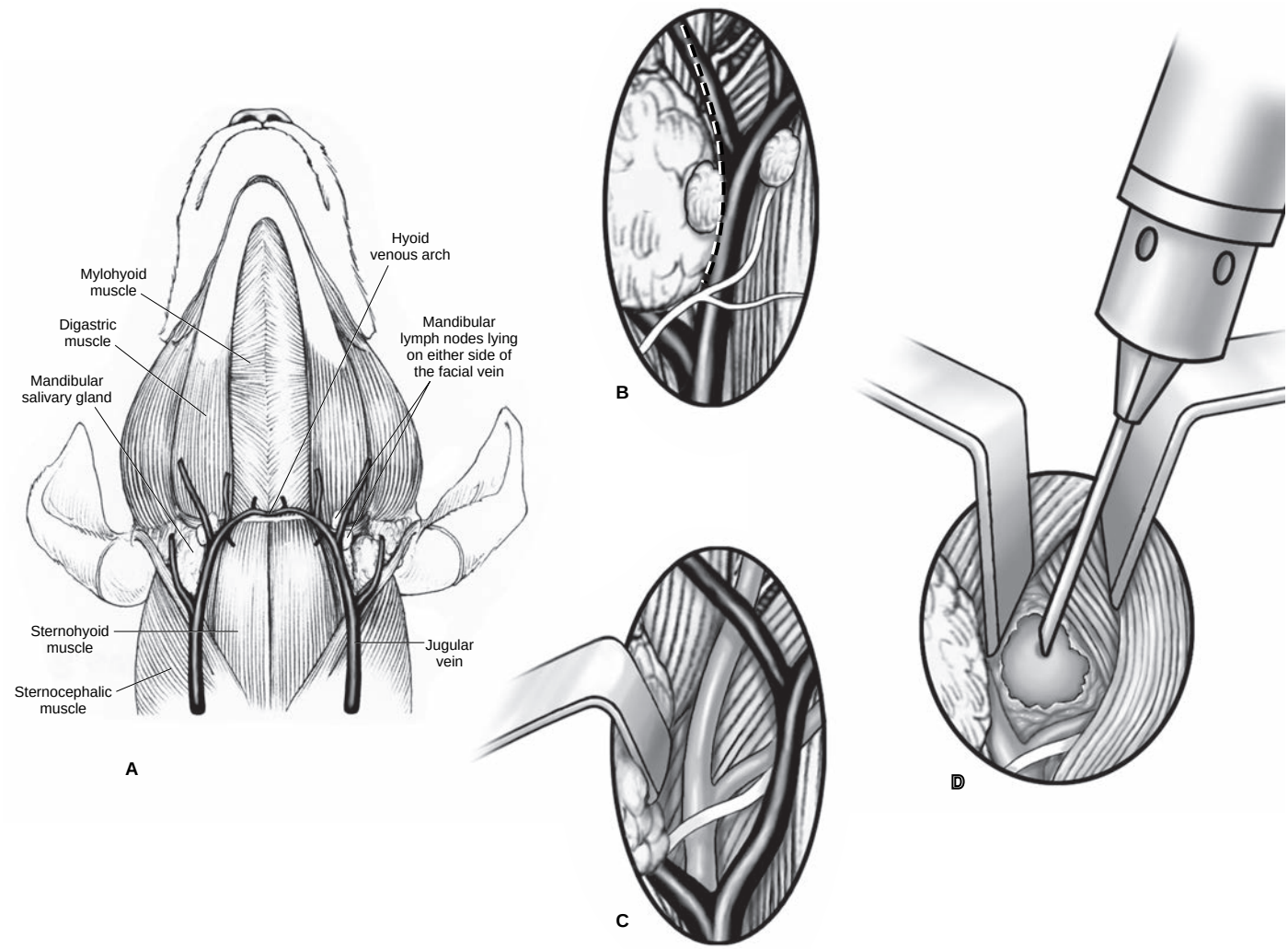


Figure 13-33. A. Superficial musculature, vessels, and salivary glands visualized during ventral bulla osteotomy dissection. **B.** Dissection for a right ventral bulla osteotomy. Once the platysma muscle has been incised, dissection proceeds medial to the submandibular salivary gland, which is separated from the jugular vein. A small branch of the vein is often ligated. **C.** Dissection proceeds between the digastricus muscle laterally and the myelohyoideus muscle laterally. The hypoglossal nerve is visible on the medial aspect of the surgical field. The bulla often lies in the "Y" formed by the bifurcation of the carotid artery. **D.** The bulla is identified by palpation and by location of the stylohyoid bone that attaches to the cranial and lateral surface of the bulla. The overlying tissue is dissected and retracted and the bulla opened using a Steinmann pin.

the bulla when it enters the tympanic cavity. In dogs with chronic otitis media and cats with long-standing polyps, the wall of the bulla can be quite thick and patience is required whle drilling with the Steinman pin. Alternatively, some surgeons prefer a powered drill for entrance to the bulla. Once an initial bulla opening has been made, it is enlarged with rongeurs.

In cats, the larger ventromedial compartment is opened first. The septum separating this compartment from the dorsolateral compartment is on the craniolateral aspect of the medial compartment. In some cats, the septum can be opened with a small, fine-tipped, single-action rongeur. In other cats, the septum must be penetrated by a Steinmen pin and the opening enlarged with rongeurs. With the bulla fully opened, the promontory is visible in both species as an oval shaped bony protuberance in the dorsal aspect of the bulla. Curettage over the promontory, particularly the caudal aspect, and in the epitympanic recess is avoided to prevent damage to the cochlear (round) and vestibular (oval) windows. Diseased or infected tissue is removed and samples are taken for biopsy and culture and sensitivity testing. The bulla cavity is thoroughly flushed with warm, balanced electrolyte solution and suctioned dry. Often, flushing and suctioning will identify residual tags of epithelial lining that are then removed. A latex drain is loosely placed into the bulla cavity without anchoring sutures. It exits through a separate small skin incision. The deeper layers of the surgical field are closed with a few single interrupted sutures of monofilament absorbable suture, taking care to avoid the hypoglossal nerve. The subcutaneous tissue and skin are closed in a routine manner. The latex drain is anchored to the skin with two single interrupted sutures.

Postoperative Care

Recovery from anesthesia is routine in most animals. The nasopharynx is inspected and suctioned while the animal is still under anesthesia as blood or flush solution can travel from the middle ear to the nasopharynx by the Eustachian tube and be aspirated after extubation if it is not removed. Cats with polyps in both middle ears that have undergone bilateral bulla surgery

must be carefully observed during anesthetic recovery. Swelling in the nasopharynx postoperatively can cause respiratory compromise. This can be alleviated by gently opening the cat's mouth to encourage mouth, rather than nasal breathing until the cat is fully recovered from anesthesia. Drains are usually removed 24-48 hours postoperatively.

Complications

Complications following ventral bulla osteotomy in dogs are uncommon but are usually associated with damage to structures of the inner ear. Clinical signs include nystagmus, head tilt, and circling. Neurologic signs are more common after ventral bulla osteotomy in cats with an 80% incidence of postoperative Horner's syndrome due to damage to the sympathetic nerve fibers in the middle ear. The clinical signs of Horner's syndrome, miosis, ptosis, and prolapse of the third eyelid resolve within 4 to six weeks in the majority of cats. Approximately 40% of cats may have clinical signs of otitis interna after ventral bulla osteotomy for polyp removal. These clinical signs are generally transient.

References

Fraser, G., Gregor, W.W., Mackenzie, C.P., et al. Canine ear disease.J Small anima Pract 1970; 10:725-754.

Getty, R. The ear. In: Evans H.E., Christensen, G.C., ed.: Miller's Anatomy of the Dog. Philadelphia: WB Saunders, 1979, pp 1062-1069.

Harvey, C.E.: Diseases of the middle ear. In Slatter, D.H., ed.: Textbook of Samll Animal Surgery, ed. 1. Philadelphia: WB Saunders, 1985, pp 1919-1923.

Kapatkin, A.S., Mathiesen, D.T., Noone, K.E. et al. Results of surgery and long-term follow-up in 31 cats with nasophyngeal polyps. J Am Anim Hosp Assoc 1990; 26:387-392.

Little, C.J.L., Lange J.G. The surgical anatomy of the feline bulla tympanic. J Small Anim Pract 1986; 27:371-378.

Little, C.J.L; Lane, J.G.; Pearson, G.R. Inflammatory middle ear disease of the dog: The clinical and pathological features of cholestetoma, a complication of otitis media. Veterinary Record. 199. 128:14, 319-322.

Lucroy, M.D., Vernau, K.M., Samii, V.F. et al. Middle ear tumours with brainstem extension treated by ventral bulla osteotomy and craniectomy in two cats. Vet Comp Oncol 2004; 2:234-242.

Smeak, D.D., Crocker, C.B., Birchard, S.J. Treatment of recurrent otitis media that developed after total ear canal ablation and lateral bulla osteotomy in dogs: Nine cases (1986-1994). J Am Vet Med Assoc 1996. 209:5, 937-942.

Section C

Digestive System

Chapter 14

Oral Cavity

Exodontic Therapy

Mark M. Smith

Introduction

Exodontics is the practice of tooth extraction. The most common indication for exodontic therapy in dogs is severe periodontal disease. Endodontic therapy is recommended for teeth affected by crown fracture exposing pulp, and pulpitis. However, it is not unusual to perform exodontic therapy when there is minimal crown available for restorative techniques, or when the owner does not authorize endodontic therapy. Exodontic therapy may also be used as a component of treatment for malocclusion.

Simple Exodontics

The periodontal ligament attaches the tooth to the bony alveolus or socket. The goal of exodontic therapy is to disrupt the periodontal ligament allowing movement of the tooth out of the alveolus. This component of the exodontic process is performed with periodontal elevators. There are various size and grip configurations for periodontal elevators. In dogs, basic periodontal elevators include instrument numbers 301s, 301, and 401.[1]

After the gingival attachment fibers are severed with a small scalpel blade, the periodontal elevator is inserted into the potential space between the tooth and alveolar bone. Initially, the elevator is rotated in the periodontal space to fatigue and tear the periodontal ligament. The position of the rotated periodontal elevator is maintained for 10 seconds to accomplish this goal. This maneuver is performed around the circumference of the coronal aspect of the root. As the exodontic procedure continues apically, the blade of the periodontal elevator is placed parallel to the root surface; the handle is dropped to be perpendicular to the long axis of the root; and the blade is turned 90°. This allows the edge of the elevator to engage the side of the root and "elevate" the root form the alveolus. Again, after movement is maximized, the position of the periodontal elevator is maintained for 10 seconds. Progress during the exodontic procedure will be noted by increased movement of the root and crown as the periodontal space expands secondary to hemorrhage and disruption of the periodontal ligament. Controlled force and patience will allow most single-rooted teeth or tooth segments to be extracted with periodontal elevators and digital manipulation. Extraction forceps are used only after the tooth is so mobile that the clinician considers the tooth or tooth segment removable with digital manipulation. The extraction forceps should engage the tooth as far apically as possible in order to decrease leverage forces on the root which could lead to root fragmentation (Figure 14-1). Generally, these non-surgical techniques are effective for incisors, first premolars, and third molars regardless of the health status of the periodontium. Multi-rooted teeth with periodontal disease and secondary mobility may be extracted using similar techniques.

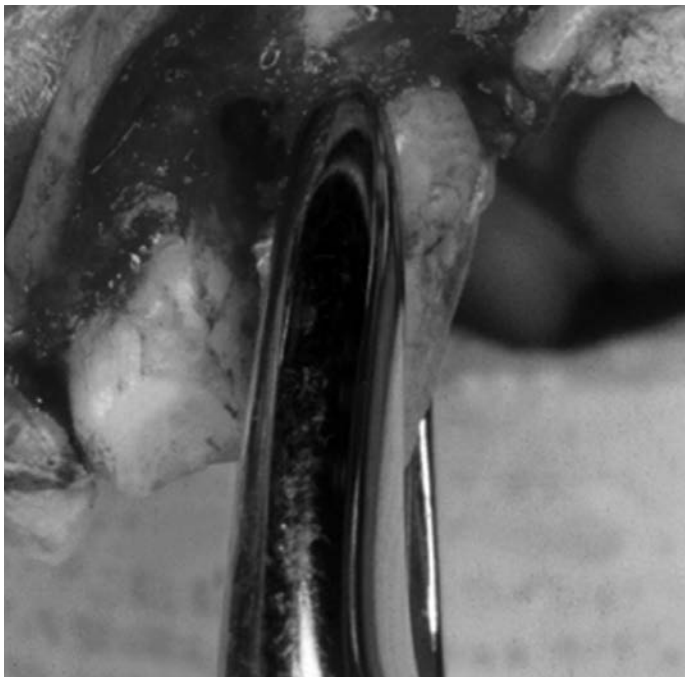


Figure 14-1. Photograph showing extraction forceps engaging as much of the crown and tooth root as possible while applying gentle force to complete the extraction of the mesiobuccal crown/root segment of the right maxillary fourth premolar tooth.

Complicated Exodontics

Non-mobile, multirooted or canine teeth are considered difficult or complicated teeth to extract. This fact is based on the complexity of the root system and sufficient periodontal attachment to prevent mobility even when there is substantial periodontal disease. Periodontally disease-free teeth with endodontic disease or malocclusion may be particularly difficult to extract based on having normal periodontal attachment. Surgical techniques are usually required for exodontic therapy of these teeth. Principles for surgical exodontic therapy include periodontal flap elevation, removal of alveolar bone to partially expose the root (s), sectioning the crown in multi-rooted teeth, crown/root segment elevation, alveoloplasty to smooth rough bone edges, and suturing of the periodontal flap over the alveolus. These principles will be highlighted in the following paragraphs describing surgical exodontic techniques for the maxillary fourth premolar, mandibular first molar, maxillary canine, and mandibular canine teeth.

Maxillary Fourth Premolar

The maxillary fourth premolar is a tri-rooted tooth with a large distal root and 2 mesial roots (mesiobuccal and mesiopalatal) emanating from a common root trunk. The procedure begins by using a #15 scalpel blade to incise a mucogingival periodontal flap. The mesial and distal incisions are made along the line angles of the tooth. Care should be taken to avoid the gingiva at the distal aspect of the maxillary third premolar and the mesial aspect of the maxillary first molar. Dorsal length of the incisions are dependant upon the size of the tooth, usually extending between 1.5 and 2.5 cm. As the mesial incision is advanced dorsally, another area to avoid is the infraorbital foramen which can be palpated through the mucosa between the maxillary third and fourth premolars. The infraorbital artery and nerve exit this foramen as they course in a rostral direction. After these vertical incisions are made, gingival fibers are incised form their attachment using either a #15 scalpel blade or a small, sharp periosteal elevator. The gingival is thin and easy to perforate when suing a sharp instrument. The technique of placing the scalpel blade parallel to the tooth surface and below the gingival, followed by short stab and prying motions is an effective way to elevate this tissue. As the mucogingival line is approached, a sharp periosteal elevator is used to elevate the buccal mucoperiosteum completing the flap.

Alveolar bone is removed form the buccal aspect of the distal and mesiobuccal roots using a high-speed hand piece and a round or pear-shaped bur. Usually the coronal one-half to two-thirds of the root is exposed by using light hand pressure to bur away this thin bone. During the alveolectomy process, it is helpful to drill slots on the mesial and distal aspects of these roots. Such bony slots provide a location to place the periodontal elevator. An analogy for this maneuver might be toe-hold during mountain climbing. During the alveolectomy, developing these "toe-holds" for the periodontal elevator will speed the extraction process. If a high-speed hand piece is not available, other instrumentation may be used for alveolectomy including bone file, rongeurs, curette, or a hobby drill with a sterilized round bur.

Crown sectioning is performed using a tapered-fissure or crosscut bur. The critical landmarks for crown sectioning are the buccal and mesial furcation entrances. Using these landmarks ensures crown sectioning with one root per crown segment (Figure 14-2). An exact "hemisection" is not necessary; however the crown must be completely cut beginning at the furcation entrances indicated. If a high-speed hand piece is not available, other instrumentation may be used for crown sectioning including a hobby drill, hack saw, or large bone cutter. This latter instrument will likely shatter the crown however crown integrity is not an important factor; only separation of the crown at the furcation.

The crown/root segments are elevated and removed using simple exodontic techniques described previously. Since the buccal alveolar bone has been removed, the crown/root segments are not elevated as much as luxated in a buccal direction. Therefore, this maneuver is easier with removal of increased amounts of buccal bone.



Figure 14-2. Photograph showing crown sectioning of the right maxillary fourth premolar tooth. The crown has been sectioned at the buccal and mesial furcations. Note the extracted mesiopalatal crown/root segment.

Following removal of the crown/root segments and confirmation that the roots have been completely removed, sharp bony edges are reduced (alveoloplasty) using a high-speed hand piece and around or pear-shaped bur. Other instruments may be used for alveoloplasty as described for alveolectomy. Alveoloplasty minimizes perforation of the periodontal flap by sharp bony edges. It also removes edges of bone which would likely require resorption during osseous healing.

Dilute chlorhexidine (0.12%) may be used to lavage the wound followed by positioning of the periodontal flap over the extraction site. The flap is sutured to the buccal mucosa and mucoperiosteum of the hard palate using chromic gut or polyglactin 910 in a simple interrupted pattern. Polydioxanone is not recommended because of its prolonged resorption time which is not necessary for routine oral wounds. Space is provided between individual sutures so that drainage may occur form the extraction site.

Mandibular First Molar

Similar exodontic techniques are used for the mandibular first molar as the maxillary fourth premolar. The periodontal flap, lateral alveolectomy, and alveoloplasty are performed as described previously (Figure 14-3). It should be noted that when compared with alveolectomy of the maxillary fourth premolar, the thickness of bone on the buccal aspect of the mandibular first molar is substantially greater. Crown sectioning is also recommended for this tooth with the shortest path being through the crown from the furcation in a distal direction. Lateral alveolectomy, visualization of the mesial and distal roots, and controlled root elevation decrease the incidence of iatrogenic mandibular fracture.

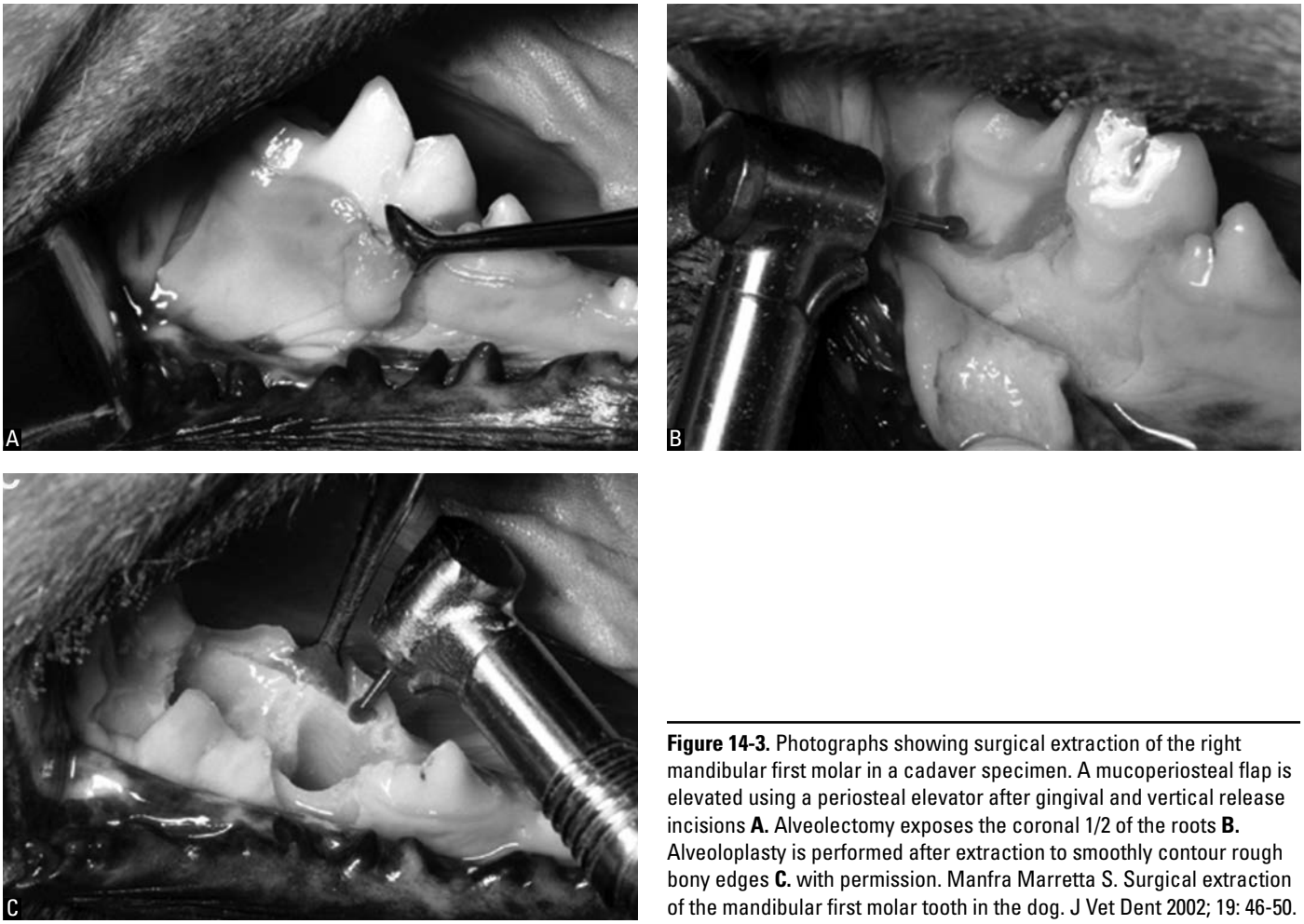


Figure 14-3. Photographs showing surgical extraction of the right mandibular first molar in a cadaver specimen. A mucoperiosteal flap is elevated using a periosteal elevator after gingival and vertical release incisions **A.** Alveolectomy exposes the coronal 1/2 of the roots **B.** Alveoloplasty is performed after extraction to smoothly contour rough bony edges **C.** with permission. Manfra Marretta S. Surgical extraction of the mandibular first molar tooth in the dog. J Vet Dent 2002; 19: 46-50.

Maxillary Canine

The maxillary canine is a large, single-rooted tooth which is difficult to extract using non-surgical techniques. Canine teeth affected by severe periodontal disease may be extracted suing non-surgical methods, however if the tooth has a healthy periodontium, it is essential to use surgical exodontic techniques. It is important to note that the root of the maxillary canine courses in a dorsal and distal direction with its apex directly above the mesial root of the maxillary second premolar. The periodontal flap incision begins in the buccal mucosa over the maxillary second premolar and is directed mesially, sloping towards the gingival at the distal line angle of the canine tooth. The gingival attachment fibers are incised along the canine tooth in a manner described previously. The flap incision is completed with a vertical relief incision form the gingival along the mesial line angle approximately 3/4 the length of the canine tooth root (Figure 14-4). Following gingival elevation, the buccal mucosa is relatively easy to mobilize form the buccal alveolar bone. An alternate flap design includes a peninsula-shape flap with mesial and distal incisions over the tooth's line angles (See Figure 14-4). Generally, regardless of flap design, the flap is sutured over bone. Therefore, the alveolectomy should be offset when compared with the periodontal flap. Lateral alveolectomy is performed using methods described previously. The alveolectomy begins near the cementoenamel junction and continues apically along the canine root (Figure 14-4). The cementum has a tan color and is readily identified compared with the hemorrhagic alveolar bone on the medial and distal sides of the tooth. During the alveolectomy process, it is helpful to purposely make gauges or slots in the alveolar bone on both the mesial and distal aspects. These focal areas of bone loss provide locations for application of the periodontal elevator (See Figure 14-4).

The canine root is elevated with the tooth being displaced in a lateral or buccal direction. If the angle of buccal displacement is acute, the root apex may fracture through the thin alveolar plate of bone separating the alveolus form the nasal cavity. If fracture leading to perforation occurs, hemorrhage may be noted form the ipsilateral nares. This problem is treated by primary wound closure of the periodontal flap over the alveolus. Incising the periosteum at the base of the periodontal flap improves flap mobility and decreases wound tension during primary closure (Figure 14-5).

Mandibular Canine

A buccal (lateral) approach has been recommended for surgical extraction of the mandibular canine tooth.[2-5] This approach requires consideration of anatomic structures including the prominent soft tissue attachment (frenulum) of the lip, the neurovascular structures exiting the mental foramen, and the roots of the first and second premolar. Considering the orientation of the root of the mandibular canine tooth is in a lingual (medial)

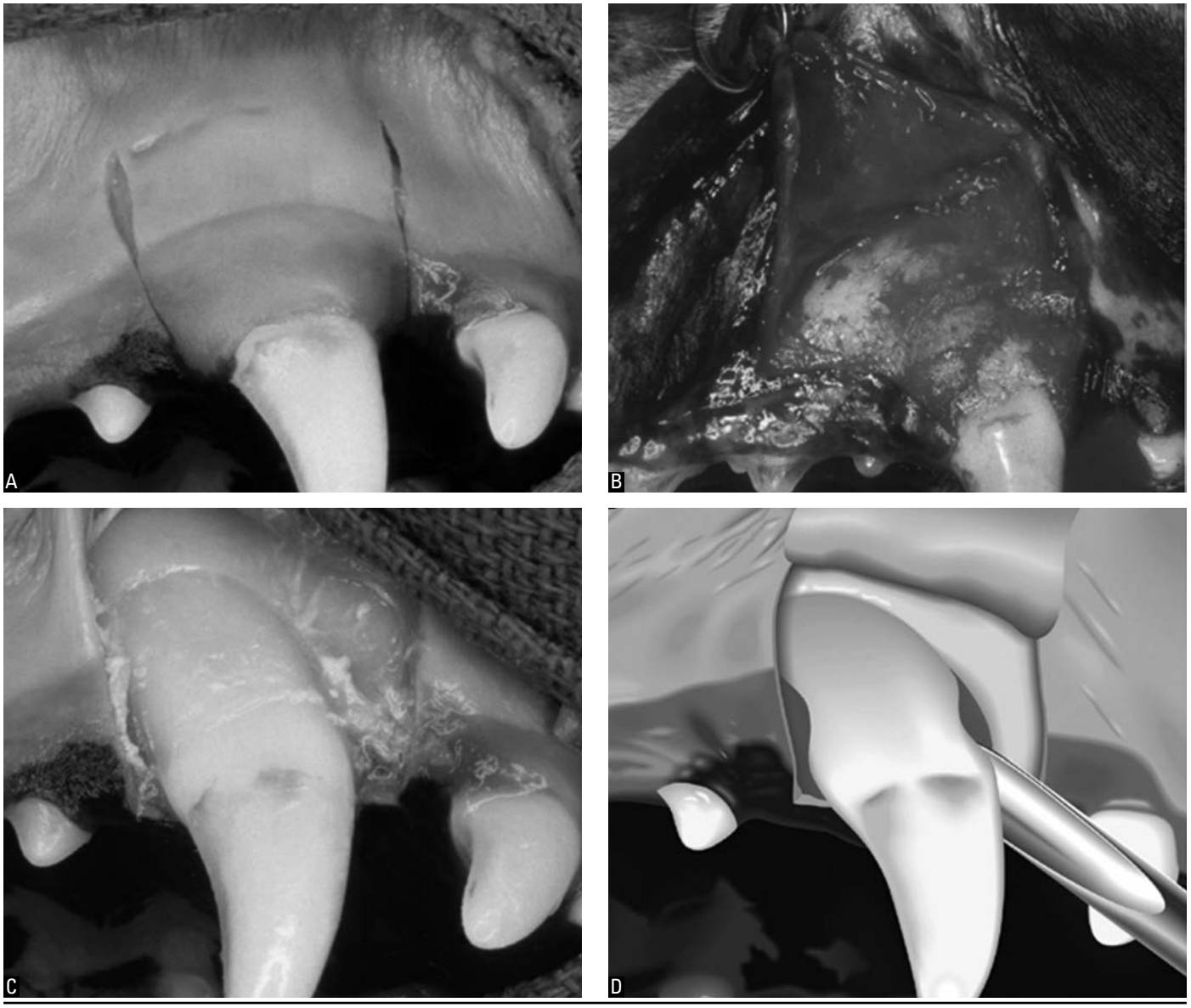


Figure 14-4. Photographs showing extraction techniques for the maxillary canine tooth. Flap design includes a peninsula flap with 2 vertical release incisions **A.** or a triangular flap with one vertical release incision **B.** Alveolectomy provides exposure to approximately 1/2 of the root **C.** while strategic exaggerated bone/tooth removal provides locations for placement of the periodontal elevator **D.** with permission. Frost Fitch P. Surgical extraction of the maxillary canine tooth. J Vet Dent 2003; 20: 55-58.

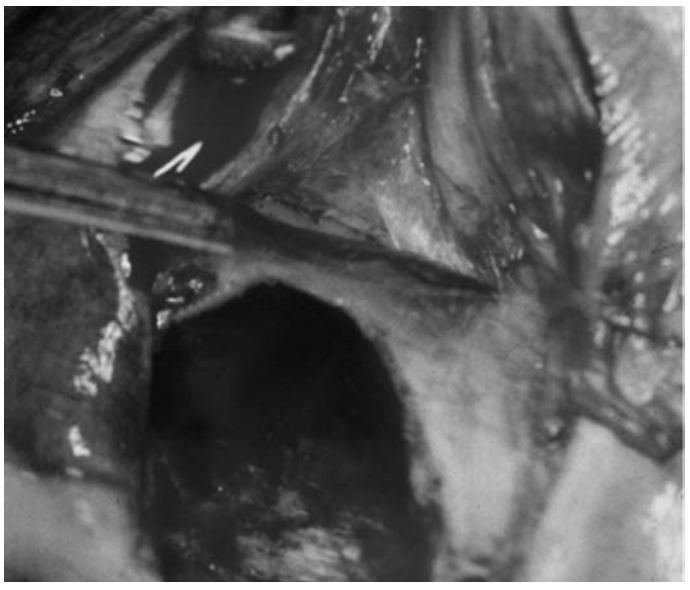
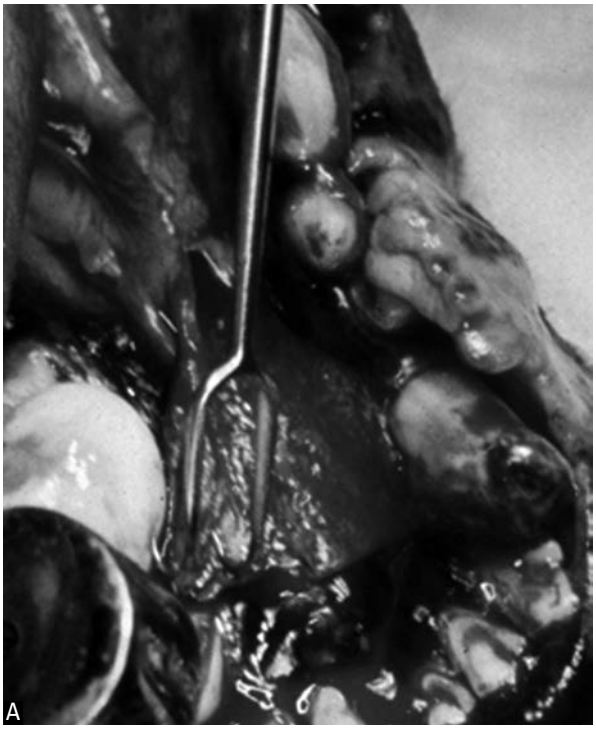


Figure 14-5. Photograph showing the periodontal release incision that enhances mobility of the flap and allows primary wound closure without tension.

direction, it would seem appropriate to consider an approach that could be performed directly over the root. Such an approach would avoid disruption of lip frenulum, potential hemorrhage from the mandibular artery and vein at the mental foramen, and iatrogenic trauma to adjacent tooth roots. A lingual approach for for surgical extraction of the mandibular canine tooth has been developed based on anatomic observations of tissues and structures of the rostral mandible and lingual orientation of the mandibular canine tooth root.[6]

The initial component of the procedure is elevation of a lingually based, full-thickness, mucoperiosteal flap. The flap is based on the symphyseal surface near the mandibular symphysis (Figure 14-6). The flap apex includes the gingival of the lingual aspect of the mandibular canine tooth. Generally, the flap base is approximately twice the width of the flap apex. A nitrogen-powered dental unit with a high-speed hand piece and round bur are sued to perform lingual alveolectomy (See Figure 14-6). Length of alveolectomy ranges form 10 to 20 mm in dogs. Periodontal elevators and extraction forceps are used to complete the extraction. The remaining alveolus is lavaged with 1.12% chlorhexidine and the flap is apposed to the buccal gingival using 3-0 polyglactin 910 in a simple interrupted pattern (See Figure 14-6).



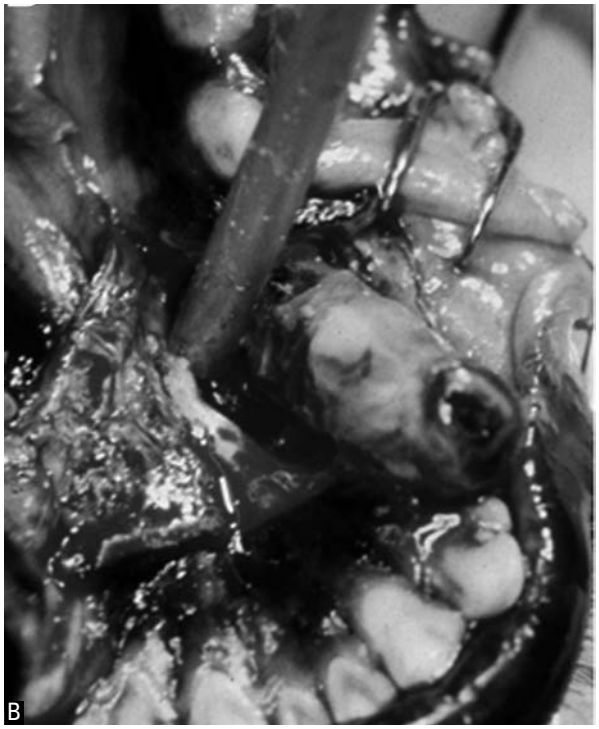




Figure 14-6. Photographs showing extraction techniques for the mandibular canine tooth. Access to alveolar bone is attained using a flap based on the lingual aspect **A.** followed by lingual alveolectomy **B.** Following extraction, the flap is apposed to the elevated gingival mucosa using absorbable suture in a simple interrupted pattern **C.**

References

1. Wiggs RB, Lobprise HB. Oral surgery. In Wiggs RB, Lobprise HB (eds): Veterinary Dentistry: Principles and Practice. Philadelphia, Lippincott-Raven, 1997, p 233.

2. Harvey CE, Emily PP. Oral surgery. In: Small Animal Dentistry. Philadelphia, Mosby, 1993, pp 316-317.

3. Eisenmenger E, Zetner K. Tooth fracture and alveolar fracture. In: Eisenmenger E, Zetner K, eds. Veterinary Dentistry. Philadelphia, Lea & Febiger, 1985, p 105.

4. Holmstrom SE, Frost P, Gammon RL. Exodontics. In: Holmstrom SE, Frost P, Gammon RL, eds. Veterinary Dental Techniques. Philadelphia, WB Saunders, 1992, p 185.

5. Tholen MA. Oral surgery. In: Tholen MA, ed. Concepts in Veterinary Dentistry. Edwardsville, KS, Veterinary Medicine Publishing, 1983, pp 90-96.

6. Smith MM. Lingual approach for surgical extraction of the mandibular canine tooth in dogs and cats. J Am Anim Hosp Assoc 32: 359-364, 1996.

Repair of Cleft Palate

Eric R. Pope and Gheorge M. Constantinescu

Introduction

Congenital palate defects can affect the primary palate, secondary palate, or both. The primary palate extends from the lip to the caudal border of the premaxilla (incisive bone). The secondary palate includes the remainder of the hard palate and the soft palate. Incomplete fusion of these structures results in cleft of the primary palate (harelip), cleft of the secondary palate, or both. Clefts of the primary palate can involve the lip (cheiloschisis), the alveolar process (alveoloschisis), or both (cheiloalveoloschisis). Clefts of the secondary palate include midline defects of the hard or soft palate and unilateral or bilateral lateral clefts of the soft palate.

Most clefts are believed to be inherited as either recessive or irregularly dominant traits. Nutritional, hormonal, and mechanical factors have also been incriminated as causes, but these factors are more likely to affect the severity of the cleft in predisposed individuals rather than being a sole cause. Intrauterine infections and exposure to toxins at specific periods during gestation can also result in cleft palate. Cleft palate has been reported in many different breeds of dogs, but the brachycephalic breeds appear to be overrepresented. The Abyssinian, Siamese, and Manx breeds of cats seem to be at increased risk.

Clinical Signs

The clinical signs vary with the location and severity of the cleft. Clefts of the primary palate involving only the lip are primarily a cosmetic defect associated with few clinical signs. Primary clefts involving the lip and premaxilla may interfere with the ability to suckle and may allow milk to enter the nasal cavity resulting in rhinitis. Because the defect is readily apparent, the inability to nurse properly is likely to be recognized earlier by observant owners and hand rearing instituted. Clefts of the secondary palate may also interfere with the ability to nurse, but because these defects are less apparent, some neonates may die of malnutrition or aspiration pneumonia before other signs are recognized. Milk or food in the nasal cavity frequently causes sneezing or gagging. Milk may be seen running from the nose. The resulting rhinitis causes a serous to mucopurulent nasal discharge that may be malodorous. Aspiration of milk or food causes coughing, and aspiration pneumonia is a common sequela. Clefts involving only the distal half of the soft palate are unlikely to result in significant clinical signs.

Preoperative Patient Evaluation and Care

Animals with clefts of the primary palate that involve only the lip often need no special care. Except for their being "sloppy eaters," the defect is usually well tolerated. Tube feeding can be instituted if the defect prevents effective nursing. Repair of these defects can be delayed until the patient is older (3 months or more), when visualization is improved and tissue manipulations are easier. Animals with clefts involving the premaxilla are more likely to have difficulty in nursing and require tube feeding. Earlier repair (7 to 9 weeks of age) can be performed in these animals to reduce the severity of the rhinitis secondary to entrance of food into the nasal cavity if oral feeding is begun at weaning. Tube feeding is recommended for patients with clefts of the secondary palate to reduce the severity of the rhinitis associated with the passage of milk into the nasal cavity and to reduce the potential for aspiration pneumonia. Depending on the size of the patient, repair of clefts of the secondary palate can be performed between 7 and 9 weeks of age if clinical signs are severe but I prefer to wait until the patient is 12 to 14 weeks old when access to the oral cavity for tissue manipulation is better and the tissues are less friable.

The diagnosis is generally obvious on physical examination. A complete examination is necessary to rule out other congenital defects. I routinely take thoracic radiographs of patients with clefts of the secondary palate before surgery to document the presence or absence of aspiration pneumonia. Aerobic and anaerobic bacterial cultures are performed on patients with purulent rhinitis, and appropriate antimicrobial therapy is initiated. Patients with minimal rhinitis are given a broad-spectrum antimicrobial perioperatively (administered when the intravenous catheter is placed before anesthesia induction and continued for up to 24 hours). Food is withheld the morning of surgery, but the operation should be performed as early in the day as possible to avoid hypoglycemia. Rhinoscopy should be considered on patients with purulent rhinitis immediately before the surgical procedure because some patients may have foreign bodies (typically plant material) that might not be dislodged by flushing during surgical preparation and result in persistent rhinitis postoperatively.

Surgical Technique

A cuffed endotracheal tube is placed after induction of anesthesia and secured to the lower jaw. Access to the pharyngeal area can be improved by pharyngotracheal intubation, but it is generally unnecessary. Clefts of the primary palate are repaired with the patient placed in ventral recumbency and the head elevated on a cushion under the mandible. Elevating the head in this manner

allows the lips to hang in a normal position and provides good surgical access. An oral speculum can be placed if the premaxilla is involved and better access to the oral cavity is needed. The hair on the muzzle is clipped, and the skin is prepared routinely. The oral cavity is prepared with dilute chlorhexidine or povidone-iodine solution.

Clefts of the secondary palate are repaired with the patient placed in dorsal recumbency (Figure 14-7). The head is placed on a soft pad or beanbag, and the maxilla is immobilized with 1-inch tape placed over the incisors or canine teeth and secured to the operating table on each side. Access to the oral cavity is obtained by taping the animal's lower jaw, tongue, and endotracheal tube to an ether screen. A malleable retractor is also useful for retracting the tongue and endotracheal tube during repair of clefts of the soft palate. Pharyngotracheal intubation can be performed if greater access is needed. The nasal cavity should be liberally flushed with saline to remove purulent exudate and possible foreign bodies before swabbing the oral cavity with dilute chlorhexidine or povidone–iodine solution.

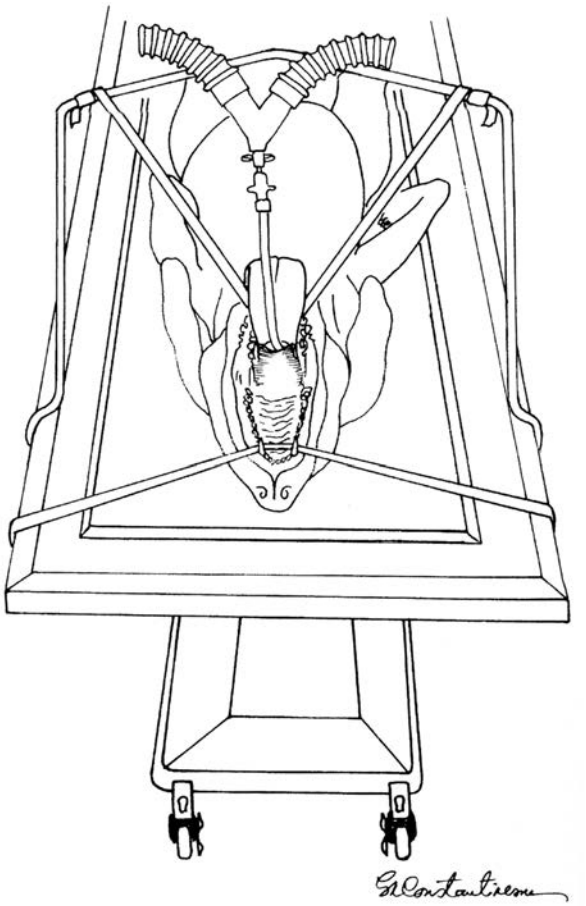


Figure 14-7. Patient positioning for surgery of the hard or soft palate.

Gentle tissue handling using skin hooks or bent hypodermic needles reduces tissue trauma. The use of electrosurgery should be minimized. Pinpoint coagulation of bleeders is acceptable, but use of the electroscalpel for making incisions and elevating flaps is not recommended. Two-layer closure in which suture lines on the nasal and oral cavity sides are offset is preferred. An airtight closure, free of tension, is mandatory. I prefer to use polyglactin 910 suture material in the oral cavity because the knot ends are not stiff and it is generally extruded by 14 to 21 days after surgery. Some of the new rapidly absorbed monofilament suture materials are preferred by some veterinary surgeons.

Cleft of the Primary Palate

The main objective in repairing a cleft of the primary palate is to establish the normal separation between oral and nasal cavities. Clefts of the primary palate involving only the lip are easy to repair. Although complex flap techniques to reconstruct the nostril and columella accurately have been described, they are generally unnecessary because of the abundance of labial tissue in animals. The edges of the cleft defect are incised to a depth of 2 to 3 mm along the entire margin of the defect to create an inner mucosal layer and outer cutaneous layer (Figures 14-8A and B). Beginning at the most dorsal point, the mucosal edges are apposed with interrupted 4-0 absorbable sutures (Figure 14-8C). Accurate tissue apposition without tension is required. Skin closure should progress from the lip margin to avoid a step deformity using 3-0 to 4-0 monofilament nonabsorbable suture material in an interrupted pattern.

If the cleft also involves the premaxilla, closure is more difficult, but the objective is the same. The critical step is achieving closure of the oronasal communication. Careful preoperative planning is necessary to identify the best source and orientation of mucosal flaps to allow tension-free closure. Abnormal development of the premaxilla may necessitate extraction of teeth to facilitate the reconstruction. Mucosal flaps based on the nasal or oral mucosa are elevated from each side of the defect and are sutured together with fine (4-0 or 5-0) absorbable suture material. Although a two-layer closure is preferred, there may not be sufficient tissue in all cases. If only a one-layer closure is performed, the nasal epithelial side should be reconstructed and the oral mucosal side allowed to heal by second intention. Finally, reconstruction of the lip is performed as previously described. Potentially, all or part of the oral mucosal defect can be covered as the lip is reconstructed.

Cleft of the Secondary Palate

The technique for closing clefts of the secondary palate depends on the extent of the defect (i.e., hard and soft palate versus either individually), the width of the defect, and the availability of tissues to close the defect. In most cases, one of the following techniques can be successfully used. Key points to consider are: 1) two-layer closures that re-establish the nasal and oral epithelial surfaces are stronger and provide the potential for bony union across the defect; 2) tension on the suture line is probably the most common reason for failure and must be avoided; and 3) preserving the blood supply to the flap, whether from the palatine vessels (Figure 14-9) in advancement flaps or the nasal cavity in "hinged" flaps, may limit the size or mobility of the flaps.

Double-Layer Mucoperiosteal Flap Technique

This technique is most useful for clefts involving less than one-third of the width of the hard palate. The first step is to create unilateral or bilateral "hinged" flaps based on the edges of the cleft that are rolled back over the defect to create an epithelium-lined closure

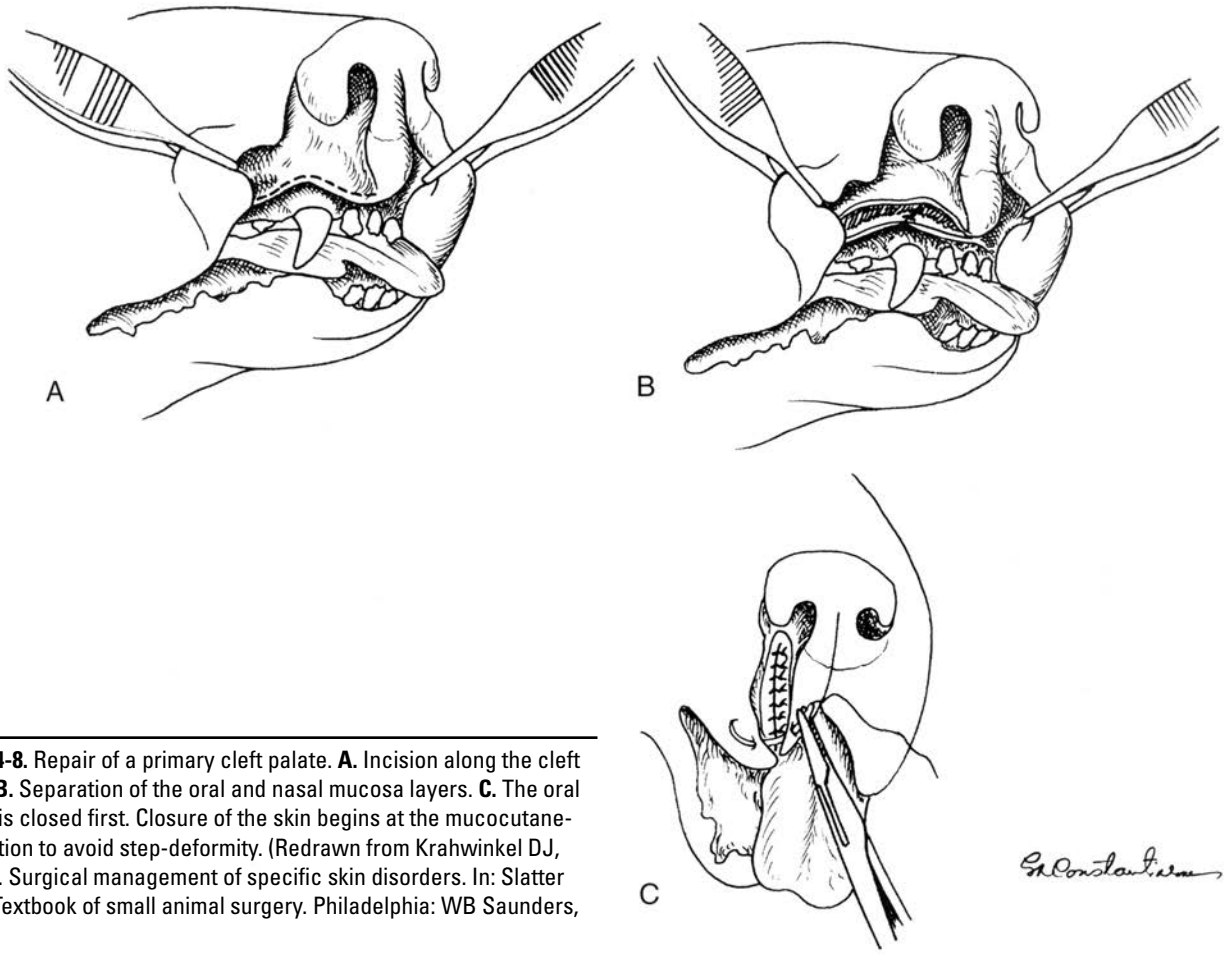


Figure 14-8. Repair of a primary cleft palate. **A.** Incision along the cleft margin. **B.** Separation of the oral and nasal mucosa layers. **C.** The oral mucosa is closed first. Closure of the skin begins at the mucocutaneous junction to avoid step-deformity. (Redrawn from Krahwinkel DJ, Bone DL. Surgical management of specific skin disorders. In: Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1985.)

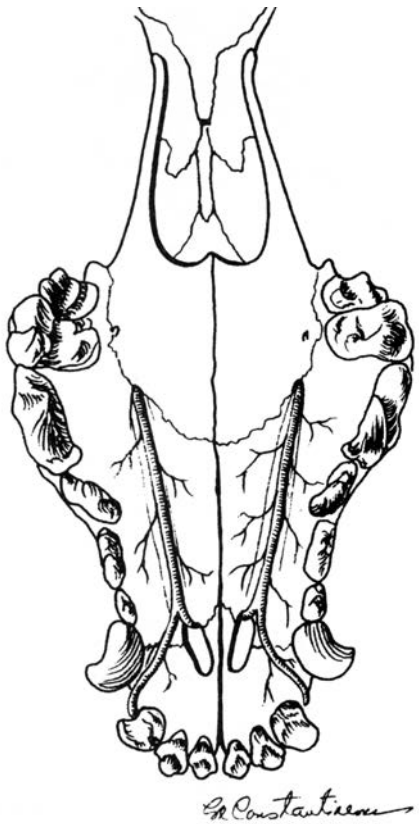


Figure 14-9. Location of the major palatine arteries.

of the floor of the nasal cavity. A unilateral flap is preferred if the cleft is not too wide (approximately 10% of the width of the palate) because the suture lines from this layer and the bipedicle mucoperiosteal advancement flap of the second layer can be offset, potentiating an airtight closure. Bilateral flaps are used on wider clefts to reduce tension on the palatine arteries as the mucoperiosteal flaps are advanced to close the oral cavity side of the defect.

In the unilateral flap technique (Figure 14-10), the hard palate mucosa is incised parallel to the cleft to create a flap that is slightly wider than the cleft. Perpendicular incisions are made at the rostral and caudal extents of the cleft to complete the flap. The flap is undermined with a periosteal elevator just to the edge of the bony defect, with care taken to preserve the blood supply coming from the nasal side. On the opposite side, the mucosa is incised along the edge of the defect to create a nasal side and an oral cavity side. The flap is rolled back toward the midline and is sutured to the nasal mucosa on the opposite side with preplaced 4-0 synthetic monofilament sutures using an interrupted pattern with the knots placed on the nasal side of the flap. The second layer of closure is started by making a releasing incision along the dental arcade on the side opposite the hinge flap to create a bipedicle flap. A periosteal elevator is used to undermine the flap beginning at the midline, with care taken to preserve the palatine arteries that enter the flap midway between the midline and the dental arcade approximately at the level of the caudal edge of the carnassial tooth (See Figure 14-9). The flap is advanced over the fistula and is sutured to the cut edge of the mucoperiosteum

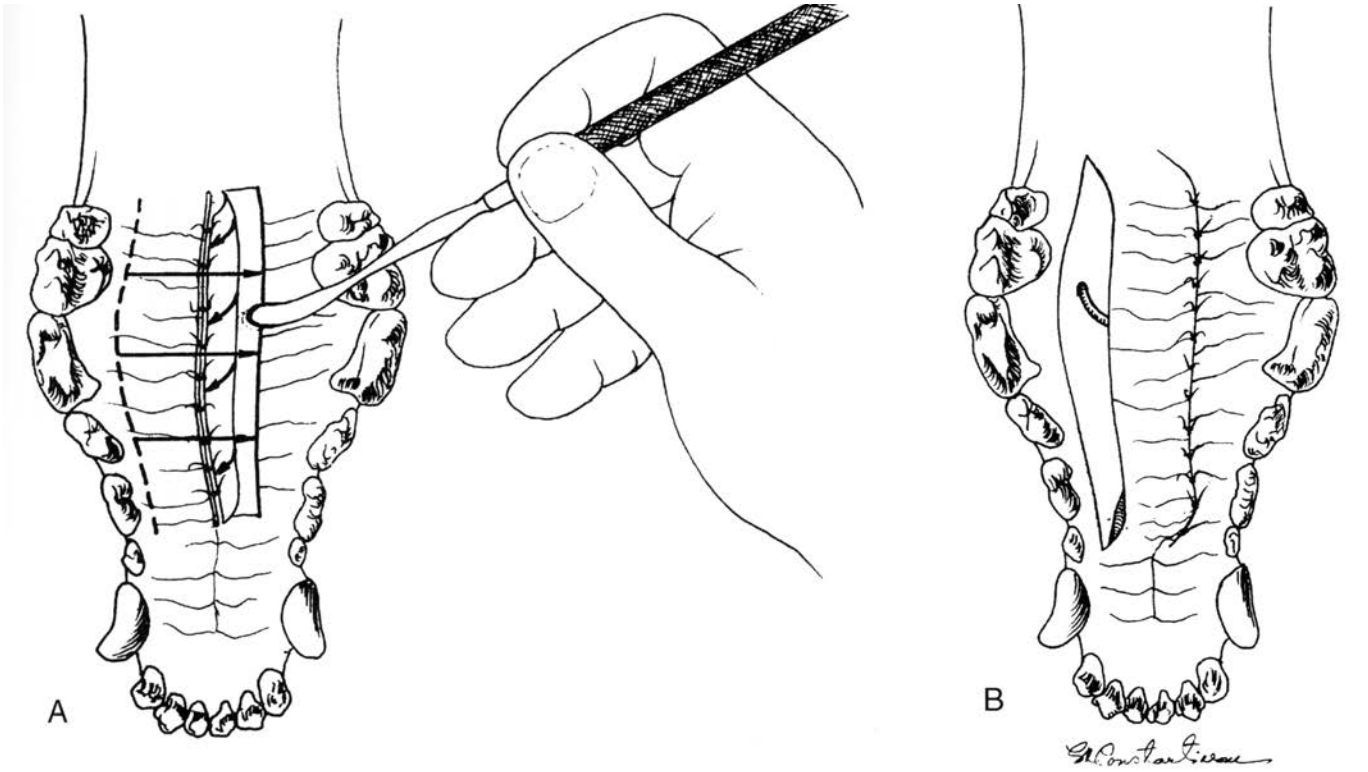


Figure 14-10. Two-layer closure using a unilateral hinge flap. **A.** Incision is made along one side of the cleft separating the nasal and oral mucosa. A unilateral hinge flap is elevated from the opposite side, "rolled" back over the defect, and sutured to nasal mucosa. A releasing incision is made along the dental arcade creating a bipedicle mucoperiosteal flap. **B.** The flap is advanced over the first layer and is sutured to the mucoperiosteum on the opposite side.

on the first side. The donor site along the dental arcade heals by second intention.

When wider defects are present, hinged flaps are elevated bilaterally, rolled back, and sutured together over the middle of the defect (Figure 14-11A-C). The second layer of the closure involves the development of bilateral, bipedicle mucoperiosteal flaps, which are advanced toward the midline and are sutured together. The hard palate mucosa is incised just medial (palatal) to the dental arcade, leaving the flap attached rostrally and caudally. The flaps are advanced toward the midline and are sutured together with 3-0 to 4-0 absorbable suture material.

The defects along the dental arcade can be allowed to heal by second intention, or they may be covered by buccal mucosal transposition flaps. Potential complications associated with allowing the defects to heal by second intention are shortening and narrowing of the maxilla, but we have not found this to be a common clinical entity. Single-pedicle or double-pedicle buccal mucosal flaps can be mobilized to cover the palatal donor sites. The buccal mucosa donor sites usually can be easily closed with a simple continuous pattern. Two weeks later, the bases of the pedicle flaps are incised and sutured.

This technique may be difficult to perform without creating excessive tension on the suture lines or palatine vessels when wide defects are present. Although the technique can also be performed as a single tissue layer closure by creating bilateral, bipedicle mucoperiosteal flaps and advancing them to the midline, the suture line lies over the center of the defect, making it more difficult to achieve an airtight closure. Moreover, constant movement of the suture line with respiration and tongue movements predisposes to dehiscence. Therefore, when wide defects are present, the following technique is recommended.

Howard Mucoperiosteal Hinge Flap

The hard palate mucosa is incised parallel to the edge of the defect so a mucoperiosteal flap slightly wider than the defect can be raised (Figure 14-12). The flap is undermined toward the midline, with care taken to maintain the blood supply from the nasal mucosa. The major palatine vessels are identified and ligated. The edge of the cleft on the opposite side is incised, and the oral mucosa is undermined for a depth of 2 to 3 mm. The mucoperiosteal hinge flap is rolled back over the defect. If it appears likely that tension will be present, a releasing incision is made along the dental arcade on the side opposite from the hinge flap. The bipedicle flap is undermined as previously described and is advanced toward the midline to eliminate the tension. The edge of the hinge flap is sutured to the underside of the mucoperiosteum on the opposite side with preplaced interrupted sutures using a mayo mattress pattern. Overlapping the edges in this manner achieves an airtight closure and minimizes movement along the suture line. The donor site(s) are allowed to heal by second intention.

Closure of Soft Palate Defects

Midline soft palate defects commonly accompany hard palate defects (Figure 14-11D-E). If possible, a two-layer overlapping technique is used. One flap is based on the nasal mucosa, and

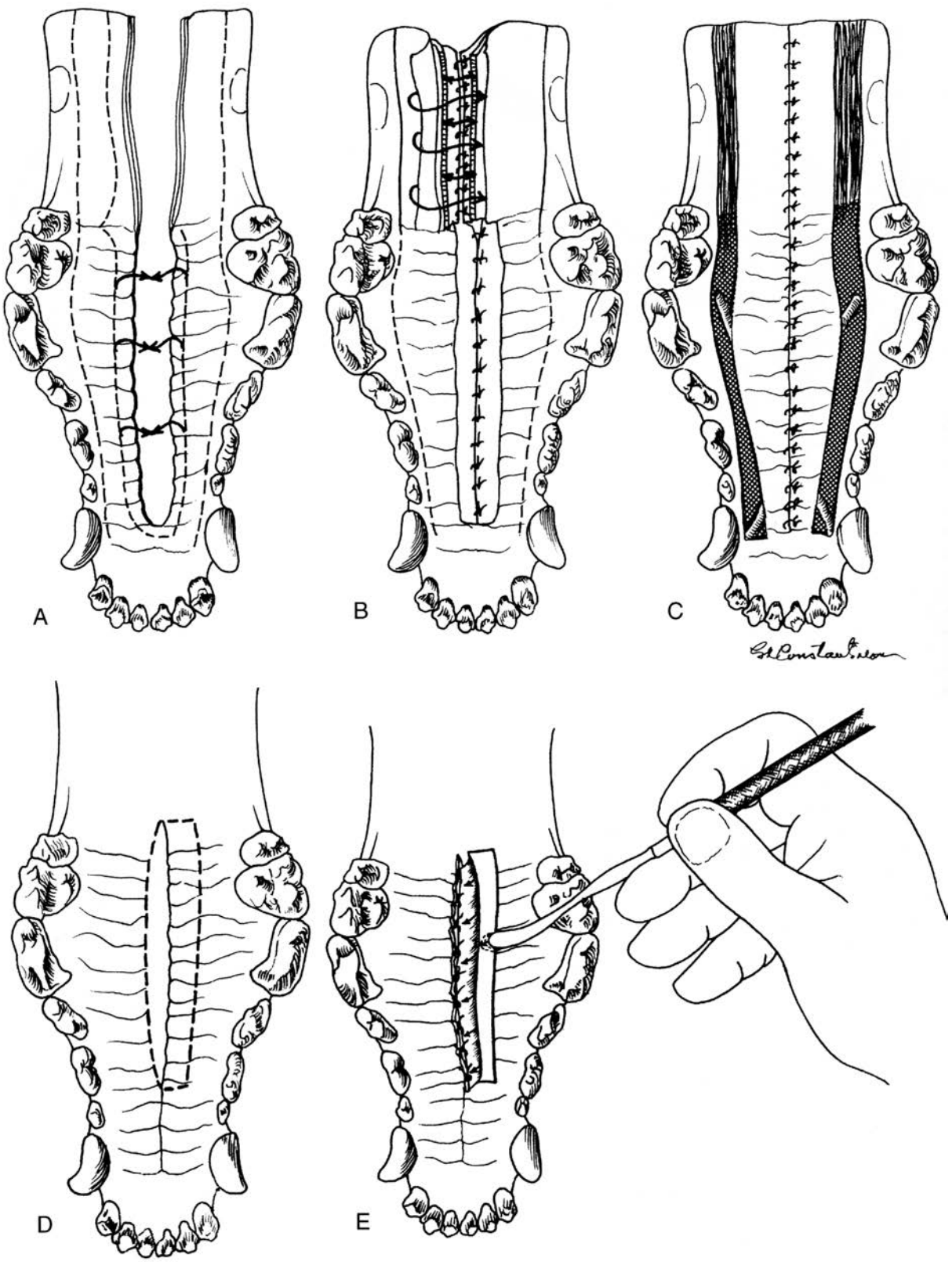


Figure 14-11. Two-layer reconstruction of a cleft of the hard palate using bilateral hinge flaps. **A.** Bilateral hinge flaps are elevated and "rolled" over the defect. The flaps are sutured together on the midline. **B.** Releasing incisions are made along the dental arcade creating bipedicle mucoperiosteal flaps. **C.** The bipedicle mucoperiosteal flaps are elevated, advanced over the first-layer closure, and sutured together on the midline. **D** and **E.** Soft palate reconstruction using an overlapping flap technique. **D.** Partial-thickness incision is made on the nasal surface of the soft palate on one side and the oral surface on the opposite side (dotted line closest to defect). The flaps are undermined to the midline. **E.** The oral mucosa-based flap is sutured to the nasal mucosa on the opposite side. Muscles are apposed if possible. The nasal mucosa-based flap is sutured to the oral mucosal on the opposite side to complete the repair. Releasing incisions are made along the pharyngeal wall, if necessary, to relieve tension. (Redrawn from Nelson AW. Upper respiratory system. In: Slatter DH, ed. Textbook of small animal surgery. 2nd ed. Philadelphia: WB Saunders, 1993.)

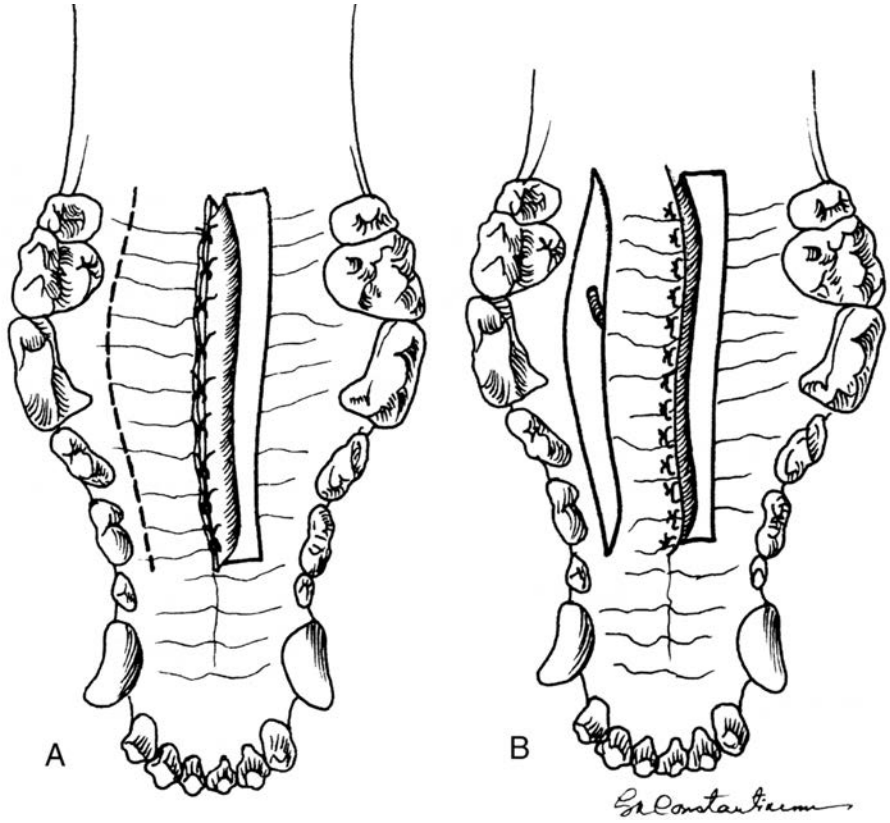


Figure 14-12. Howard mucoperiosteal hinge flap. **A.** Mucoperiosteal flap based on the edge of the cleft is elevated. An incision is made along the edge of the cleft on the opposite side, and the mucoperiosteum is undermined for several millimeters. **B.** If the flap is wide enough, mattress-type sutures are preplaced to pull the edge of the hinge flap under the mucoperiosteum on the opposite side. If tension is present, a releasing incision is made along the dental arcade and the mucoperisoteum is undermined so it can slide toward the midline and relieve the tension.

the second flap is based on the oral mucosa. The soft palate on one side is retracted laterally and rostrally to expose the nasal mucosa. The mucosa is incised the same distance from the edge as the width of the defect to create an orally based flap. On the opposite side, the oral mucosa is incised the same distance from the edge as the first flap to create a nasal mucosa-based flap. The flap based on the nasal side (i.e., side in which incision was made in the oral mucosa) is rolled back and is sutured to the lateral edge of the incision in the nasal mucosa on the other side of the defect. An attempt is made to suture the palatine muscles along the midline. The oral mucosa-based flap is moved across and is sutured to the oral mucosa incision on the opposite side. If any tension is present, releasing incisions are made in the oral mucosa laterally near the wall of the pharynx.

Lateral and bilateral clefts of the soft palate are occasionally seen. Lateral clefts can be repaired by direct closure if minimal tension is present or with flaps elevated from the dorsolateral pharyngeal wall if excessive tension is present. Direct closure is performed by incising the edge of the palate defect to create an oropharyngeal and nasopharyngeal side. The pharyngeal mucosa dorsolateral to the tonsil is incised. A two-layer closure is performed beginning with the dorsal (nasopharyngeal) side. I prefer to use a monofilament absorbable material (3-0 to 4-0) in a continuous pattern on the nasopharyngeal side of the defect. I prefer to close the oropharyngeal layer with interrupted cruciate sutures using the same suture material.

Bilateral clefts are much more difficult to close. I have not been able to re-establish normal length of the soft palate but in the limited number of cases I have done clinical signs have been alleviated or markedly improved if more than one-half of the normal length of the soft palate has been achieved. Trying to extend the soft palate much beyond this point has resulted in excessive tension and postoperative dehiscence. If sufficient pharyngeal tissue can be mobilized, the defects are closed as described above but generally this type of closure will result in excessive tension and predispose to dehiscence. A tension-free closure is more likely achieved by making releasing incisions in the pharyngeal mucosa which essentially creates bipedicle advancement flaps. Alternatively single pedicle flaps can be elevated bilaterally from the pharyngeal mucosa dorsolateral to the tonsillar crypt and sutured to the soft palate after incising it along the edge. A one layer closure is performed with 3-0 to 4-0 monofilament suture material using a cruciate suture pattern. The donor site is left to heal by second intention.

Postoperative Care

Intravenous fluids are continued until the patient recovers from anesthesia. Immature animals are given a liquid meal replacement diet or gruel after recovery from anesthesia. Placement of an esophagostomy tube should be considered if tension exists on the suture line. Tube feeding is continued for at least 1 week until healing is confirmed. A soft diet is fed for a minimum of 1 month. Chew toys and other hard objects should also be withheld for a minimum of 1 month.

Dehiscence is the most common complication of cleft palate repair. The incidence can be minimized by performing tension-free closures and by gentle tissue handling. Repair of palatal dehiscences\should be delayed for 3 to 4 weeks to allow inflammation from the initial surgery to decrease. Owners should be cautioned at the initial examination that more than one operation may be necessary to achieve complete closure of the palatal defect.

Suggested Readings

Griffiths LG, Sullivan M: Bilateral overlapping mucosal single-pedicle flaps for correction of soft palate defects. J Am Anim Hosp Assoc.2001;37:183-6.

Harvey CE: Palate defects in dogs and cats. Compend Contin Educ Pract Vet 1987; 9:405-4l8.

Radlinsky MG: Congenital ornonasal fistula (cleft palate). In: Fossum TW (ed). Small animal surgery 4th ed. St Louis: Mosby-Elsevier, 2013.

Howard DR, et al: Mucoperiosteal flap technique for cleft palate repair in dogs. J Am vet Med Assoc 1974; 165:352.

Reiter AM, Holt DE: Palate. In Tobias KM, Johnston SA eds. Veterinary Surgery Small Animal, St. Louis: Elsevier-Saunders,2012.

Salisbury SK. Surgery of the palate. In: Bojrab MJ, ed. Current techniques in small animal surgery. 3rd ed. Philadelphia: Lea & Febiger. 1990.

Repair of Oronasal Fistulas

Eric R. Pope and Gheorghe M. Constantinescu

Introduction

Oronasal fistulas most commonly result from dental disease or its treatment (i.e., poor extraction technique), but they may also be caused by trauma, electrical burns, complications of maxillary fracture, and excision of nonneoplastic masses involving the hard palate, as well as by complications of surgery, radiation, or hyperthermia treatment of maxillary neoplasias. Common clinical signs of oronasal fistula include sneezing and serous, serosanguineous, or purulent nasal discharge. Food particles or foreign bodies are occasionally seen in the nose. The diagnosis is often obvious during physical examination. Oronasal fistula due to periodontal disease or periapical infection is usually diagnosed by periodontal probing or radiography. The palatal surface of the maxillary canine teeth is a common site of oronasal fistula in small breeds of dogs.

Preoperative Evaluation

A complete physical examination and laboratory studies appropriate for the patient's anesthetic classification are indicated. Thoracic radiographs should be obtained when patients present with a cough or increased respiratory sounds (or history of either), to rule out aspiration pneumonia. Patients usually require anesthesia for thorough examination of the mouth and for skull radiography. The periodontal probe is useful for identifying small oronasal fistulas, particularly those associated with periodontal disease. Intraoral radiographic techniques are preferred for identifying periodontal and periapical disease. Rhinoscopy should also be considered in patients with obvious oronasal fistula and purulent nasal discharge because foreign bodies may enter the nasal cavity through the fistula and may contribute to the rhinitis. Bacterial culture and sensitivity testing are performed on patients with severe purulent rhinitis or aspiration pneumonia. Culture samples are collected by bronchoalveolar or transtracheal wash in patients with aspiration pneumonia. Alternatively, a broad-spectrum antimicrobial with efficacy against anaerobes can be given empirically. Treatment is continued for 10 to 14 days. In patients with minimal signs of infection, perioperative antimicrobials are administered intravenously when the catheter is placed before induction of anesthesia and are continued for 24 hours only.

Surgical Techniques

Successful repair of oronasal fistulas requires a well-supported, airtight closure that is free of tension. The options for surgical closure of oronasal fistulas are determined by the size, location, and chronicity of the fistula. Although many different techniques have been described, our preference is to perform a double-flap closure that reestablishes continuity of the nasal and oral mucosa whenever possible. Chronic fistulas, in which the nasal and oral mucosa have healed together, provide the option of creating "hinge" flaps based on the edge of the fistula similar to those described in the discussion of cleft palate repair in an earlier section of this chapter. These flaps receive their blood supply from vessels in the nasal mucosa that anastomose with vessels in the oral mucosa during the healing process.

Alveolar Ridge Fistulas

The technique used for repairing oronasal fistulas located along the dental alveolar ridge is determined primarily by the size and chronicity of the defect. Small fistulas resulting from advanced periodontal disease or tooth extraction are closed with a one-layer or two-layer technique, depending on whether the fistula is acute or chronic. Acute fistulas are corrected with single-pedicle advancement or transposition flaps from the buccal mucosa. My preference is to excise a 2- to 3-mm wide rim of mucosa from the palatal, rostral, and caudal edges of the fistula so the suture line lies over bone. This technique helps to stabilize the flap against movement and aids in the formation of an airtight seal. Necrotic tissue and sharp bone edges are removed, and the wound is thoroughly lavaged. Single-pedicle advancement flaps are used unless they will restrict lip movement excessively (Figure 14-13). Slightly diverging incisions are made in the gingival and labial mucosa starting at the rostral and caudal borders of the fistula and extending laterally. The labial mucosa and submucosa between the incisions is elevated by sharp and blunt dissection from the underlying bone. If a longer flap is needed, the dissection is continued toward the lip margin separating the layers of the lip. The flap should be sufficiently long that it can be advanced across the defect without tension. The flap is sutured with simple interrupted or cruciate mattress sutures using 3-0 to 4-0 synthetic absorbable suture material.

If the single-pedicle flap is likely to restrict movement of the lip, a transposition flap is used to repair the fistula (Figure 14-14). Because of the abundance of cheek tissue in most breeds of dogs,

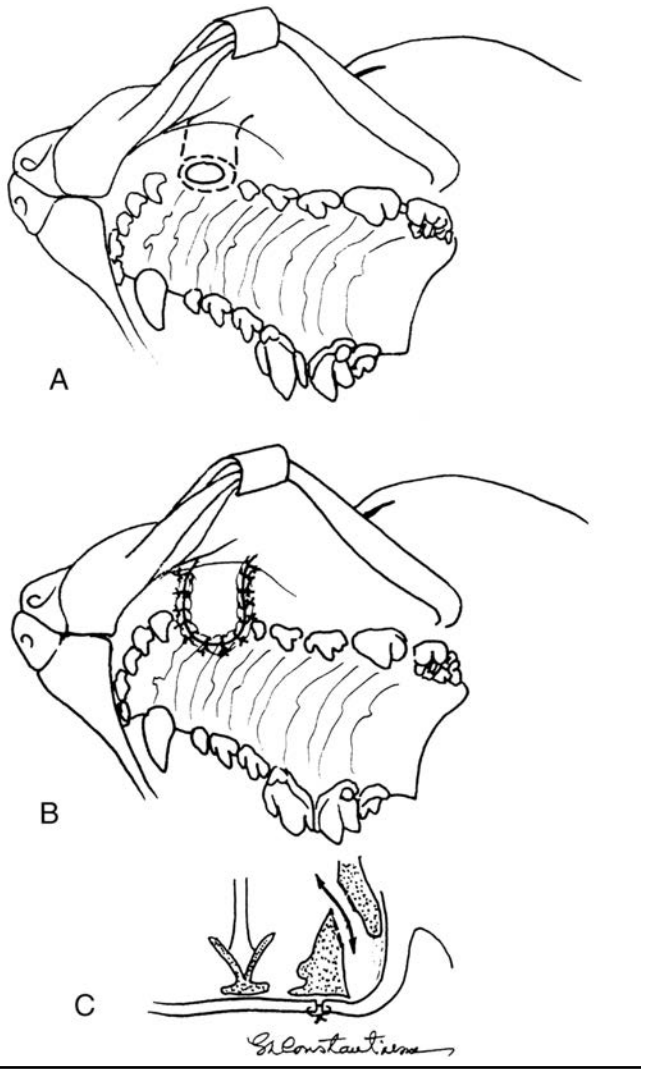


Figure 14-13. Repair of an oronasal fistula with a single pedicle advancement. **A.** A 2-to 3-mm rim of mucosa is removed around the edge of the fistula. Slightly diverging incisions are made in the mucosa starting at the rostral and caudal borders of the defect. **B.** The flap is undermined, advanced over the defect, and sutured. **C.** Excising the rim of mucosa places the suture line over bone, providing better support.

I usually base transposition flaps on the rostral extent of the fistula and develop the flap caudally if the defect is located rostrally. The first incision is made beginning at the caudal most point of the lateral border of the fistula and then continued caudally. The flap should be long enough to allow transposition of the flap over the flap without tension. A second incision is made parallel to the first one, so the width of the flap is equal to the width of the defect. The incisions are connected caudally. The flap is undermined by sharp and blunt dissection to make the flap as thick as possible. The flap is rotated over the fistula and is sutured as previously described. The donor site is closed with an interrupted or simple continuous pattern. Conversely, I make the base of the flap at the caudal extent of the fistula if it is located more caudally in the alveolar ridge.

Chronic fistulas, in which the oral and nasal mucosa have healed together, can be repaired using a double-flap closure technique that provides a mucosal surface on both oral and nasal sides of the fistula. The first step is to create one or two "hinge" flaps based on the edge of the fistula that are rolled back over the fistula so the mucosal surface is on the nasal side (See Figure 14-14D). If a single flap is used, it is usually raised from the hard palate. The alternative is to create opposing flaps from the hard palate and the labial (buccal) gingiva that are rolled back over the fistula. After the flaps have been created, the rostral and caudal edges of the fistula are incised to create nasal and oral sides. The hinge flaps are sutured to the nasal mucosa laterally or to each other at the center of the defect and to the rostral and caudal edges with interrupted sutures using 3-0 to 5-0 synthetic absorbable suture material. The second step is to create a flap from the buccal mucosa to cover the first layer of closure and the donor site on the hard palate completely. This step generally requires a transposition flap, as described earlier.

Large oronasal fistulas, resulting from the excision of neoplasms, are repaired with labial mucosa and submucosa advancement flaps (see the discussion of maxillectomy in the next section of this chapter). After completion of the maxillectomy, hemorrhage is controlled by packing the wound with gauze sponges. Diverging incisions are made in the labial (buccal) mucosa and submucosa extending toward the lip margin as far as necessary to allow closure of the defect without tension. The flap is created by undermining the mucosa and submucosa between the incisions by sharp and blunt dissection. The flap is sutured to the hard palate in two layers using synthetic absorbable suture material. The first layer apposes the submucosa of the labial flap with the mucoperiosteum of the hard palate. The sutures are placed so the knots lie in the nasal cavity. The second layer of sutures apposes the flap and hard palate mucosa with the knots in the oral cavity.

Central Hard Palate Fistulas

Oronasal fistulas in the central portion of the hard palate are often more of a challenge given that reconstruction with labial (buccal) flaps is not an option because of the dental arcade. Oronasal fistulas rostral to the upper fourth premolar are amenable to closure with hard palate mucoperiosteal transposition flaps. Central hard palate oronasal fistulas at the level of the upper fourth premolar, or more caudal, can often be more easily closed with a partial-thickness transposition flap or a hinge flap from the soft palate. Another recently described option is the angularis oris axial pattern flap. The mucoperiosteal transposition flap is planned so one edge of the defect is incorporated into one side of the flap (Figure 14-15A). Laterally, an incision is made parallel to the defect so the flap is 2 to 3 mm wider than the defect, if possible. The transverse diagonal (distance between the most lateral extent of the base of the flap and the rostral edge of the fistula) is measured to ensure creation of a flap of adequate length. Because the mucoperiosteum contains little elastic tissue, the pliability of these flaps is limited. Moreover, these flaps do not stretch, so the flap must be made long enough to avoid tension. Once the dimensions of the flap have been determined, the mucoperiosteum is incised. I make the side incisions first and the rostral incision last. By making alternating short incisions from the lateral and medial edges, the major palatine artery can usually be identified and clamped with hemostats before transection. Although some veterinary surgeons just

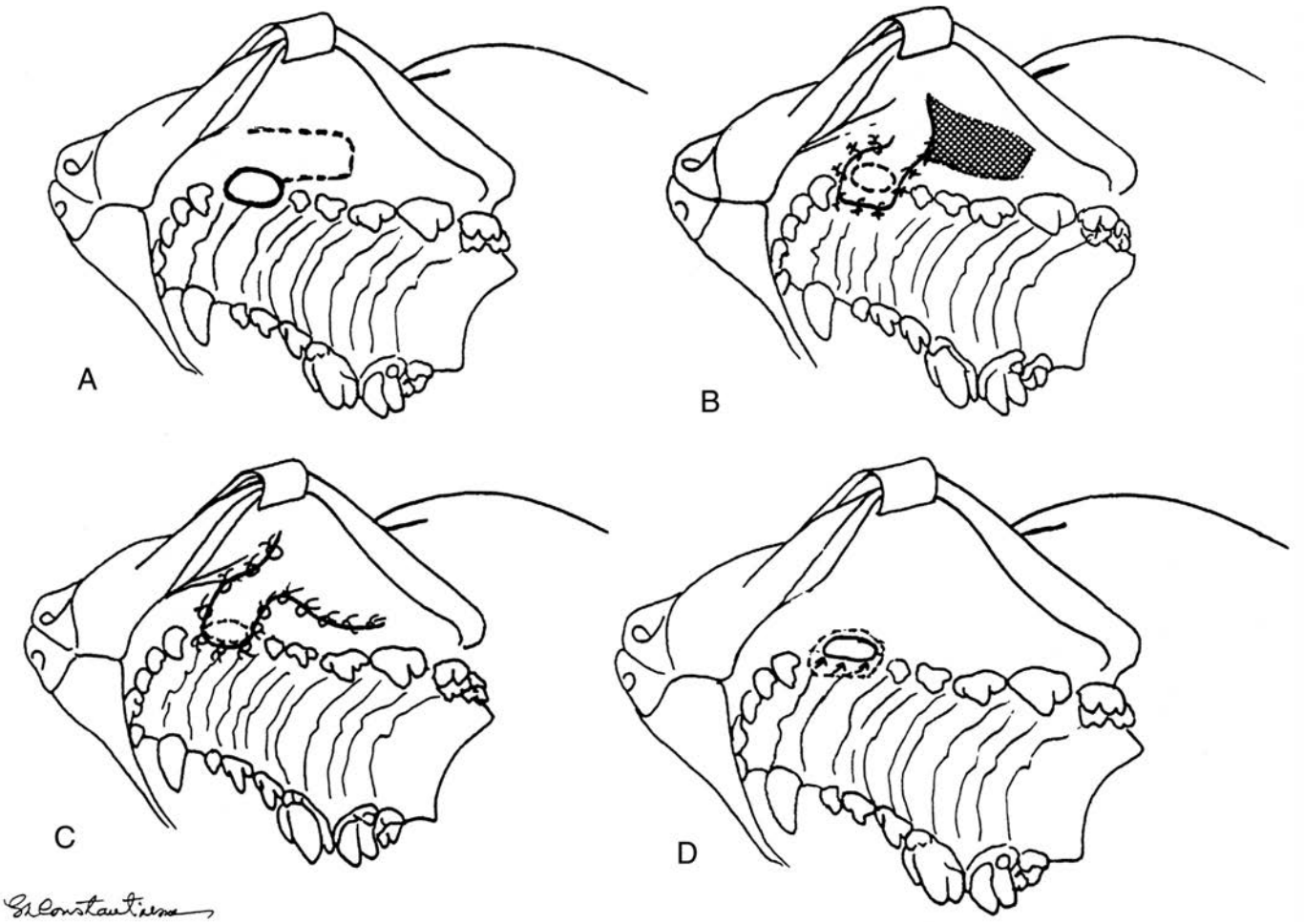


Figure 14-14. Oronasal fistula repair using a transposition flap. **A.** Incisions for a rostrally based flap. **B.** The flap is undermined and transposed over the defect. **C.** Closure of the donor and recipient sites. **D.** When chronic fistulas are present, a hinge flap can be raised from the hard palate side of the defect and sutured laterally. A transposition flap is used to cover the flap and donor site.

sever the vessel as the rostral incision is made, retraction of the vessel rostrally may make grasping it for ligation difficult. The flap is elevated from bone with a periosteal elevator, with care taken not to injure the major palatine artery. The flap is transposed to cover the defect. In some instances, removing a triangular segment of mucoperiosteum from the caudal aspect of the fistula to the base of the flap is necessary to facilitate transposition of the flap over the defect. Because no soft tissue secures the flap on one side of the fistula (the side adjacent to the donor site), holes can be drilled in the hard palate bone with a small K-wire to allow placement of sutures to secure the flap along the edge of the fistula (Figure 14-15B). These sutures should be preplaced. The remainder of the flap is sutured in one or two layers with synthetic absorbable suture material. The exposed bone of the donor site is allowed to heal by second intention.

Fistulas located more caudally can be reconstructed using a partial-thickness flap from the soft palate. The transposition flap is designed to incorporate the edge of the defect into one side of the flap (Figure 14-15C). The oral mucosa of the soft palate is incised, and a partial-thickness flap is elevated by sharp and blunt dissection. Again, one must elevate a flap of sufficient length to avoid tension on the closure. The flap is moved over the defect and is sutured with synthetic absorbable suture material. The donor site is allowed to heal by second intention.

The angularis oris axial pattern flap has been recommended for reconstructing difficult or recurrent palate defects. Depending on head conformation, this flap can be used to reconstruct defects caudal the canine teeth. Maximum length is achieved when the flap is elevated as an island sized flap leaving only the vessels and a small amount of surrounding soft tissue attached at the donor site. Identification of the vessels can be difficult even with the use of transillumination and a pencil Doppler probe. Anatomic review and practice on cadavers is highly recommended before attempting this procedure on a clinical patient.

Postoperative Care

The pharyngeal area should be examined and any blood suctioned before extubation. Most patients are allowed nothing by mouth overnight. A soft diet is recommended for 3 to 4 weeks. Use of chew toys and other hard objects should also be avoided during this time. An esophagostomy tube can be placed if one desires to avoid oral feeding. In most instances, problems with healing become evident within the first week. If dehiscence occurs, the feeding tube can be maintained until another repair is attempted in 3 to 4 weeks. Tube feeding decreases the amount of material that can enter the nose and worsen the inflammatory response. Most complications can be avoided by gentle tissue handling, by achieving a tension-free closure, and by accurate

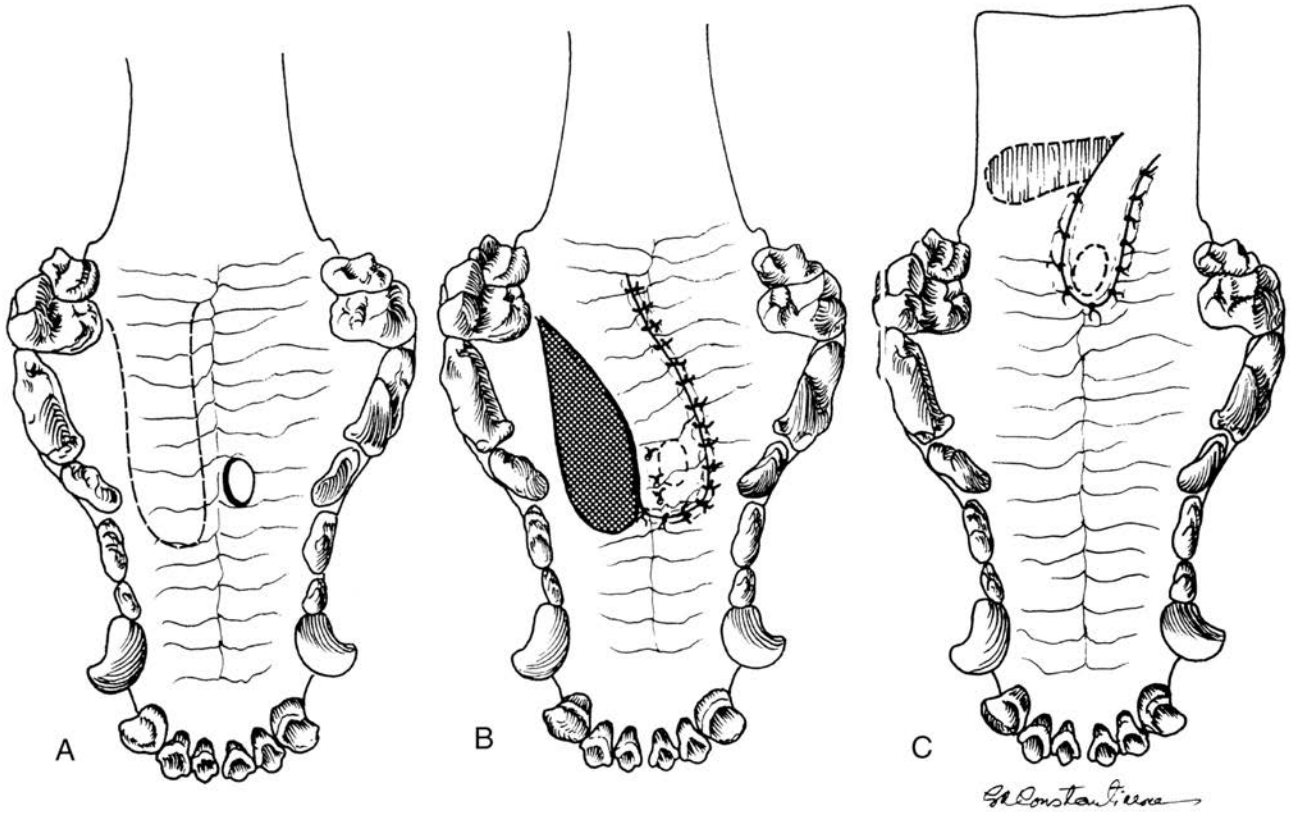


Figure 14-15. Central palate fistulas can be closed with transposition flaps **A** and **B** from the hard palate mucoperiosteum or with partial thickness flaps from the soft palate **C**.

suture placement. Although most fistulas can be successfully closed, instances of failure have been reported even after multiple attempts at surgical correction. Several different types of obturators have been used to create a barrier to movement of materials into the nasal cavity. A simple and successful technique is to use a nasal septal button to achieve obturation. The device is self-retaining but can be removed if necessary.

Suggested Readings

Bryant KJ, Moore K, McAnulty, JF: Angularis oris axial pattern buccal flap for reconstruction of recurrent fistulae of the palate. Vet Surg. 2003 Mar-Apr;32(2):113-9.

Ellison GW, Mulligan TW, Fagan DA. et al: A double reposition flap technique for repair of recurrent oronasal fistulas in dogs. J Am Anim Hosp Assoc 1986;22:803.

Gunn C. Lips, oral cavity and salivary glands. In: Gourley IR, Vasseur PB. eds. General small animal surgery. Philadelphia: JB Lippincott, 1985.

Harvey CE. Palate defects in dogs and cats. Compend Contin Educ Pract vet 1987;9:405-418.

Hedlund CS, Fossum TW. Acquired oronasal fistulae. In: Fossum TW (ed): Small animal surgery 3rd ed. St Louis: Mosby-Elsevier, 2007.

Nelson AW: Nasal passages, sinus, and palate. In: Slatter DH ed. Textbook of small animal surgery. 3rd ed. Philadelphia: WB Saunders, 2003.

Salisbury SK. Surgery of the palate. In: Bojrab MJ. ed. current techniques in small animal surgery. 3rd ed. Philadelphia: Lea & Febiger, 1990.

Salisbury SK, Richardson DC. Partial maxillectomy for oronasal fistula repair in the dog. J Am Anim Hosp Assoc I986;22:185.

Smith MM, Rockhill AD: Prosthodontic appliance for repair of an oronasal fistula in a cat. J Am Vet Med Assoc. 1996; 208:1410-2.

Maxillectomy

William Culp, William S. Dernell and Stephen J. Withrow

Maxillectomy

Maxillectomy is the resection of variable portions of the maxillary, incisive, and palatine bones and closure of the resulting oronasal defect with a labial mucosal-submucosal flap. The remaining bony structure of the muzzle maintains adequate stability and contour, eliminating the need for bone replacement. Closure of the maxillectomy site is limited by the availability of normal labial mucosa. Tumors that extensively involve the labia or cross the midline of the hard palate may not be amenable to complete resection because of the inability to close the defect. Appearance and function generally are good to excellent after maxillectomy. One study found that 85% of owners surveyed were satisfied with the outcome of a mandibulectomy or maxillectomy procedure. Forty four percent cited difficulty in eating as a complication; reduction in pain and improvement in quality of life were perceived and resulted in the overall satisfaction.[1]

Indications for maxillectomy are similar to those for mandibulectomy and include oral neoplasia, chronic osteomyelitis, and maxillary fractures with severe bone or soft tissue injury or loss. Another indication for maxillectomy is oronasal fistula.[2-4] A maxillectomy is most often performed for local disease control of oral cancer. The oropharyngeal region is the fourth most common site of malignant neoplasia in the dog. The most common

oropharyngeal neoplasms in the dog are malignant melanoma, squamous cell carcinoma, fibrosarcoma, and epulides or tumors arising from the periodontal ligament.[5-8] In the cat, squamous cell carcinoma is the most common oropharyngeal cancer, followed by fibrosarcoma, undifferentiated sarcoma, hemangiosarcoma, lymphoma, and osteogenic sarcoma. Malignant melanoma and epulides occur rarely in the cat.[8,9] Odontogenic tumors, such as inductive fibroameloblastoma, are the most common benign oral tumors in the cat.[10] Oropharyngeal tumors tend to be locally aggressive and slow to metastasize, except malignant melanoma, caudal tongue tumors,[11] and pharyngeal and tonsillar squamous cell carcinoma.[6-8] Morbidity and mortality often result from local disease rather than from distant metastasis; many animals die or are euthanized because of signs of local disease, such as infection, dysphagia, and aspiration pneumonia, before metastases occur.

Control of local disease is the first goal of most surgical treatments for oral cancer. Limited soft tissue excisions without concurrent ostectomy for attempted cure of oral tumors often fails because of recurrence of the tumor at the primary surgical site. Maxillectomy accompanied by en bloc soft tissue resection for oral tumors has the potential for prolonged remission or cure in certain malignant diseases. Control of local disease improves the quality of life even though distant metastasis may ultimately occur. Surgical resection should be considered as a first line of treatment for almost all oral neoplasms. Radiation therapy can be considered as primary treatment for tumors that show consistent responses to radiation, such as lymphoma, other round cell tumors and acanthomatous epulis. Radiation often serves in an adjuvant role to surgery for treatment of oral tumors. Chemotherapy is indicated for oral neoplasia with a high probability of metastasis; however, highly metastatic oral tumors such as malignant melanoma tend to have only a moderate response to chemotherapy.[12]

Four basic maxillectomy techniques are available to the veterinary surgeon:[2,4] unilateral rostral maxillectomy, bilateral rostral maxillectomy, total unilateral maxillectomy and caudal maxillectomy. The need to perform an incisivectomy, or removal of the incisive bones (region rostral to the canine teeth) is generally not encountered. The combination of bilateral rostral maxillectomy and nasal planum resection has also been described for disease that involves the planum.[13,14] Maxillectomy can be combined with resections of the ventral orbit, zygoma, dorsal orbit and calvarium (orbitectomy procedures) for more extensive, caudal disease.[15]

Preoperative Evaluation

The preoperative workup for maxillectomy is similar to that for mandibulectomy. The minimum database includes a complete blood count, biochemical profile, urinalysis, and thoracic radiographs for detection of distant metastasis. Regional lymph node aspirates should also be examined cytologically to detect nodal disease. A technique for surgical staging oropharyngeal lymph nodes has been described and may be helpful for establishing prognosis and treatment plans for malignant melanoma.[16,17] Evidence of systemic disease or metabolic abnormalities may preclude or alter the mode of therapy and prognosis.

Radiographs alone (of the skull and tumor site) are adequate for assessing bone involvement and preoperatively planning margins for smaller tumors rostral to the 3rd premolar tooth and showing little involvement with the maxillary or nasal bones. Radiographs should be taken while the patient is under general anesthesia. Lateral, ventrodorsal, and oblique radiographs may be helpful, however, the ventrodorsal or dorsoventral intraoral view is generally the most useful view. For caudal and more extensive tumors (that involve various portions of the orbit, zygoma, and mandibular ramus), computed tomography (CT) or magnetic resonance imaging (MRI) are important, if not essential. Generally, CT is preferred because of the affinity for bone detail as the degree of bone involvement will often dictate surgical margins and feasibility of the operation. With improvements in technique and interpretation of MRI, this modality may become preferred under certain circumstances.[18] The radiographic assessment should include evaluation of cortical bone continuity, alterations in bone density, periosteal new bone formation, and involvement of adjacent soft tissues.

An incisional biopsy for accurate tissue identification is also important before definitive therapy is undertaken. The biopsy site should be selected so complete resection of the mass (See Chapter 5) and labial flap closure is not compromised. Each patient can be assigned a World Health Organization staging classification (TNM; tumor, node, metastasis) and clinical stage which are prognostic for disease outcome and can help dictate treatment planning.[19]

General Surgical Considerations

Boundaries for maxillectomy for oral neoplasms with or without cortical bone penetration and destruction are determined by preoperative imaging and oral examination. Minimally, a 1 cm or larger, grossly visible, tumor free margin should be obtained on all cut surfaces, however, this is dependent on tumor type, site, histologic grade and overall treatment goals.

As a rule, an oronasal defect created after resection of tumors that cross the caudal midline is more difficult to close than a defect created from resection of tumors that do not cross the midline. Availability of normal labial and palatal mucosa generally is the limiting factor. New techniques are continuously being developed and evaluated for closure of more extensive oronasal defects which may allow closure of tissue excisions which cross midline. Aggressive preoperative imaging and surgical planning (including closure options) must be done in cases where aggressive resection is being considered to maximize success.[20-25] The use of preoperative modeling may assist surgical planning, especially for resections in sensitive skull sites. Three-dimensional models can be created from CT or MRI images which can allow better visualization of disease extent and involvement of surrounding tissues (Protomed Custom Anatomical Models, Arvada, CO). If bone change is evident on preoperative imaging, the excised tissue should be imaged immediately following resection to determine whether adequate bone disease free surgical margins were obtained, prior to closure.

The pathologist must ascertain any extension of neoplasia to a cut edge. Margins of interest (osteotomy edges and closest soft tissue margin) should be identified with India ink or other suitable marking system, or tissue margins should be submitted in separate containers. This technique aids the pathologist in determining the adequacy of mass removal (See Chapter 5). Specimens should be placed in 10% buffered formalin and submitted for histopathologic evaluation. Tumor extension to a cut margin generally implies the need for additional surgery or adjuvant therapy such as chemotherapy or, more commonly, radiation.

Perioperative antibiotics are recommended. Antibiotic therapy for more than 24 hours is not indicated unless dictated by the situation. Although surgery of the oral cavity is considered contaminated or "dirty," infection is rarely a postoperative complication. The antibiotic chosen should be effective against the bacterial flora normally found in the oral cavity, including gram positive cocci (e.g., Staphylococcus sp. and Streptococcus sp.) and gram negative rods (e.g., Proteus and Pasteurella spp.). The first generation cephalosporins, penicillins, and synthetic penicillins are generally considered effective prophylactic oral antibiotics.[26]

In the authors experience, polydioxanone (PDS, Ethicon, Inc., Somerville, NJ), polyglactin 910 (coated Vicryl, Ethicon, Inc.), polyglycolic acid (Dexon, Davis and Geek, Inc., American Cyanamid Co., Manati, PR), and polyglyconate (Maxon, Davis and Geek, Inc.) sutures (3-0 or 4-0) are prefered for wound closure after maxillectomy. These relatively nonreactive sutures minimize oral mucosal irritation and maintain adequate tensile strength during the critical early period of healing. Polydioxanone and polyglyconate have the advantages of being monofilament and absorbable. Their absorption is slower (than polyglactin 910 and polyglycolic acid), however, and food can cling to the suture, or suture knots can be irritating, resulting in oral mucosal ulceration if the suture is not removed after healing. Although polyglactin 910 and polyglycolic acid are absorbable, they are braided suture materials and may increase the possibility of bacterial adherence or may result in a greater inflammatory response causing oral mucosal irritation. These latter two suture materials lose tensile strength sooner than the monofilament absorbables, a characteristic that should be considered if adjuvant radiation or chemotherapy may be administered postoperatively or if other patient factors exist that might result in delayed wound healing. The absorption rate of various suture materials has been evaluated in vivo for use in the oral cavity in cats.[27] A reverse cutting swaged on needle has been beneficial in suturing the tough, fibrous soft tissues of the oral cavity. This type of needle causes less surgical trauma when passed through tissues and provides better suture purchase into the soft tissues than other needle types.[28] Use of electrocautery should be kept to a minimum. Incisions within the oral cavity made with electrocautery are more likely to have delayed healing or to become dehiscent than incisions made with a scalpel.[2,29]

The choice of preanesthetic medication and induction agents is based on preoperative evaluation, personal preference, and expertise. The use of a narcotic is generally recommended for its analgesic effects. Adequate postoperative analgesia for 2 to 3 days is indicated, usually involving a combination of narcotics and non-steroidal anti-inflammatory agents. Some dogs may need to be treated with additional agents, depending on pain response. Preoperative or intraoperative nerve blocks using a long acting local anesthetic to the infraorbital nerve ventral to the zygoma may decrease anesthetic needs and postoperative pain.[30,31]

After induction, general anesthesia should be maintained with a gas inhalant and oxygen. An endotracheal tube with an inflatable cuff is used to prevent aspiration of blood and fluid. Once the animal is positioned, prior to the start of surgery, the inflation of the endotracheal tube cuff should be checked again, and upon recovery, extubation with the cuff partially inflated may assist in removal of blood that has accumulated in the oropharynx. The tube should be secured to the animal's lower jaw to minimize surgical interference. Because intraoperative hemorrhage can be significant, a patent intravenous access catheter must be maintained at all times. A balanced electrolyte solution (10 ml/kg per hour) is started immediately after induction and is continued throughout the surgical procedure until the animal has recovered. Fluid levels may need to be increased, or whole blood, plasma, or colloids may need to be considered, depending on the degree of blood loss or hypotension. If the planned resection involves only intraoral tissues, clipping the patient's hair is either not necessary or minimally required. The exception would be when using the combined approach for dorsally located maxillary tumors (see total unilateral and caudal maxillectomy section below) where the muzzle on the surgical side should be clipped and prepped for surgery.[32]

Temporary unilateral or bilateral carotid artery occlusion has decreased blood volume loss and has improved visualization of the surgical field during maxillectomy.[33] This procedure can be considered but is not routine. After removal of the tissue to be excised, and if carotid artery ligation was performed, blood flow is reestablished to allow maximum circulation to the surgical site. The blood flow to the nasal cavity and palatal mucosa originates from terminal branches of the maxillary artery, the main continuation of the external carotid artery. Experimentally and clinically, the common carotid artery has been permanently occluded both unilaterally and bilaterally in dogs without causing neurologic or ischemic deficits.[33,34] This situation may not be true, however, in the cat.[35]

Positioning of the patient is critical to visualize the entire surgical field. In our experience, placement of the animal in dorsal recumbency with the mouth taped open provides the greatest exposure. The lower jaw, tongue, and endotracheal tube are taped to an anesthesia screen. Movement of the head should be restricted by adhesive tape (Figure 14-16). For more dorsally located tumors involving the maxillary and nasal bones, a combined intraoral and translabial approach can aid in resection exposure. In these cases, lateral or ipsilateral positioning and the placement of a mouth gag are preferred. The oral cavity is prepared by repeated flushing and swabbing with a 10% dilution of povidone iodine solution (Betadine, Purdue Frederick Co., Norwalk, CT). The surgical site is draped, with drapes applied to the mucocutaneous junction of the upper labia as well as to the lower jaw.

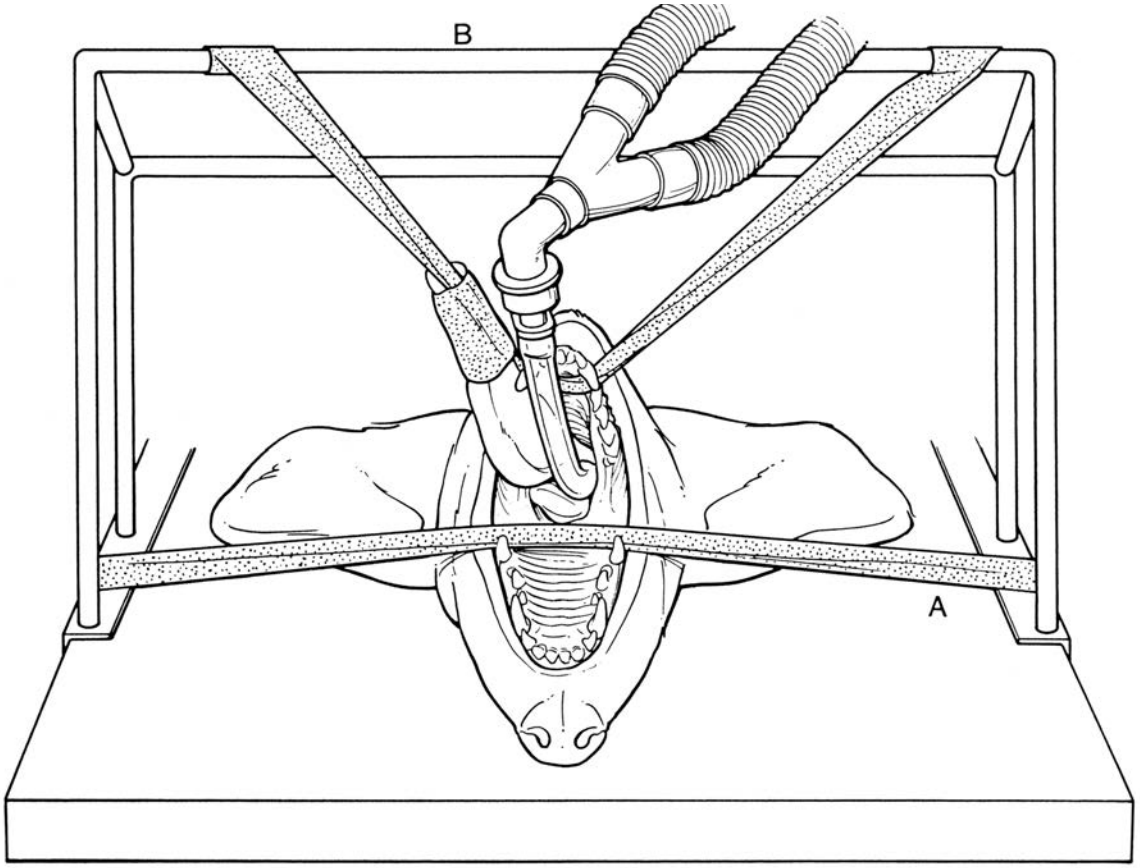


Figure 14-16. The dog is placed in dorsal recumbency with the upper jaw secured to the surgical table with adhesive tape *A.* The lower jaw, tongue, and endotracheal tube are suspended by tape from an anesthesia screen *B.* A gauze sponge has been placed in the caudal oropharynx to prevent passive aspiration.

Surgical Techniques

Unilateral Rostral Maxillectomy

Unilateral rostral maxillectomy is indicated for lesions that are located rostral to the second premolar and do not come up to or cross the midline. The labial and gingival mucosa rostral and lateral to the tumor is incised at least 1 cm from the gross margins of the lesion. The incision is continued through the hard palate mucosa caudal and medial to the lesion (Figure 14-17A). Hemorrhage from the hard palate mucosal incision generally is marked and requires ligation, electrocoagulation, and pressure to control. An oscillating bone saw or an osteotome and mallet may be used to cut the underlying bone following the mucosal incision lines. The surgeon should try to create curved bone margins, rather than square edges, to assist tissue apposition and healing. The incised segment of bone is freed of soft tissue attachments and is levered en bloc out of the surgical site. Branches of the major palatine artery may be visualized and require ligation. Nasal turbinates should be visible at this time. If tumor has penetrated the bone or if the turbinates are traumatized during the resection, they should be excised with a scalpel or scissors and submitted for histologic examination. Before closure, the surgical site is copiously lavaged with sterile physiologic saline.

The oronasal defect created is covered with a labial mucosal submucosal flap. The flap should be designed so sufficient tissue is obtained to cover the defect without tension. The flap should consist of mucosa, submucosa, and as much subcutaneous tissue as possible. The flap is elevated at the level of the dermis, is left attached at both ends, and is elevated only to the point that allows defect coverage without tension. The surgeon often can establish a tissue plane when undermining the labial mucosa and submucosa with Metzenbaum scissors (Figure 14-17B). Adequate blood supply and minimal tension are the critical factors for the survival of the mucosal-submucosal flap. The base of the pedicle must be of sufficient width to allow adequate vascularity to reach the tip of the flap.

The flap is sutured into position with a one layer or two layer closure. In a two layer closure, the first or deep layer consists of simple interrupted sutures placed from labial submucosal tissue to palatal submucosa or through holes predrilled in the bony hard palate. This deep layer is especially important for patients that are anticipated to undergo adjuvant radiation or chemotherapy, because of the effects on wound healing. The second or superficial layer consists of simple interrupted or continuous sutures that appose the palatal mucosa to the labial mucosa (Figure 14-17C). This superficial closure is used alone if a single layer closure technique is chosen. Undermining the palatal mucosa 2 to 3 mm may help in tissue apposition in this closure (Figure 14-18). If tension is encountered, additional undermining of the labial flap (toward the mucocutaneous junction) should first be attempted. If this does not relieve tension, mattress sutures can be placed in addition to the primary sutures.

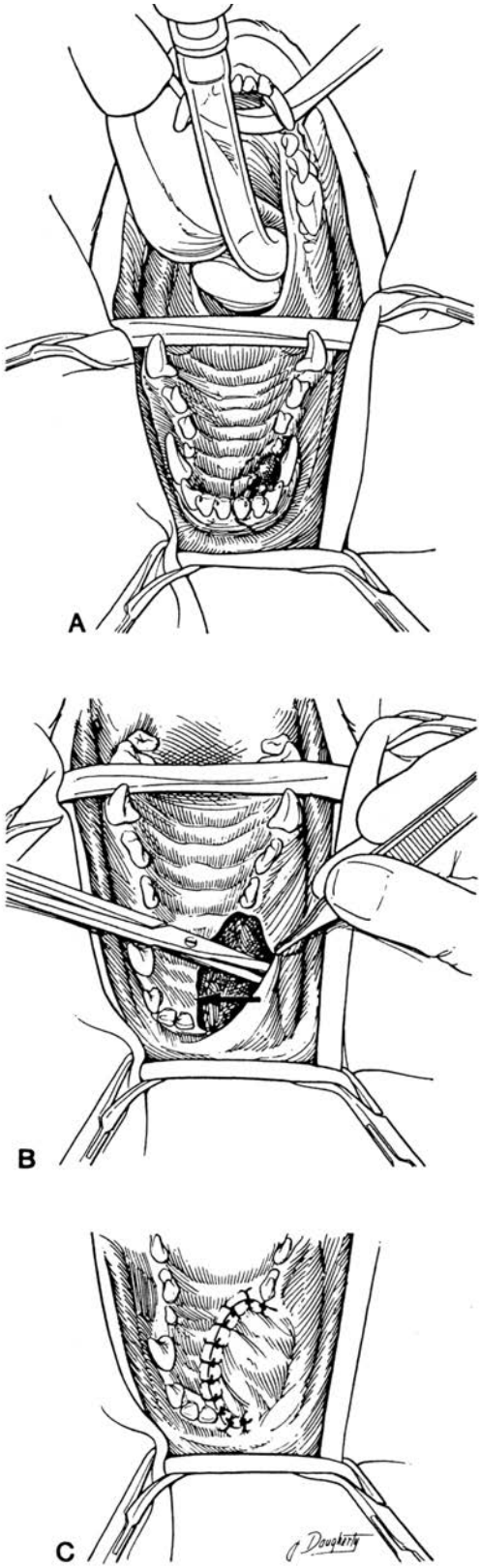


Figure 14-17. Unilateral rostral maxillectomy. **A.** Mucosal incision is indicated by the dotted line. **B.** Undermining the labial mucosa-submucosa for a lip margin based flap in which the mucosal surface faces the oral cavity. **C.** Simple interrupted or continuous closure of the mucosal flap.

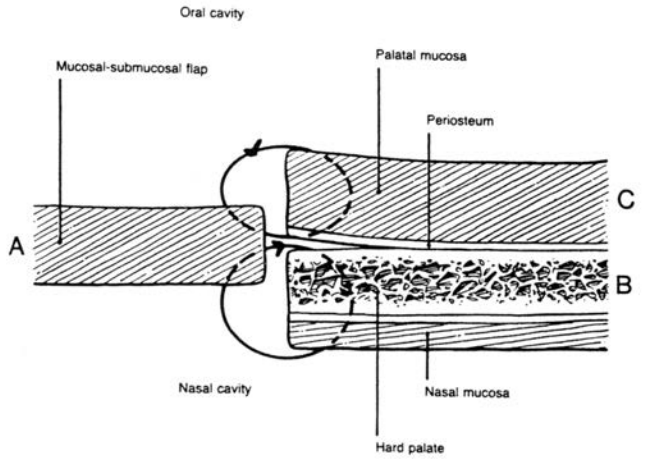


Figure 14-18. A two layer closure *A.* is used to position the mucosal submucosal flap over the defect created in a unilateral rostral maxillectomy. The first or deep layer *B.* consists of simple interrupted sutures placed from the submucosa through predrilled bone holes in the bony hard palate. The second or superficial layer *C.* consists of simple interrupted or continuous sutures opposing the labial mucosa to the mucoperiosteum of the hard palate.

Bilateral Rostral Maxillectomy

Bilateral rostral maxillectomy is indicated for lesions that come up to or cross the midline and are rostral to the second premolar. In essence, this procedure is similar to unilateral rostral maxillectomy, except the entire rostral bony floor of the nasal cavity is excised (Figure 14-19A). Resections rostral to the canine teeth will not result in any deformity of the nasal planum or bridge of the nose. Resections caudal to the canine teeth will at least result in a slight drop of the planum and a ventral sloping of the bridge of the nose. At this level, disruption of the nasal passages is rare. Resections more caudal than the immediate distal border of the canine teeth may result in sufficient soft tissue (ventral) deviation to disrupt normal air passage. In these cases, additional measures are needed to support the nose. The placement of dorsal supporting (tacking, imbricating or plication) sutures may be all that is necessary to support the tissues until fibrosis occurs. More rigid support in the form of an external splint (plastic or aluminum plate or rod) sutured to the soft tissues may also be effective. The combination of bilateral rostral maxillectomy or incisivectomy with nasal planum resection has been described for tumors affecting both the rostral maxilla and the planum.[13] This combination resection may be indicated for more caudally located maxillary tumors where resection will result in extensive loss of support of the soft tissues of the nose.

Closure is similar to that in the unilateral procedure, only performed bilaterally. Half the flap is undermined from each side of the maxillectomy defect (Figures 14-19B and C). Submucosa can be attached to predrilled bone holes in the hard palate (Figure 14-19D-F). The caudal half of each flap is sutured to the palatal mucosa from that side to the midline. The rostral halves are sutured together to form a T shaped closure. The labial mucosa is sutured to the palatal mucosa and the opposing labial mucosa using simple interrupted or simple continuous sutures (Figure 14-19G).

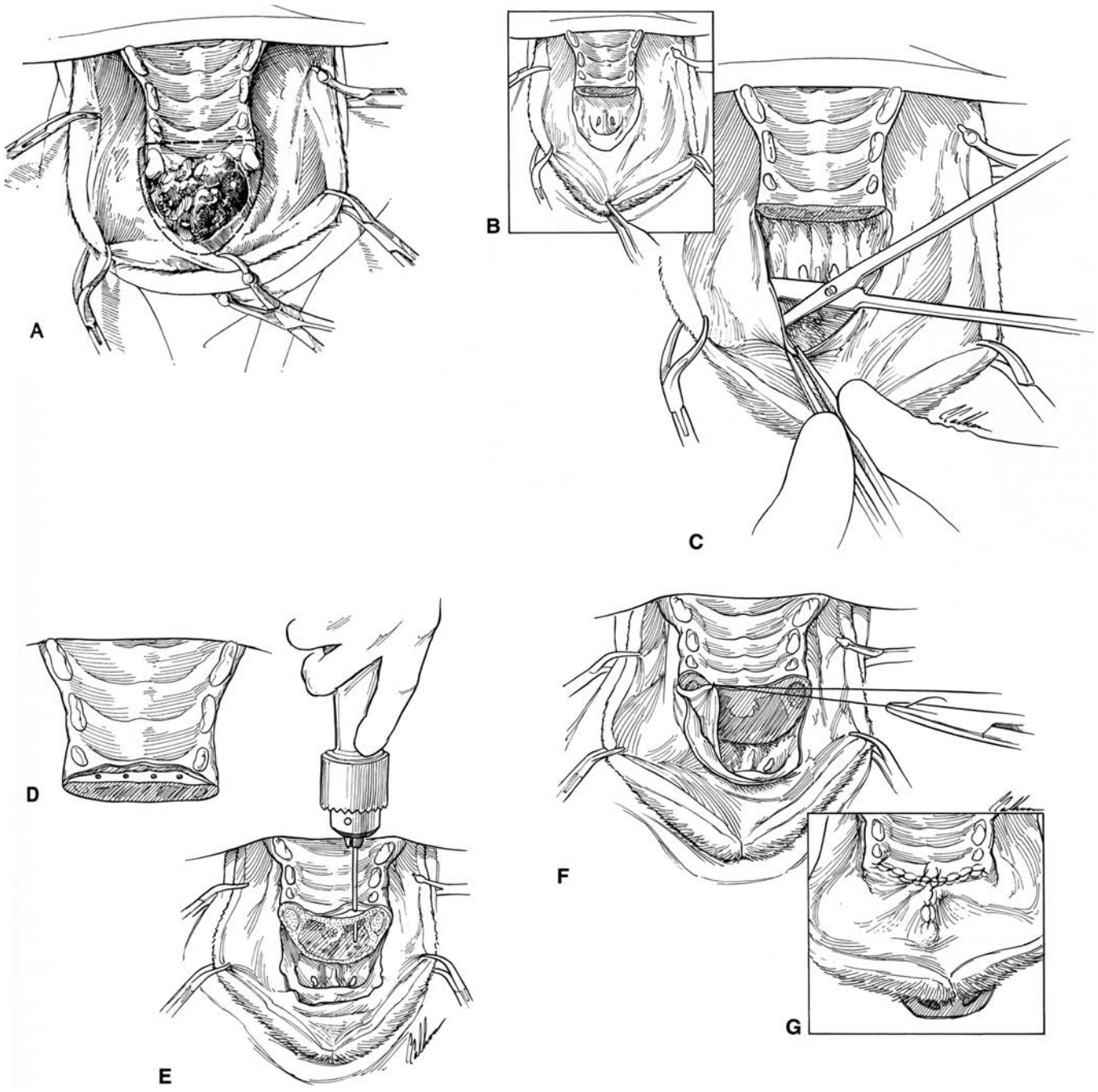


Figure 14-19. Bilateral rostral maxillectomy. **A.** The dotted line indicates the area to be excised. (Reprinted with permission from Withrow SJ, Nelson AW, Manley PA, et al. Premaxillectomy in the dog. J Am Anim Hosp Assoc 1985;2 1:50. **B.** The labial mucosa is incised perpendicular to the cut edge of the maxilla extending rostrally to the lip margin. **C.** Both sides of the labial mucosa are undermined deep to the submucosa and extending to the lip margins. **D** and **E.** Two to four bone holes can be placed in the rostral edge of the bony hard palate. **F.** Submucosa immediately under the mucosa is attached to the predrilled bone holes using preplaced simple interrupted sutures. **G.** Mucosal closure is completed by suturing half of the flap from each side to the mucoperiosteum of the hard palate and the remainder to the opposite side using simple interrupted or simple continuous sutures.

Total Unilateral Maxillectomy and Caudal Maxillectomy

The most aggressive of the maxillectomy procedures described here, total unilateral maxillectomy, is indicated for tumors that involve the majority of the hard palate on one side without crossing the midline. It involves removal of the oral mucosa, teeth, and portions of the incisive, maxillary, palatine, and zygomatic bones. The degree of resection is dictated by the size of the lesion, its location, the degree of tissue involvement, and the expected biologic behavior and grade of the tumor. Any portion of the maxilla can be excised unilaterally and still can result in normal function and acceptable cosmetics. Caudal maxillary resections can be combined with resections of portions of the inferior orbit, zygoma, or mandibular ramus, depending on the degree of tissue involvement (Figure 14-20).[15]

For the combined dorsolateral and intraoral approach utilized with total unilateral maxillectomy, the dorsal approach involves an incision made through the skin of the lip or muzzle at or above the dorsal aspect of the mass; this incision is made parallel to the lip margin. If there is a biopsy tract in the skin, the incision is carried around this tract to leave it attached to the specimen (as an island) to be resected. The skin and/or subcutaneous tissue are undermined dorsal to the mass, extending to the mucosal reflection dorsal to the dental arcade. Adequate soft tissue margins must be maintained around the tumor. The buccal mucosa is incised at this point to allow communication with the intraoral dissection (see below). This creates a bipedical skin/mucosal flap over the resection site, facilitating exposure.[32]

The mucosal incision is begun rostrally at the labial-gingival junction dorsal to the incisors and is continued lateral and caudal to the level of the last molar tooth. Medially, the incision begins between the central incisors and extends along the midline of the hard palate. The two incisions are joined together just caudal to the last molar tooth at the junction of the hard and soft palate (Figure 14-21A). Hemorrhage is often marked and is controlled with ligation, electrocautery, and pressure. An ostectomy is then performed along the incision lines with either an oscillating saw or an osteotome and mallet.

The caudal osseous incisions are at the rostral aspect of the zygomatic arch. The terminal branches of the maxillary artery are in this region and need to be identified and ligated. Once the ostectomy incisions are complete, the tissue to be resected is levered loose, soft tissue attachments are excised, and the section is removed intact from the surgical site. Exposed or transected vessels can be identified and ligated at this time. If temporary occlusion of the common carotid artery has been performed, blood flow should be reestablished to allow identification of transected vessels. When tumor penetrates the bone of the hard palate, the nasal turbinates, which overlie this area, should be excised with scissors or a scalpel and submitted for histopathologic examination. Turbinate hemorrhage can be controlled with a combination of ligation, electrocoagulation, and pressure. The use of mandibular symphysiotomy to facilitate exposure for caudal maxillectomy has been reported.[36]

A lip margin-based flap is created by undermining the labial mucosa and submucosa from the maxillectomy site toward the lip margin (Figure 14-21B). The mucosal-submucosal flap must be of adequate size and sufficiently undermined so it can be brought into apposition with the mucoperiosteum of the hard palate without tension. After thorough irrigation of the surgical site and confirmation of complete hemostasis, the labial mucosal-submucosal flap is sutured to the subperiosteally elevated edge of the hard palate mucoperiosteum with simple interrupted or

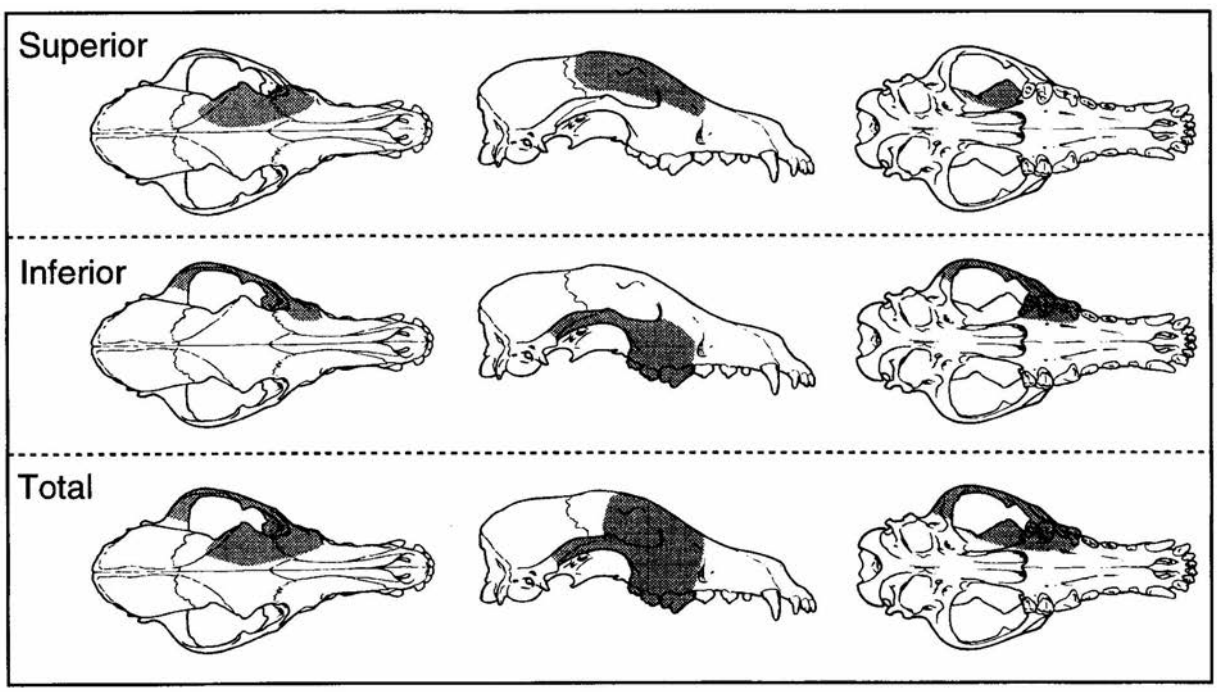


Figure 14-20. Examples of orbitectomy resection options (shaded portions). Reprinted with permission from O'Brien MG, Withrow SJ, Straw RC, et al. Total and Partial orbitectomy for the treatment of periorbital tumors in 24 dogs and 6 cats: A retrospective study. Vet Surg 1996;25:471-479.

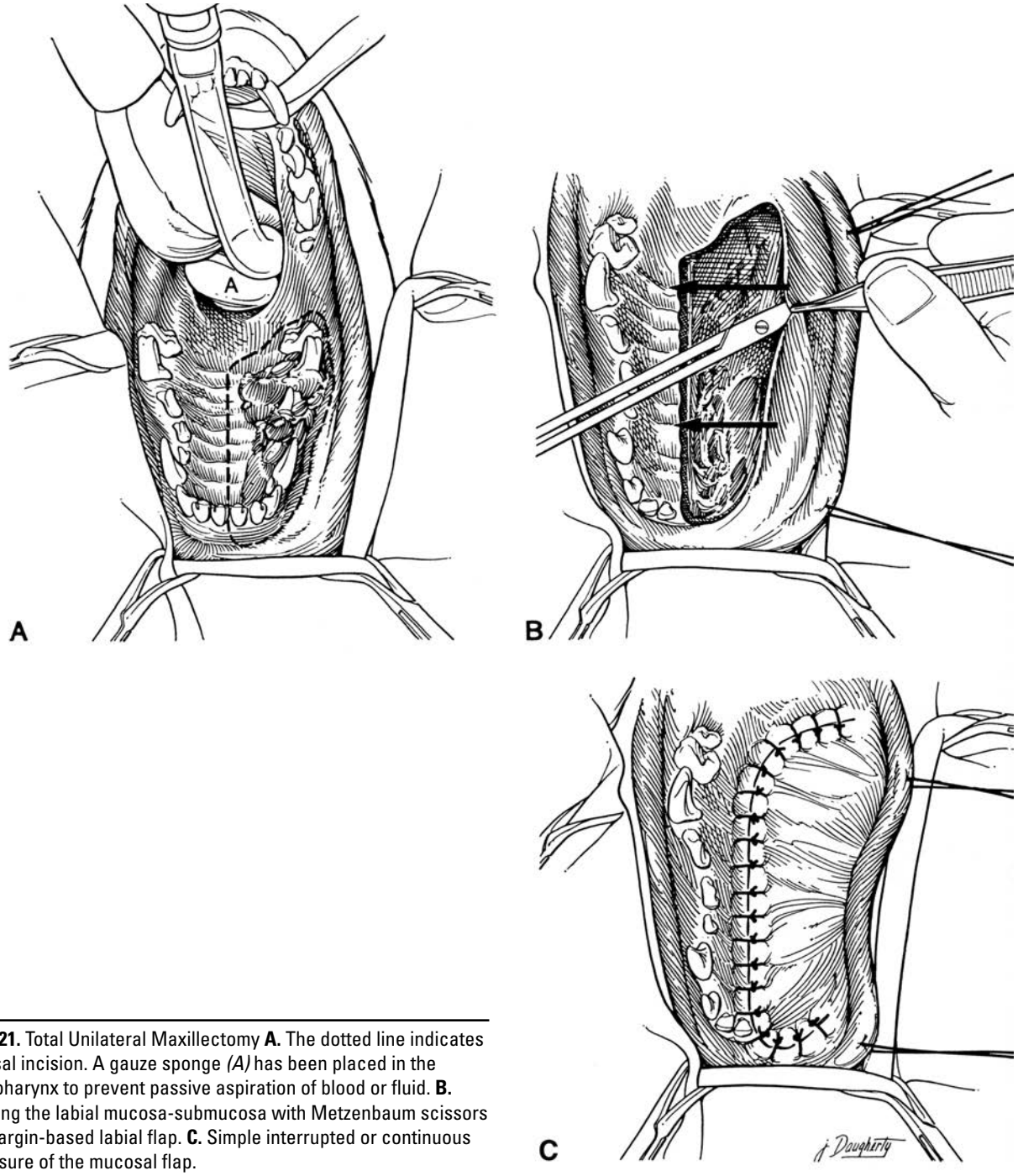


Figure 14-21. Total Unilateral Maxillectomy **A.** The dotted line indicates the mucosal incision. A gauze sponge *(A)* has been placed in the caudal oroharynx to prevent passive aspiration of blood or fluid. **B.** Undermining the labial mucosa-submucosa with Metzenbaum scissors for a lip margin-based labial flap. **C.** Simple interrupted or continuous suture closure of the mucosal flap.

simple continuous sutures (Figure 14-21C). If indicated, submucosal sutures can be placed through predrilled bone holes in the hard palate before closing the mucosal flap. The oropharynx is suctioned of blood before the animal is allowed to recover from anesthesia.

For cases with persistent, excessive blood loss from the nasal turbinates, placement of a Foley catheter can aid in control of hemorrhage. The tip of the catheter is placed through the external nares and passed along the ventral meatus to the site of the hemorrhage. The cuff is either inflated at the site of loss, or, if the site cannot be identified, it is inflated at the very caudal aspect of the nasal cavity. Inflation of the cuff directly over the site will apply pressure and assist in control of hemorrhage. Inflation of the cuff caudal to the site will force the blood loss out of the nasal cavity and allow better quantitative measurement. Without this, large volumes of blood can be swallowed by the patient after recovery masking the true volume of loss and preventing appropriate support. The Foley catheter can then be removed once hemorrhage has subsided. Another option is to pack the nasal cavity with gauze from a roll, exiting the end of the gauze from the external nares. Once hemorrhage subsides the gauze can then be carefully pulled. This may require heavy sedation or a short general anesthetic.

Postoperative Care and Sequelae

Because of the aggressiveness of maxillectomy procedures, the animal should be supported for the first 24 hours postoperatively

with parenteral fluids and analgesics. Close observation within a critical care unit is preferred, especially following larger resections. The use of continuous rate infusion narcotic agents will often result in smoother recovery and maintenance of pain control. An Elizabethan collar is often necessary to prevent self induced trauma to the surgical site. The patient is allowed water after recovery from anesthesia, and soft foods are offered 24 to 48 hours after surgery. Feeding small meatballs made from canned food for the first few days can assist the patient in prehending food and decrease messiness associated with eating immediately postoperatively. Pharyngostomy, esophagostomy, and gastrostomy tubes rarely are necessary in dogs. In the authors' experience, cats undergoing maxillectomy procedures are best supported by enteral feeding tubes during the immediate postoperative period.

The surgical site should be visualized for evidence of dehiscence and should be kept free of debris by flushing the mouth with water daily. Wound breakdown is the most significant postoperative complication after maxillectomy. Suture line tension, excessive use of electrocautery, ischemic necrosis of the mucosal submucosal flap, and tumor recurrence are the major causes of dehiscence. Except for tumor recurrence, most problems result from technical error by the surgeon and can be eliminated by following proper case selection and technique and by minimizing surgical trauma. If the sutures holding the flap in place break down after surgery, the animal should be reanesthetized and the flap resutured. At the time of resuturing, rebiopsy of the surgical site is always indicated; what appears to be granulation tissue can easily be residual tumor. Up to 33% of maxillectomy patients have some degree of dehiscence during the postoperative period.[13,37] Not all cases of dehiscence, however, are of clinical significance. Dehiscence is most commonly noted after caudal maxillectomy or total unilateral maxillectomy, when tumors cross the midline, and whenever mucosa has been sutured next to a tooth on the occlusal margin of the ostectomy. Tension free closure at the level of the ostectomy can be achieved by extracting an additional tooth, by elevating the palatal and labial gingiva, and by suturing the mucosal flaps over the alveolar bone. If dehiscence results in oronasal fistula formation, secondary closure should be attempted to avoid additional complications. Techniques for closure of oronasal fistulas are described in (See Chapter 14 on Repair of Oronasal Fistulas).

A concave deformity of the muzzle contour can occur after partial maxillectomy and repair with a labial mucosal-submucosal flap. Such indentation generally results from an insufficient amount of normal labial tissues. It generally can be corrected by incising the base of the labial flap 3 weeks after surgery to allow the lip to return to its normal position. This procedure is rarely indicated because function is generally unaffected by the lip indentation.

Recently, the development of a salivary mucocele following a caudal maxillectomy was reported. Initial clinical signs developed 15 days postoperatively, and included swelling of the left side of the face, exophthalmos, third eyelid protrusion and pain when the mouth was opened.[38] The most common complications following maxillectomy have been reported.[39]

In patients that undergo bilateral rostral maxillectomy, removal of the bony hard palate caudal to the canine teeth may shorten the nose. In some cases, the upper lip may actually be positioned caudal to the lower canines when the mouth is closed, especially if imbrication or plication sutures are used. Drooping of the nares and rostral muzzle also occurs when the mouth is open.

Follow up

Initial re-evaluation is recommended 7 days following maxillectomy. This is the time period where dehiscence is most common, therefore a thorough oral exam is indicated to evaluate for dehiscence or other complications. At the same time, sutures that have loosened and are causing irritation can be removed. Maxillectomies performed for excision of tumor should then be evaluated at 1 month and then every 3 months during the first postoperative year. Evaluations should include both visualization and palpation of the oral cavity, muzzle, and regional lymph nodes. Thoracic radiographs, depending on tumor type, may also be indicated for detection of distant metastasis. If gross evidence of local tumor recurrence or suspicious areas can be detected, an incisional biopsy should be performed. Skull radiographs or advanced imaging may be beneficial, but they are often difficult to evaluate, especially in the distinction of tumor and bony reactions resulting from surgical trauma. Complete surgical excision with adequate tumor free margins generally is difficult to obtain after documentation of local tumor recurrence. Chemotherapy and radiation therapy are alternative adjunctive therapies to consider in such cases.

Table 14-1 lists approximate reported local recurrence and median survival rates after maxillectomy for the major histopathologic tumor groups found in the dog.[1,3,13-16] A lack of reported cases in the cat precludes drawing any conclusions concerning survival rates.

Table 14-1. Approximate Reported Local Recurrence and Survival Data for Oral Tumors Treated with Maxillectomy

Tumor Type	Number	Local Recurrence (%)	Median Survival (months)
Acanthomatous epulis	10	10	26
Ameloblastoma	23	13	22
Malignant melanoma	40	40	8
Squamous cell carcinoma	16	31	18
Fibrosarcoma	35	46	12
Osteosarcoma	17	35	5

(Data from references 2,4,37,40-42)

References

1. Fox LE, Geoghegan SL, Davis LH, et al. Owner satisfaction with partial mandibulectomy or maxillectomy for treatment of oral tumors in 27 dogs. J Am Anim Hosp Assoc 1997;33:25-31.

2. Withrow SJ, Nelson AW, Manley PA, et al. Premaxillectomy in the dog. J Am Anim Hosp Assoc 1985;21:49 55.

3. Salisbury SK, Richardson DC. Partial maxillectomy for oronasal fistula repair in the dog. J Am Anim Hosp Assoc 1986;22:185 192.

4. Salisbury SK, Richardson DC, Lantz GC. Partial maxillectomy and premaxillectomy in the treatment of oral neoplasia in the dog and cat. Vet Surg l986;15:16 26.

5. Dorn CR, Taylor DO, Frye FL, et al. Survey of animal neoplasms in Alameda and Contra Costa Counties, California. I. Methodology and descrip¬tion of cases. J Natl Cancer Inst 1968;40:295-305.

6. Theilen GH, Madewell BR. Tumors of the digestive tract. In: Theilen GH, Madewell BR, eds. Veterinary Cancer Medicine. Philadelphia: Lea & Febiger, 1987:499 534.

7. Head KW. Tumors of the alimentary tract. In: Molten JE, ed. Tumors in Domestic Animals. 3rd ed. Berkeley: University of California Press, 1990:347 428.

8.Norris AM, Withrow SJ, Dubielzig RR. Oropharyngeal neoplasms. In: Harvey CE, ed. Veterinary Dentistry. Philadelphia: WB Saunders, 1985:123 139.

9. Cotter SM. Oral pharyngeal neoplasms in the cat. J Am Anim Hosp Assoc 1981;17:917 920.

10. Dernell WS, Rullinger GH. Surgical management of ameloblastic fibroma in the cat. J Small Anim Pract 1994;35:35 38.

11. Carpenter LG, Withrow SJ, Powers BE, et al. Squamous cell carcinoma of the tongue in ten dogs. J Am Anim Hosp Assoc 1993;29:17 24.

12. Rassnick KM, Ruslander DM, Cotter SM, et al. Use of carboplatin for treatment of dogs with malignant melanoma: 27 cases (1989-2000). J Am Vet Med Assoc 2001;218:1444-1448.

13. Kirpensteijn J, Withrow SJ, Straw RC. Combined resection of the nasal planum and premaxilla in three dogs. Vet Surg 1994;23:341 346.

14. Lascelles BDX, Henderson RA, Seguin B, et al. Bilateral rostral maxillectomy and nasal planectomy for large rostral maxillofacial neoplasms in six dogs and one cat. J Am Anim Hosp Assoc 2004;40:137-146.

15. O'Brien MG, Withrow SJ, Straw RC, et al. Total and partial orbitectomy for the treatment of periorbital tumors in 24 dogs and 6 cats: A retrospective study. Vet Surg 1996;25:471-479.

16. Smith MM. Surgical approach for lymph node staging of oral and maxillofacial neoplasms in dogs. J Am Anim Hosp Assoc 1995;31:514-517.

17. Herring ES, Smith MM, Robertson JL. Lymph node staging of oral and maxillofacial neoplasms in 31 dogs and cats. J Vet Dent 2002;19:122-126.

18. Kafka UC, Carstens A, Steenkamp G, et al. Diagnostic value of magnetic resonance imaging and computed tomography for oral masses in dogs. J S Afr Vet Assoc 2004;75:163-168.

19. Owen L, ed. TNM classification of tumors in domestic animals. Geneva: World Health organization, 1980.

20. Beck JA, Strizek AA. Full-thickness resection of the hard palate for treatment of osteosarcoma in a dog. Aust Vet J. 1999;77:163-5

21. Smith MM. Island palatal mucoperiosteal flap for repair of oronasal fistual in a dog. J Vet Dent 2001;18:127-129.

22. Bryant KJ, Moore K, McAnulty JF. Angularis oris axial pattern buccal flap for reconstruction of recurrent fistulae of the palate. Vet Surg 2003;32:113-119.

23. Sager M, Nefen S. Use of buccal mucosal flaps for the correction of congenital soft palate defects in three dogs. Vet Surg 1998;27:358-363.

24. Griffiths LG, Sullivan M. Bilateral overlapping mucosal single-pedicle flaps for correction of soft palate defects. J Am Anim Hosp Assoc 2001;37:183-186.

25. Dundas JM, Fowler JD, Shmon CL, et al. Modification of the superficial cervical axial pattern skin flap for oral reconstruction. Vet Surg 2005;34:206-213.

26. Prescott JF, Baggot JD. Principles of antimicrobial drug selection and use. In: Prescott JF and Baggot JD, eds. Antimicrobial Ther¬apy in Veterinary Medicine. Boston: Blackwell Scientific Publi¬cations, 1988:55 70.

27. DeNardo GA, Brown NO, Trenka-Benthin S, et al. Comparison of seven different suture materials in the feline oral cavity. J Am Anim Hosp Assoc 1996;32:164-172.

28. Dernell WS, Harari J. Surgical devices and wound healing. In: Harari J, ed. Surgical Complications and Wound Healing in Small Animal Practice. Philadelphia: WB Saunders, 1993:249 376.

29. Salisbury SK, Thacker HL, Pantzer EE, et al. Partial maxillectomy: comparison of suture materials and closure techniques. Vet Surg 1985;14:265 276.

30. Beckman B, Legendre L. Regional nerve blocks for oral surgery in companion animals. Comp Cont Ed Pract Vet 2002;24:439-442.

31. Gross ME, Pope ER, O'Brien D, et al. Regional anesthesia of the infraorbital and inferior alveolar nerves during noninvasive tooth pulp stimulation in halothane-anesthetized dogs. J Am Vet Med Assoc 1997;11:1403-1405.

32. Lascelles BDX, Thomson MJ, Dernell WS, et al. Combined dorsolateral and intraoral approach for the resection of tumors of the maxilla in dogs. J Am Anim Hosp Assoc 2003;39:294-305.

33. Hedlund CS, Tangner CH, Elkins AD, et al. Temporary bilateral carotid artery occlusion during surgical exploration of the nasal cavity of the dog. Vet Surg 1983;12:83 85.

34. Clendenin MA, Conrad MC. Collateral vessel development after chronic bilateral common carotid artery occlusion in the dog. Am J Vet Res 1979;40:1244 1248.

35. Gillian LA. Extra and intracranial blood supply to brains in the dog and cat. Am J Anat 1976;146:237-253.

36. Mouatt JG, Straw RS. Use of mandibular symphysiotomy to allow extensive caudal maxillectomy in a dog. Aust Vet J 2002;80:272-276.

37. Schwarz PD, Withrow SJ, Curtis CR, et al. Partial maxillary resection as a treatment for oral cancer in 61 dogs. J Am Anim Hosp Assoc 1991;27:617 624.

38. Clarke BS, L'Eplattenier HF. Zygomatic salivary mucocele as a postoperative complication following caudal hemimaxillectomy in a dog. J Small Anim Pract 2010;51:495-498.

39. Matthiesen DT, Manfra Marretta S. Results and complications associated with partial mandibulectomy and maxillectomy techniques. Probl Vet Med 1990;2:248-275.

40. Wallace J, Matthiesen DT, Patnaik AK. Hemimaxillectomy for the treatment of oral tumors in 69 dogs. Vet Surg 1992; 21:337 341.

41. White RAS, Gorman NT, Watkins SB, et al. The surgical man¬agement of bone involved oral tumours in the dog. J Small Anim Pract 1985;26:693 708.

42. White RAS. Mandibulectomy and maxillectomy in the dog: re¬sults of 75 cases. Presented at the 22nd Annual Meeting of the American College of Veterinary Surgeons, San Antonio, 1987.

Mandibulectomy

William Culp, William S. Dernell and Stephen J. Withrow

Mandibulectomy

Mandibulectomy is the resection of variable sections of the mandible and closure of the surgical site with lingual and labial mucosa and submucosa. No replacement of bone or stabilization is required in most cases. Appearance, owner acceptance, and function are generally excellent after mandibulectomy.[1]

Six mandibular removal procedures have been described:[2-4] 1) unilateral rostral mandibulectomy (resection including three incisors, canine and first and second premolars); 2) bilateral rostral mandibulectomy (resection including all incisors, both canines and first and second premolars of both mandibles); 3) total unilateral mandibulectomy; 4) caudal mandibulectomy; 5) segmental horizontal body mandibulectomy; and 6) mandibular rim excision. Variations and combinations of these are used, depending on lesion type and location. Mandibulectomy can be combined with resections involving the maxilla and orbit, depending on the severity of disease.[4]

Indications

Mandibulectomy is performed for local control of oral neoplasia, for treatment of chronic mandibular osteomyelitis, and for salvage of patients with mandibular fractures with severe bone or soft tissue injury. Removal of oral tumors is the most common indication for mandibular resections. The oropharyngeal region is the fourth most common site of malignant neoplasia in the dog. The most common oropharyngeal neoplasms in the dog are malignant melanoma, squamous cell carcinoma, fibrosarcoma, and epulides or tumors arising from the periodontal ligament.[5-8] In the cat, squamous cell carcinoma is the most common oropharyngeal cancer, followed by fibrosarcoma, undifferentiated sarcoma, hemangiosarcoma, lymphoma, and osteogenic sarcoma. Malignant melanoma and epulides occur rarely in the cat.[8,9] Odontogenic tumors, such as inductive fibroameloblastoma, are the most common benign oral tumors in the cat.[10] Oropharyngeal tumors tend to be locally aggressive and slow to metastasize, except malignant melanoma, caudal tongue tumors,[11] and pharyngeal and tonsillar squamous cell carcinoma.[6-8] Without treatment, morbidity and mortality often result from local disease rather than from distant metastasis.

Control of local disease is the first goal of most surgical treatments for oral cancer. However, limited soft tissue excisions for attempted cure of oral tumors often fail because of recurrence of the tumor at the primary surgical site. Mandibulectomy accompanied by en bloc soft tissue resection for oral tumors has the potential for prolonged remission or cure in certain malignant diseases. If nothing else, the quality of life can be dramatically improved, even though distant metastasis may ultimately occur. Surgical resection should be considered as a first line of treatment for all oral neoplasms. Radiation therapy can be considered as primary treatment especially for tumors that show consistent responses to radiation, such as lymphoma, other round cell tumors and acanthomatous epulis. Radiation can be used in combination with surgical resection to improve local control where complete resection is not feasible or does not result in long term local control.[12]

Preoperative Evaluation

Routine hematologic and biochemical profiles, as well as urinalysis, should be performed on all candidates for mandibulectomy for anesthetic considerations and to identify any coexisting medical problems such as anemia. In cases of oral neoplasia, the tumor should be clinically staged according to the World Health Organization staging systems using the TNM (tumor, node, metastasis) classification, before definitive treatment is selected.[13] Staging requires an incisional biopsy while the patient is under general anesthesia (See Chapter 5), as well as analysis of a regional lymph node aspirates and thoracic radiographs to detect regional and distant metastasis. Preoperative staging helps to determine the appropriate treatment and prognosis and also helps the client to decide whether to pursue therapy. The evaluation of sentinel lymph nodes is increasing in popularity and new techniques are being developed that can better characterize the major draining lymph nodes or oral tumors.[14]

Imaging of the mandible taken while the patient is under general anesthesia should be obtained preoperatively in all cases of oral cancer. Radiographs should include lateral, ventrodorsal, and oblique views, as well as an open-mouth view if the tumor involves the rostral mandible. Fine detail screen with high-contrast film at low kilovolt potential is recommended. Advanced imaging modalities, such as computed tomography or magnetic resonance imaging, are often necessary for evaluation of tissue involvement and for planning surgical margins, especially for caudal lesions that involve the ramus and temporomandibular joint.[15] Patients with tumors that are adherent or "fixed" to the underlying mandible without radiographic evidence of invasion are still candidates for mandibulectomy since bone removal is often the only way to obtain (deep) normal tissue margins.

Boundaries for mandibulectomy for benign neoplasms with or without evidence of cortical bone penetration into the medullary cavity should be determined with image-guidance and by oral examination. Cortical bone penetration by malignant neoplasms with suspected bone marrow involvement is the main indication for total unilateral mandibulectomy versus segmental or rostral mandibulectomy. If tumor cells follow the neurovascular bundle within the medullary cavity of the mandible, the entire mandible (minimally, the mandibular body) must be removed to excise the tumor completely. This is especially important in patients with malignant melanoma, fibrosarcoma, and osteosarcoma.

Cases with disease that is invasive into labial or intramandibular skin may still be candidates for mandibulectomy. Various options for soft tissue reconstruction are available.[16] Such closure will likely result in haired skin lying within a portion of the oral cavity. This is generally well tolerated, however, increased salivation can be seen as well as mild dermatitis of the skin of the chin in these cases due to salivary soiling.

Mandibulectomy is also performed for treatment of chronic osteomyelitis or extensive bone or soft tissue injury. Often, these patients are presented in a debilitated condition. A gastrostomy tube can be placed to assist the anorectic preoperative and postoperative patient to maintain proper nutrition and hydration. Because most mandibular fractures are open fractures, broad spectrum antibiotics are recommended. The duration of antibiotic therapy depends on the type and severity of infection.

General Surgical Considerations

When mandibulectomy is performed for treatment of an oral neoplasm, at least a 1 cm, grossly visible, tumor free margin should be obtained on all cut surfaces. If bone change is evident on preoperative imaging, the removed section of mandible should be radiographed to aid in determining whether adequate bony disease-free surgical margins were obtained. Margins of interest (osteotomy edges and soft tissue margins) should be identified with India ink or other suitable marking system, or margins should be submitted in separate containers. This procedure aids the pathologist in determining the adequacy of mass removal (See Chapter 5). The entire specimen is then placed in 10% buffered formalin and is submitted for histopathologic evaluation. Tumor extension to the cut margins generally implies the need for additional surgery or adjuvant radiation.

Mandibulectomy is considered a contaminated or "dirty" surgical procedure. Therefore, therapeutic levels of antibiotics are indicated at the time of surgery. Parenteral prophylactic antibiotic therapy begun preoperatively or intraoperatively and continued for a maximum of 24 hours is recommended when osteomyelitis is not already established. The antibiotic chosen should be effective against the bacterial flora normally found in the oral cavity, including gram positive cocci (e.g., Staphylococcus sp. and Streptococcus sp.) and gram negative rods (e.g., Proteus and Pasteurella spp.). The first generation cephalosporins, penicillins, and synthetic penicillins are generally considered effective prophylactic oral antibiotics.[17]

In the author's experience, polydioxanone (PDS, Ethicon, Inc., Somerville, NJ), polyglactin 910 (coated Vicryl, Ethicon, Inc.), polyglycolic acid (Dexon, Davis and Geek, Inc., American Cyanamid Co., Manati, PR), and polyglyconate (Maxon, Davis and Geek, Inc.) sutures (3-0 or 4-0) are prefered for wound closure after mandibulectomy. These relatively nonreactive sutures minimize oral mucosal irritation and maintain adequate tensile strength during the critical early period of healing. Polydioxanone and polyglyconate have the advantages of being monofilament and absorbable. Their absorption is slower than polyglactin 910 and polyglycolic acid, however, and food can cling to the suture, or suture knots can be irritating, resulting in oral mucosal ulceration if the suture is not removed after healing. Although polyglactin 910 and polyglycolic acid are absorbable, they are braided suture materials and may increase the possibility of bacterial adherence or may result in a greater inflammatory response causing oral mucosal irritation. These latter two suture materials lose tensile strength sooner than the monofilament absorbables, a characteristic that should be considered if adjuvant radiation or chemotherapy may be administered postoperatively or if other patient factors exist that might result in delayed wound healing. The absorption rate of various suture materials has been evaluated in vivo for use in the oral cavity in cats.[18] A reverse cutting swaged on needle has been beneficial in suturing the tough, fibrous soft tissues of the oral cavity. This type of needle causes less surgical trauma when passed through tissues and provides better suture purchase into the soft tissues than other needle types.[19] Use of electrocautery should be kept to a minimum. Incisions within the oral cavity made with electrocautery are more likely to have delayed healing or to become dehiscent than incisions made with a scalpel.[2,20]

The choice of preanesthetic medication is based on the preoperative evaluation and on personal preference. A narcotic is often recommended for its analgesic effect. A local nerve block of the inferior alveolar nerve preoperatively or intraoperatively using a long acting local anesthetic may also decrease postoperative pain and may lower anesthetic requirements.[21,22]

After induction of anesthesia, an endotracheal tube should be inserted, and anesthesia should be maintained with a gas inhalant and oxygen. A cuffed endotracheal tube is mandatory to prevent passive aspiration of blood and fluid. Once the animal is positioned, prior to the start of surgery, inflation of the endotracheal tube cuff should be checked again, and upon recovery, extubation with the cuff partially inflated may assist in removal of blood that has accumulated in the oropharynx. The tube is anchored to the patient's muzzle to minimize its interference during surgery. Isotonic crystalloid fluid therapy is started immediately after induction at an initial dose of 10 ml/kg per hour. At times, hemorrhage is brisk, and the dose should be increased as dictated by the situation. Whole blood, plasma or colloids may be indicated, depending on the degree of blood loss. The patient is placed on a protected hot water blanket and is monitored at all times with a continuous electrocardiogram and preferably with either direct or indirect blood pressure measurements. Before the surgical procedure is begun, the cuffed endotracheal tube should be checked again to ensure that an airtight seal has been created with the trachea to prevent the aspiration of blood.

Depending on the type of mandibulectomy performed, the hair over the dorsal or ventral muzzle may or may not need to be clipped. Procedures done entirely through an intraoral approach usually do not require clipping. For procedures requiring caudal approaches, such as total unilateral mandibulectomy and caudal mandibulectomy, hair should be clipped in the region of the commisure of the lip caudally to the base of the ear. Clipped regions are routinely prepared for aseptic surgery. The oral cavity should be swabbed with a 10% dilution of povidone iodine solution (Betadine, Purdue Frederick Co., Norwalk, CT). A mouth speculum is placed between the teeth on the normal side to keep the mouth open to assist in exposure. The surgical area is draped as aseptically as possible.

Surgical Techniques

Unilateral Rostral Body Mandibulectomy

Tumors or injuries involving the incisors, lower canine, or first two premolars on one side are indications for unilateral rostral body

mandibulectomy. The soft tissues medial to this region must be free of tumor to obtain a tumor free margin and to allow for adequate soft tissues for closure (Figure 14-22A). A bilateral rostral body mandibulectomy should be considered if the medial soft tissue structures are involved or if an adequate tumor free margin cannot be obtained.

The animal is placed in lateral or dorsal recumbency with the affected mandible placed upwards. The labial mucosa is incised at a minimum of 1 cm outside the visible limits of the tumor (Figure 14-22B). The dissection is continued around the body of the mandible to the sublingual mucosa until the symphysis and the caudal limit of the proposed ostectomy are exposed (Figure 14-22C). The sublingual and mandibular salivary gland ducts open under the body of the tongue on the sublingual caruncle and are generally preserved. If excising this area is necessary, an attempt should be made to ligate these ducts.

After exposure of the symphysis, the tough fibrous joint is split with an osteotome and mallet or oscillating saw to separate the two mandibles (Figure 14-22D). If the tumor has crossed over or is adjacent to the symphysis, the rostral osteotomy should be directed eccentrically between the incisors or canine tooth on the opposite hemimandible to excise the symphyseal joint completely. Because the body of the mandible is dense and brittle, an oscillating saw or Gigli wire is used to make the caudal osteotomy. Tapering the osteotomy at the occlusal margin decreases suture line tension on the mucosal closure (Figure 14-22E). This may require the removal of an additional tooth. Hemorrhage from the mandibular medullary cavity is from the mental artery and vein and may be brisk. Bleeding is best controlled with ligation, however, cautery or bone wax can be used, especially in smaller dogs where the medullary canal is too small to access the vessels for ligation. Remaining portions of abnormal tooth roots should be removed. No attempt is made to stabilize the two mandibles together (Figure 14-22F).

An one layer simple interrupted or continuous suture closure of the sublingual mucosa to the labial mucosa attached to the skin is accomplished with 3-0 or 4-0 suture (Figure 14-22G). The areas with the highest incidence of dehiscence are at each end (rostral and caudal) of the incision line. The use of a single simple interrupted suture at these points, potentially encircling an adjacent tooth (passing the suture subgingivally beneath the tooth crown) can aid to decrease the incidence of dehiscence. These interrupted sutures are in addition to the remaining suture line. The hair of the skin is partially in the mouth, and care should be taken to prevent inversion of the suture line. In some cases, tumor may adhere to the skin, thus requiring its excision. In these patients, partial closure and allowing the defect to heal by second intention should result in a cosmetically acceptable appearance. Alternatively, direct closure of haired skin of the lip to sublingual mucosa can be performed. Increased salivation can be seen as well as mild dermatitis of the skin of the chin in these cases due to salivary soiling.

Bilateral Rostral Mandibulectomy

Bilateral rostral mandibulectomy is indicated for tumors or injuries that cross the midline rostral to the second premolar (Figure 14-23A). This procedure is commonly used in cancer patients because of the frequent soft tissue involvement of the opposite mandible. Even with unilateral disease, some patients function better with a bilateral resection. If the surgeon has any question about the extent of disease (crossing the midline or not), bilateral resection should be performed.

The patient can be placed in lateral, dorsal, or sternal recumbency. Dorsal recumbency affords the greatest exposure for dissection and osteotomy, whereas ventral recumbency affords the greatest exposure of the oral cavity for more difficult closures (Figure 14-23B). This procedure is similar to unilateral rostral mandibulectomy, except bilateral resection is performed. No attempt is made to stabilize the two mandibles together, although an experimental study showed rapid bony union and adequate patient tolerance of a combination of plating and implantation of bone graft or synthetic graft. Redundant skin may need to be removed before it is sutured to the sublingual mucosa during closure. This is easily accomplished by excising a V shaped wedge of skin with the apex located ventrally. The excision can be performed at the most rostral tip of the exposed skin or just lateral to this point. The location selected should be based first on location of the tumor and second on cosmetics. Any adherent skin overlying the tumor should be excised, to ensure a tumor free margin. During suturing of the labial mucosa to the sublingual mucosa, the surgeon should attempt to create a soft tissue ridge rostrally to help keep saliva in the mouth (Figure 14-23C). The hair of the skin may be partially in the mouth, but care should be taken to prevent inversion of the suture line. In some cases, tumor may adhere to the skin, thus requiring its excision. As with unilateral rostral mandibulectomy, partial closure and allowing the defect to heal by second intention should result in a cosmetically acceptable appearance. Alternatively, direct closure of haired skin of the lip to sublingual mucosa can be performed. Increased salivation can be seen as well as mild dermatitis of the skin of the chin in these cases due to salivary soiling.

Total Unilateral Mandibulectomy

Total unilateral mandibulectomy, the most aggressive form of mandibulectomy, entails removal of one mandible. The procedure is indicated for patients with tumors or injuries involving a large segment of the mandible or for those with tumors (e.g., malignant melanoma, fibrosarcoma, osteosarcoma) that appear to have penetrated the medullary cavity.

The patient is placed in lateral or ipsilateral recumbency, with the involved mandible placed upwards. The commissure of the lip is first incised at its midpoint, full thickness, to the rostral edge of the manibular ramus (Figure 14-24A). A modified incision, directed from the commissure to the coronoid process has been recently described that may improve exposure to deeper tissues.[23] The incision is then continued through the skin and the subcutaneous and fascial tissue to the level of the temporomandibular joint. Branches of the facial artery and vein are ligated or cauterized as necessary. The parotid duct is generally dorsal to this incision.

The labial mucosa is then incised, to ensure a visible 1 cm tumor free margin, beginning at the symphysis and extending caudally

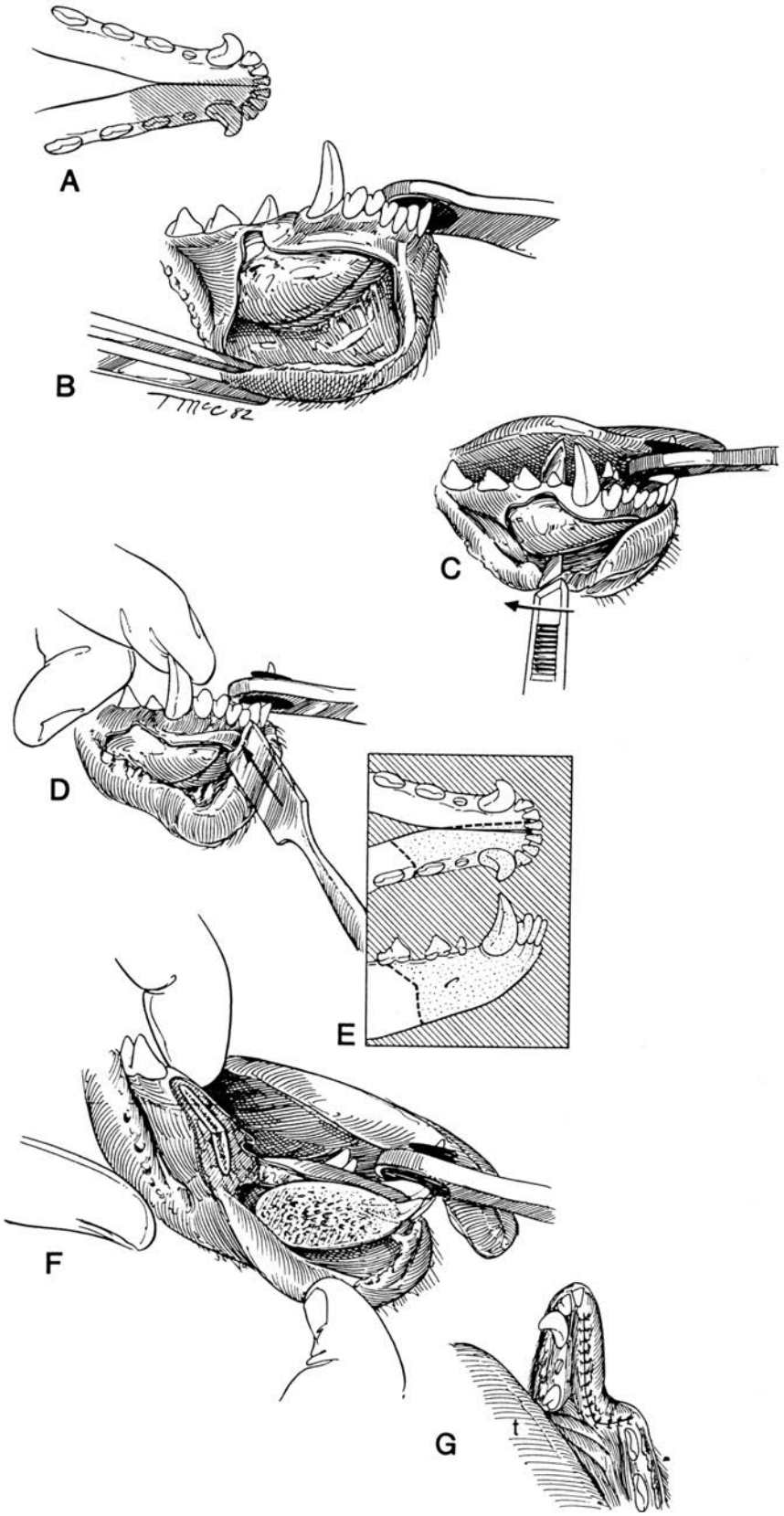


Figure 14-22. Unilateral rostral mandibulectomy. **A.** The shaded area represents the region of the mandible to be excised. **B.** The labial mucosa is incised and the rostral mandible is undermined to expose the symphysis and caudal limit of the proposed ostectomy. **C.** The sublingual attachments in the rostral intermandibular space are incised. **D.** An osteotome is used to split the symphysis. **E.** The dotted lines indicate the proposed osteotomy site for removal of the tumor adjacent to the symphysis. Note the eccentric osteotomy of the rostral mandible to include the symphysis and the tapered caudal osteotomy. **F.** Ostectomy site after unilateral rostral body mandibulectomy. No attempt is made to stabilize the two hemimandibles together. **G.** Single layer simple interrupted or simple continuous closure of the ostectomy site. *t*, tongue. (Reprinted with permission from Withrow SJ, Holmberg DL. Mandibulectomy in the treatment of oral cancer. J Am Anim Hosp Assoc 1983;19:275 276.)

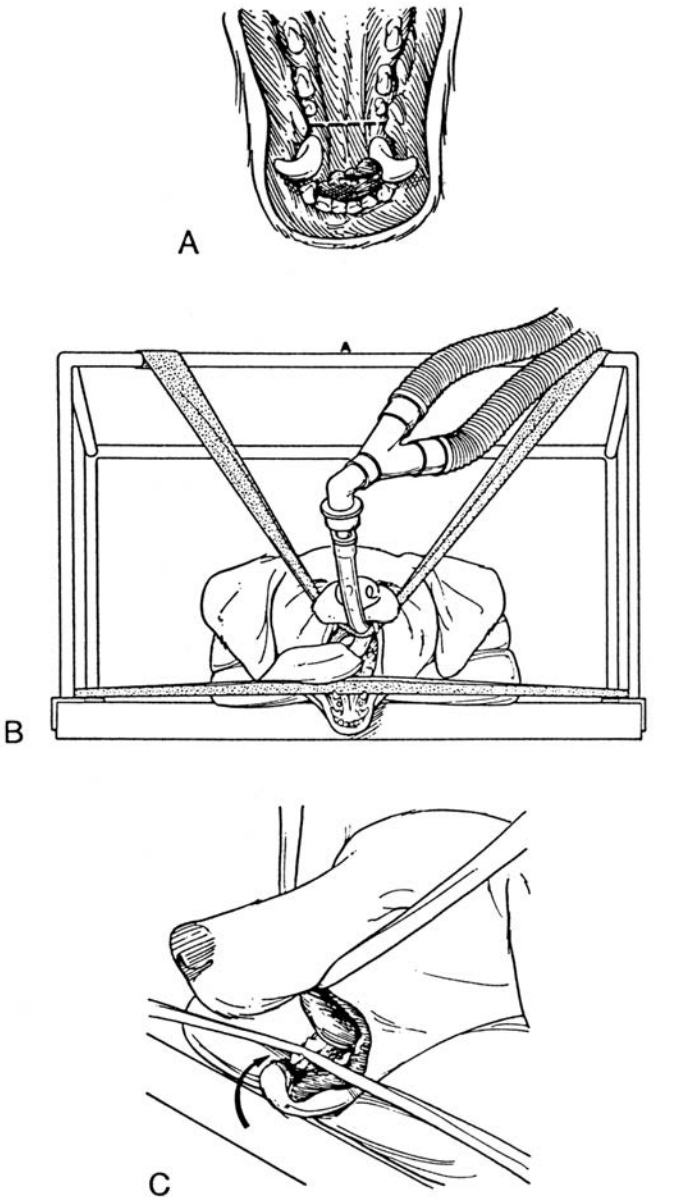


Figure 14-23. Bilateral rostral mandibulectomy. **A.** The dotted line indicates the proposed ostectomy site for tumor excision. **B.** With the dog in sternal recumbency, the rostral lower jaw overhangs the surgical table and is taped to the table with adhesive tape. The upper jaw is taped to an anesthesia screen *(A)* along with the endotracheal tube. **C.** A soft tissue ridge or "dam" is created to help keep saliva in the mouth.

to the angle of the mandible (Figure 14-24B). The mandibular and sublingual ducts, if identifiable, are ligated at this time. The dissection is carried completely around the body of the mandible; the genioglossus, geniohyoideus, and mylohyoideus muscles are cut where they attach to the medial surface of the mandible. The sublingual mucosa is incised to free the lateral border of the tongue. As much mucosa as possible is saved to aid closure. Once the body is free of soft tissue attachments, the symphysis is cut with an osteotome and mallet or oscillating saw (Figure 14-24C). This technique allows free lateral movement of the affected mandible, enhancing visualization for caudal dissection.

For rostrally located masses with suspected bone marrow involvement, the body of the mandible can be resected at the rostral edge of the masseter muscle angling caudally toward the angular process, leaving the dorsal aspect of the mandibular ramus and the temporomandibular joint intact (Figure 14-24D). If this is performed, the surgeon can then move to closure (See Figure 14-25B and C).

If total unilateral mandibulectomy is performed, the masseter muscle is next sharply dissected off the ventrolateral surface and ventral margin of the ramus of the mandible and then is retracted dorsally and caudally (Figure 14-24E). The digastricus muscle is then incised at its insertion on the ventrocaudal border of the mandibular body (Figure 14-24F). With lateral retraction of the mandibular body, the pterygoideus muscles are incised where they insert medially on the ventrocaudal surface of the angle of the mandible (Figure 14-24G). Extreme care is necessary at this time to avoid accidental cutting of the inferior alveolar artery, a branch of the maxillary artery, before its identification and ligation. This vessel passes across the lateral surface of the medial pterygoideus muscle before entering the mandibular canal on the medial side. An attempt to ligate this vessel should be made in all patients, preferably prior to transection. The mandibular foramen is located ventromedial and just rostral to the border that extends between the angular and coronoid processes of the mandible. After the capsule of the temporomandibular joint is visualized and incised both medially and laterally, the joint is luxated (Figure 14-24H). This allows removal of the temporalis muscle as it inserts on the coronoid process of the mandible and of any remaining loose fascial attachments.

Closure is specific to each case, depending on the amount of soft tissue excised, but in all cases dead space must be closed, followed by mucosal apposition. A modification of the closure described below has been reported with similar cosmetic and functional outcome. The incidence of wound dehiscence was similar as well.[23] A three layer suture closure is recommended. The deep layer consists of opposing the pterygoideus, masseter, and temporalis muscles. The remaining closure sequence entails the stromal layer located below the mucosa followed by a mucosal layer. A continuous suture pattern works best in the mucosa to obtain a seal.

In the caudal third of the incision, the oral mucosa lateral to the base of the tongue and oropharynx is sutured to the mucosa of the soft or hard palate. In the middle third of the incision, the labial mucosa is sutured to the sublingual mucosa remaining lateral to the tongue. This is continued to the rostral edge of the commissure incision. Because removal of the entire mandible results in loss of lateral support for the tongue, lateral drifting of the tongue often occurs. Closing the commissure of the lip farther rostrally (than the original site) can help to maintain the normal position of the tongue. To do this, the margin of the upper lip, where it previously met the lower lip to form the commissure, is incised at full thickness along its margin to the level of the first premolar tooth (Figure 14-25A). A three layer suture closure consisting of mucosa, subcutaneous tissue, and skin is then performed (Figure 14-25B and C). Because of excess tension at the rostral extent of the suture line when the mouth is opened, a vertical mattress suture with buttons or a rubber stent may be considered. To complete the closure, the symphyseal oral mucosa is sutured to the lower labial mucosa, as described for a unilateral rostral mandibulectomy.

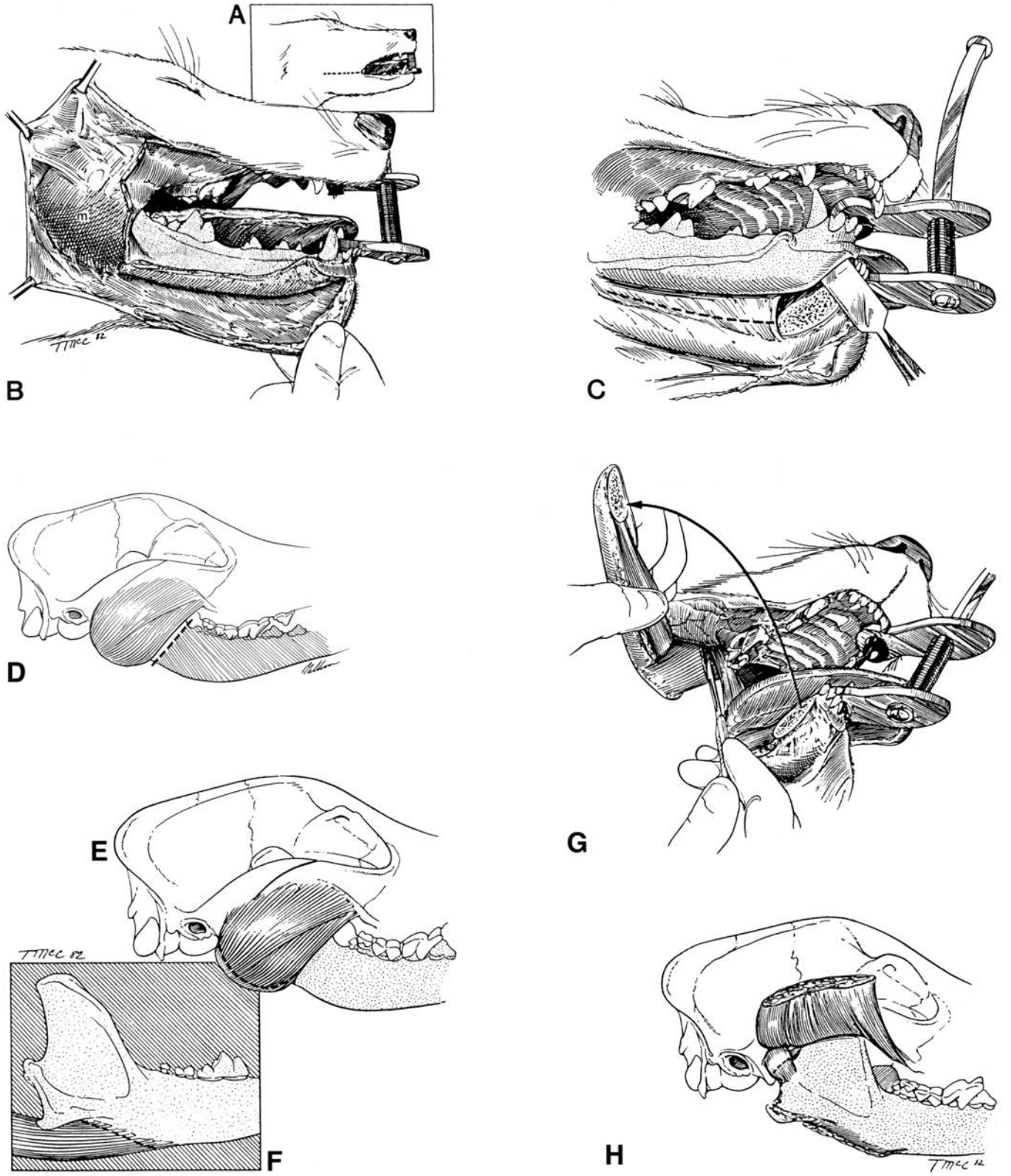


Figure 14-24. Total unilateral mandibulectomy. **A.** The dotted line indicates the skin incision. **B.** The labial mucosa is dissected free from the masseter muscle (m) and mandible, respectively, after being incised. The dotted area represents the area on the mandible involved by tumor. **C.** The symphysis is split with an osteotome. The dotted line represents the incision level for removal of the intramandibular muscles. **D.** The dotted line represents the level of resection for rostrally located tumors that involve the mandibular medullary cavity. The cavity ends at the level of the rostral attachment of the masseter muscle. **E.** The dotted line represents the masseter muscle incision. **F.** The attachment of the digastricus muscle. **G.** The pterygoideus muscles are incised medially. Care must be taken to avoid cutting the inferior alveolar artery before it is identified and ligated. **H.** The masseter muscle has been incised and elevated to expose the temporomandibular joint. The dotted line represents the joint capsule incision. (Reprinted with permission from Withrow SJ, Holmberg DL. Mandibulectomy in the treatment of oral cancer. J Am Anim Hosp Assoc 1983; 19:277 278.)

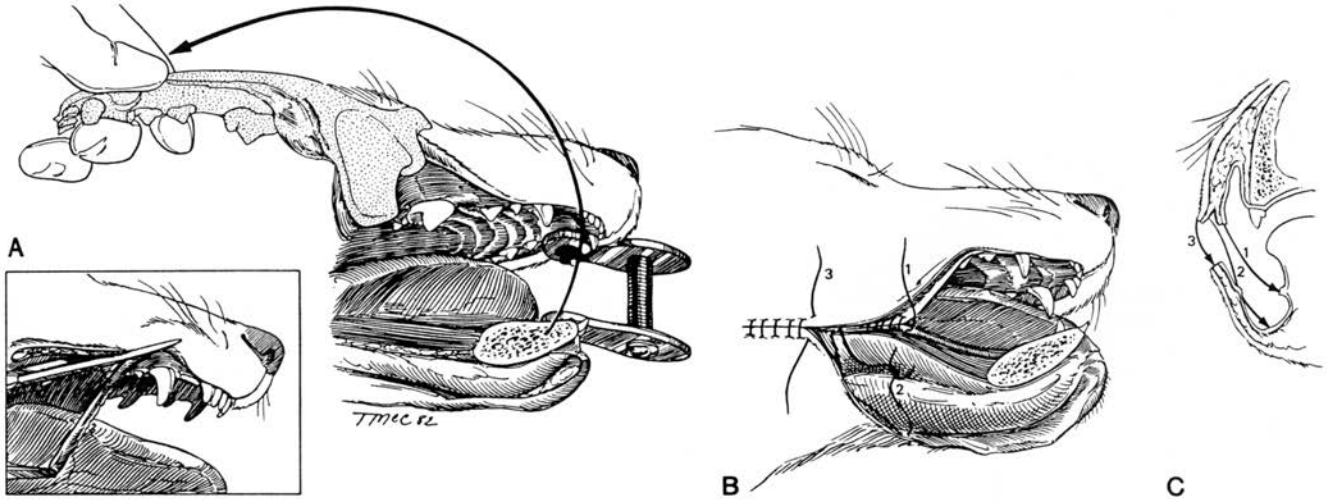


Figure 14-25. Cheiloplasty, to prevent lateral drooping of the tongue, and closure after total unilateral mandibulectomy. **A.** Full thickness incision of the upper lid margin to the level of the first premolar or canine tooth. **B** and **C**. Three layer closure: 1, oral mucosa; 2, subcutaneous tissue; 3, skin closure. (Reprinted with permission from Withrow SJ, Holmberg DL. Mandibulectomy in the treatment of oral cancer. Am Anim Hosp Assoc 1983; 19:279.)

Caudal Mandibulectomy

Caudal mandibulectomy (removal of part or all of the mandibular ramus) is indicated for tumors or injuries involving the angle, temporomandibular joint, or ramus of the mandible. This procedure is versatile enough to allow preservation of the temporomandibular joint or excision of the entire mandible caudal to the last molar. This procedure can be combined with resection of the zygoma or inferior orbit for lesions with more extensive tissue involvement.

The animal is placed in lateral recumbency with the affected side placed upwards. A curved skin incision is made over the length of the ventral aspect of the zygomatic arch (Figure 14-26A). Multiple small vessels are encountered, and several thin superficial muscles are incised as they cross lateral to the zygomatic arch. The periosteum is incised over the lateral surface of the zygomatic arch. With a periosteal elevator, the temporalis and masseter muscles are subperiosteally elevated off the dorsal and medial aspect and the ventral aspect, respectively, of the zygomatic arch (Figure 14-26B). Care should be taken not to injure the infraorbital artery, nerve, and vein as they course just medial to the zygomatic arch. Once the zygomatic arch is free of soft tissue attachments, it is cut with an oscillating saw or Gigli wire at its rostral and caudal margins (Figure 14-26C); an osteotome should not be used because it tends to shatter the hard, brittle bone of the zygomatic arch. Bleeding at the cut edges of the osteotomy site can be stopped with electrocautery or bone wax.

The masseter muscle is elevated ventrally off the lateral surface of the mandibular ramus. The temporalis muscle is similarly elevated off the medial and rostral aspect of the mandibular ramus. Care should be taken as the medial dissection is continued ventrally to avoid the inferior alveolar vessel. This vessel crosses the lateral surface of the medial pterygoideus muscle and enters the mandibular foramen located just rostral and ventral to the temporomandibular joint. If the temporomandibular joint is to be included in the excision, this vessel must be ligated and the medial pterygoideus muscle incised and elevated off the ventromedial aspect of the mandibular angle. The mandible is cut ventral and rostral to the involved bone with an oscillating saw or Gigli wire. Depending on the extent of the lesion to be removed, one may preserve the temporomandibular joint or include the joint in the excised bone (Figure 14-26D). At this point, the ramus can be easily removed by incising any loosely attached muscle and fascia; the temporomandibular joint is dislocated if necessary.

After copious lavage with physiologic saline, the muscle groups at the angle of the mandible are closed together to obliterate dead space. Replacing the osteotomized zygomatic arch is not necessary. The fascia of the masseter and temporalis muscles are then reattached to each other. Closure is completed with placement of subcutaneous and skin sutures.

Segmental Mandibulectomy

Segmental mandibulectomy is indicated for benign disease processes and for malignant tumors that do not penetrate cortical bone and are confined external to the cortex of the body between the first premolar and the last molar.

The animal is placed in lateral recumbency with the affected side placed upwards. The labial and lingual mucosa is incised 1 cm outside the visible limits of the tumor. Dissection is continued completely around the mandibular body until it is exposed for 360°. An oscillating saw or Gigli wire is then used to cut the mandibular body 1 cm rostral and caudal to the lesion. The dorsal aspect of the osteotomy should be angled away from the lesion (Figure 14-27A). Hemorrhage from the mandibular medullary cavity may be brisk. Bleeding is best controlled with ligation, however, cautery or bone wax can be used, especially in smaller dogs where the medullary canal is too small to access vessels for ligation. Normally, no attempt is made to replace the bony defect or stabilize the cut bone ends. Healing and eventual

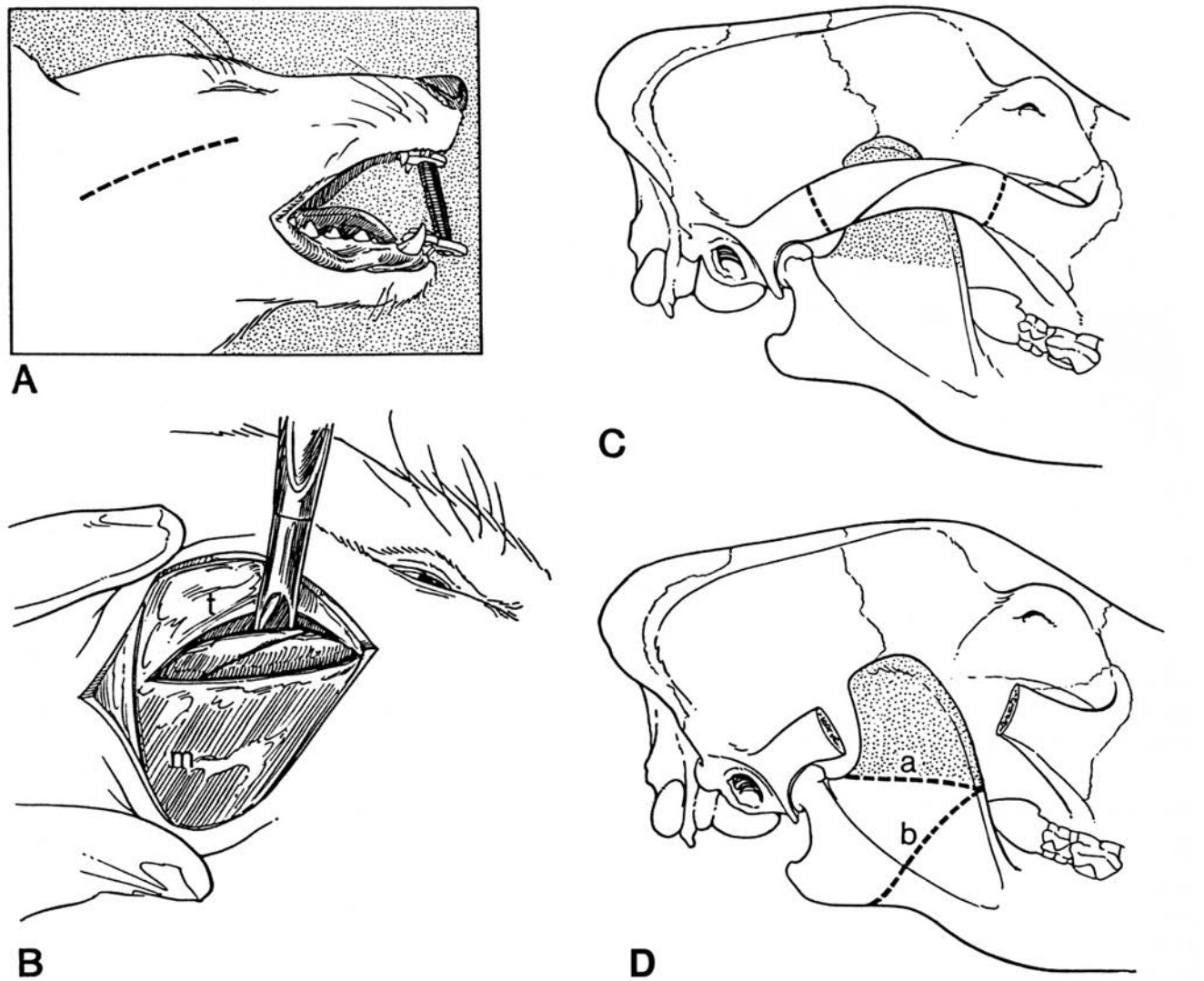


Figure 14-26. Caudal mandibulectomy. **A.** The dotted line represents the direction of the skin incision over the zygomatic arch. **B.** The temporalis *(t)* and masseter *(m)* muscles are elevated subperiosteally from the zygomatic arch. **C.** The dotted lines represent the rostral and caudal osteotomy sites on the zygomatic arch. The shaded area on the ramus represents the proposed mandibular ostectomy. **D.** The dotted lines represent various ostectomy sites for tumor removal. The temporomandibular joint is preserved *(a)* or removed *(b)* depending on tumor involvement of the ramus. (Reprinted with permission from Withrow SJ, Holmberg DL Mandibulectomy in the treatment of oral cancer. J Am Anim Hosp Assoc 1983; 19:280 281.)

stabilization is from fibrous tissue bridging the osteotomy gap. There have been reports of successful grafting or implant stabilization; additionally, the use of an osteoinductive factor (recombinant human bone morphogenetic protein-2) to stimulate bone formation has been described.[24,25] However, the vast majority of dogs function well with no effort made to fill the defect intra-operatively. There have also been reports of canine experimental models that have been used to assess bone regeneration in osteotomy sites using distraction techniques and a membrane barrier. Short and long term clinical effects and outcome have not been evaluated.[26] A one layer closure of sublingual mucosa to the remaining labial mucosa attached to the skin is accomplished with 3 0 or 4 0 suture material, similar to that used in unilateral rostral mandibulectomy (Figure 14-27B).

Mandibular Rim Excision

The mandibular rim excision procedure is a variation of a segmental mandibulectomy in that the ventral aspect of the mandible is not removed.[27] This procedure may prevent some of the postoperative complications noted in cases of segmental mandibulectomy (see below); however, the indications for this procedure are limited. Rim excision should only be considered in patients with very small tumors that are based on the occlusal surface and are not invading into the mandibular canal. Additionally, a preoperative CT scan is mandatory to assess these patients for disease that is more extensive than what can be palpated or seen grossly.

In general, patients are placed in sternal recumbency for a mandibular rim excision procedure and the surgical approach is similar to the segmental procedure except that 360° dissection is not necessary.[27] The ostectomy can be performed with an oscillating saw or burr; an attempt should be made to avoid the mandibular canal. While a right-angled rim excision can be performed, the curvilinear configuration is preferred.[27] At the

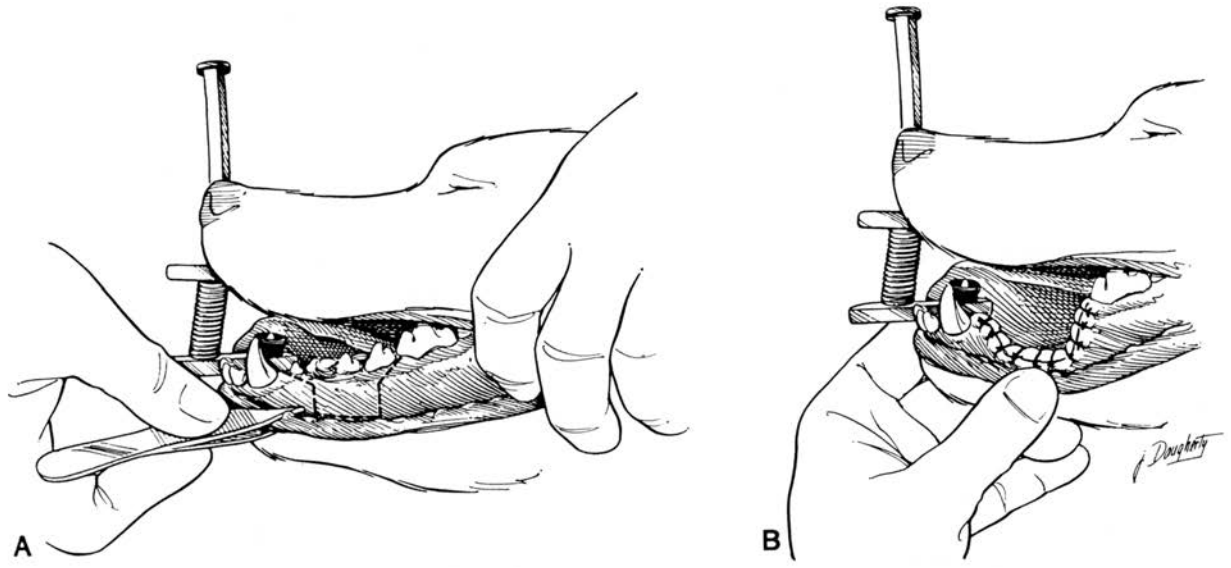


Figure 14-27. Segmental mandibulectomy. **A.** The dotted line indicates the proposed area to be excised. The osteotomies should be tapered away from the lesion on the occlusal surface to minimize suture line tension. **B.** Simple interrupted or simple continuous closure of mucosa.

completion of the ostectomy, the surgical site is flushed, and the adjacent gingiva is sutured over the bony defect using 3-0 or 4-0 monofilament suture material in a simple continuous pattern.[27]

Postoperative Care and Complications

Analgesics generally are indicated for the first 24 hours postoperatively, particularly after the more aggressive procedures (i.e., total unilateral mandibulectomy) Narcotic agents are often used in combination with non-steroidal anti-inflammatory drugs. A constant rate infusion of fentanyl can be considered. Maintenance parenteral fluids (20 ml/kg three times daily) also are recommended during this time. Antibiotics generally are not given for longer than 24 hours postoperatively. An Elizabethan collar should be placed on the patient as soon as it is sternally recumbent to prevent self induced trauma to the surgical site. The collar should be kept on the patient for the first 10-14 days.

Patients may have water and soft foods on the day after surgery for all types of mandibulectomy. Feeding small meatballs made from canned food for the first few days can assist the patient in prehending food and decrease messiness associated with eating immediately postoperatively. Most animals are able to maintain hydration and caloric intake by 24 to 48 hours postoperatively. Pharyngostomy, esophagostomy, or gastrostomy tubes are rarely necessary in dogs. The surgical site should be kept free of debris by flushing the mouth with water daily. After complete healing, return to the animal's normal diet is encouraged.

Complications are few after any type of mandibulectomy. Postoperative infection is rare unless a deep-seated infection was present at the time of surgery. The abundant blood supply to the oral cavity is a major reason for the low incidence of infection.

If dehiscence occurs at the surgery site, delaying closure for 7 to 10 days to allow better delineation of necrotic tissue and development of a healthy granulation bed is recommended. Dehiscence generally results from self induced trauma by the animal, excessive use of electrocautery, premature feeding of hard foods before adequate healing, or excessive tension at the suture line. Overall dehiscence rates are reported to be less than 13%.[28,29] Total unilateral mandibulectomy has the highest potential for dehiscence.

Excess tension is most often noted at the rostral extent of the cheiloplasty after total unilateral mandibulectomy or at the occlusal bone margin after unilateral and bilateral rostral mandibulectomy and segmental mandibulectomy. Tension free closure of the mucosal suture line at the level of the ostectomy can be achieved by angling the dorsal (occlusal) bone margin away from the lesion and by suturing the mucosa over the tapered bone. This may require extraction of an additional tooth. Drooping of the tongue to one side of the mouth can occur after total unilateral mandibulectomy if cheiloplasty is not performed or if the wound dehisces. Prehensile function of the tongue generally is normal, however.

If ostectomy is performed caudal to the second premolar bilaterally, loss of prehensile function and drooping of the tongue may occur after bilateral rostral mandibulectomy. This complication is a result of loss of support to the base of the tongue. In our experience, most animals regain complete control of tongue function in time. The owners and veterinarian must be willing to hand feed these animals during the recovery period. Different types of food should be tried (i.e., soft or hard), and a compliant and persistent owner is required. Oral feeding should be encouraged to allow the animal to adapt and develop a "new" prehensile function of the tongue.

After total unilateral mandibulectomy, edema or a "false" ranula may develop at the lateral base of the tongue on the surgically treated side. This condition is self limiting and generally disappears within 7 days. Removal of the sublingual and mandibular salivary glands is not necessary for resolution of this condition. Ligation or surgical trauma and inflammation with occlusion of the ducts of these glands at the time of surgery lead to atrophy of the glands.

The only common long term common complication of mandlibulectomy is shifting of the lower jaw toward the operated side. This shift results from loss of a portion of the mandibular support at either the temporomandibular joint or the symphyseal region. The malocclusion that results generally is clinically insignificant. Occasionally, filing down the top 20% of the remaining lower canine tooth may be necessary because of chronic irritation and ulceration of the hard palate mucosa. Mandibular drift can be more of a problem in cats. Extended nutritional support is often indicated for more extensive resections in cats. The most common complications following mandibulectomy have been reported.[30]

Follow up

Initial re-evaluation is recommended 7 days following mandibulectomy. This is the time period where dehiscence is most common, therefore a thorough oral exam is indicated to evaluate for dehiscence or other complications. At the same time, sutures that have loosened and are causing irritation can be removed. When mandibulectomy is performed for tumor excision, periodic checks should be then be performed at 1, 3, 6, 9, and 12 months. The animal should be evaluated for local tumor recurrence, nodal and distant metastasis. When the surgical margins of either the histologic sections or the postoperative radiographs suggest an incomplete or close surgical margin, more frequent rechecks are recommended. Less frequent rechecks are required when mandibulectomy is performed for treatment of benign neoplasia, chronic mandibular osteomyelitis or mandibular fractures.

Table 14-2 lists approximate recurrence and median survival rates reported for dogs undergoing mandibulectomy for oral tumors. In a series of 42 cats undergoing mandibulectomy, recurrence and survival rates at 1 and 2 years were 56% and 49%, 60% and 57%, respectively.[29]

Table 14-2. Approximate Reported Local Recurrence and Survival Data for Oral Tumors Treated by Mandibulectomy

Tumor Type	Number	Local Recurrence (%)	Median Survival (months)
Acanthomatous epulis	47	0	28
Ameloblastoma	44	22	19
Malignant melanoma	75	13	8
Squamous cell carcinoma	73	7	9
Fibrosarcoma	53	34	11
Osteosarcoma	64	16	13

(Data from references 28, 31-39)

References

1. Fox LE, Geoghegan SL, Davis LH, et al. Owner satisfaction with partial mandibulectomy or maxillectomy for treatment of oral tumors in 27 dogs. J Am Anim Hosp Assoc 1997;33:25-31.

2. Withrow SJ, Holmberg DL. Mandibulectomy in the treatment of oral cancer. J Am Anim Hosp Assoc 1983;19:273 286.

3. Bradley RL, MacEwen EG, Loar AS. Mandibular resection for removal of oral tumors in 30 dogs and 6 cats. J Am Vet Med Assoc 1984;184:460 463.

4. O'Brien MG, Withrow SJ, Straw RC, et al. Total and partial orbitectomy for the treatment of periorbital tumors in 24 dogs and 6 cats: a retrospective study. Vet Surg 1996;25:471-479.

5. Dorn CR, Taylor DO, Frye FL, et al. Survey of animal neoplasms in Alameda and Contra Costa Counties, California. I. Methodology and descrip¬tion of cases. J Natl Cancer Inst 1968;40:295-305.

6. Theilen GH, Madewell BR. Tumors of the digestive tract. In: Theilen GH, Madewell BR, eds. Veterinary Cancer Medicine. Philadelphia: Lea & Febiger, 1987:499 534.

7. Head KW. Tumors of the alimentary tract. In: Molten JE, ed. Tumors in Domestic Animals. 3rd ed. Berkeley: University of California Press, 1990:347 428.

8. Norris AM, Withrow SJ, Dubielzig RR. Oropharyngeal neoplasms. In: Harvey CE, ed. Veterinary Dentistry. Philadelphia: WB Saunders, 1985:123 139.

9. Cotter SM. Oral pharyngeal neoplasms in the cat. J Am Anim Hosp Assoc 1981;17:9l7 920.

10. Dernell WS, Rullinger GH. Surgical management of ameloblastic fibroma in the cat. J Small Anim Pract 1994;35:35 38.

11. Carpenter LG, Withrow SJ, Powers BE, et al. Squamous cell carcinoma of the tongue in ten dogs. J Am Anim Hosp Assoc 1993;29:17 24.

12. Hutson CA, Willauer CC, Walder EJ, et al. Treatment of mandibular squamous cell carcinoma in cats by use of mandibulectomy and radiotherapy: seven cases (1987-1989). J Am Vet Med Assoc 1992;201:777-781.

13. Owen L, ed. TNM classification of tumors in domestic animals. Geneva: World Health Organization, 1980.

14. Tuohy JL, Milgram J, Worley DR, et al. A review of sentinel lymph node evaluation and the need for its incorporation into veterinary oncology. Vet Comp Oncol 2009;7:81-91.

15. Kafka UC, Carstens A, Steenkamp G, et al. Diagnostic value of magnetic resonance imaging and computed tomography for oral masses in dogs. J S Afr Vet Assoc 2004;75:163-168.

16. Dundas JM, Fowler JD, Shmon CL, et al. Modification of the superficial cervical axial pattern skin flap for oral reconstruction. Vet Surg 2005;34:206-213.

17. Prescott JF, Baggot JD. Principles of antimicrobial drug selection and use. In: Prescott JF, Baggot JD, eds. Antimicrobial Therapy in Veterinary Medicine. Boston: Blackwell Scientific Publications, 1988:55 70.

18. DeNardo GA, Brown NO, Trenka-Benthin S, et al. Comparison of seven different suture materials in the feline oral cavity. J Am Anim Hosp Assoc 1996;32:164-172.

19. Dernell WS, Harari J. Surgical devices and wound healing. In: Harari J, ed. Surgical Complications and Wound Healing in Small Animal Practice. Philadelphia: WB Saunders, 1993:349 376.

20. Salisbury SK, Thacker HL, Pantzer EE, et al. Partial maxillectomy: comparison of suture materials and closure techniques. Vet Surg 1985;14:265 276.

21. Beckman B, Legendre L. Regional nerve blocks for oral surgery in companion animals. Comp Cont Ed Pract Vet 2002;24:439-442.

22. Gross ME, Pope ER, O'Brien D, et al. Regional anesthesia of the infraorbital and inferior alveolar nerves during noninvasive tooth pulp stimulation in halothane-anesthetized dogs. J Am Vet Med Assoc 1997;11:1403-1405.

23. Felizzola CR, Stopiglia JS, de Arújo VC, et al. Evaluation of a modified hemimandibulectomy for treatment of oral neoplasms in dogs. J Vent Dent 2002;19:127-135.

24. Bracher KE, Trout NJ. Use of a free cortical ulnar autograft following en bloc resection of a mandibular tumor. J Am Anim Hosp Assoc 2000;36:76-79.

25. Rubio-Bueno P, Sanroman F, Garcia P, et al. Experimental mandibular regeneration by distraction osteogenesis with submerged devices: preliminary results of a canine model. J Craniofac Surg 2002;13:224-230.

26. Peled M, Machtei EE, Rachmiel A. Osseous reconstruction using a membrane barrier following marginal mandibulectomy: an animal pilot study. J Periodontol 2002;73:1451-1456.

27. Arzi B, Verstraete FJM. Mandibular rim excision in seven dogs. Vet Surg 2010;39:226-231.

28. Schwarz PD, Withrow SJ, Curtis CR, et al. Mandibular resection as a treatment for oral cancer in 81 dogs. J Am Anim Hosp Assoc 1991;27:60l 610.

29. Northrup NC, Selting KA, Rassnick KM, et al. Outcomes of cats with oral tumors treated with mandibulectomy: 42 cases. J Am Anim Hosp Assoc 2006;42:350-360.

30. Matthiesen DT, Manfra Marretta S. Results and complications associated with partial mandibulectomy and maxillectomy techniques. Probl Vet Med 1990;2:248-275.

31. Salisbury SK, Lantz GC. Long term results of partial mandibulectomy for the treatment of oral tumors in dogs. J Am Anim Hosp Assoc 1988;24:285 294.

32. Kosovsky JK, Matthiesen DT, Manfra Marretta S, et al. Results of partial mandibulectomy for the treatment of oral tumors in 142 dogs. Vet Surg 1991;20:397 401.

33. White RAS, Gorman NT. Wide local excision of acanthomatous epulides in the dog. Vet Surg 1989;18:12 14.

34. White RAS. Mandibulectomy and maxillectomy in the dog: results of 75 cases. Presented at the 22nd Annual Meeting of the American College of Veterinary Surgeons, San Antonio, 1987.

35. Vernon FF, Helphrey M. Rostral mandibulectomy: 3 case reports in dogs. Vet Surg 1983;12:26 29.

36. Penwick RC, Nunamaker DM. Rostral mandibulectomy: a treatment for oral neoplasia in the dog and cat. J Am Anim Hosp Assoc 1987;23:19 25.

37. White RAS, Gorman NT, Watkins SB, et al. The surgical management of bone involved oral tumours in the dog. J Small Anim Pract 1985;26:693 708.

38. Bjorling DE, Chambers IN, Mahaffey EA. Surgical treatment of epulides in dogs: 25 cases (1974 1984). J Am Vet Med Assoc 1987;190:1315 1318.

39. Straw RC, Powers BE, Klausner J, et al. Canine mandibular osteosarcoma: 51 cases (1980-1992). J Am Anim Hosp Assoc 1996;32:257-262.

Tongue, Lip, and Cheek Surgery

Laura D. Dvorak and Earl F. Calfee, III

Tongue

In dogs and cats the tongue is a muscular organ that assists in food prehension, mastication, swallowing, taste, thermoregulation, vocalization, and grooming. Most of the tongue is skeletal muscle consisting of the genioglossus and geniohyoid muscles. Indications for partial excision of the tongue include congenital anomalies (macroglossia), glossitis, traumatic injuries (lacerations, ulcerations and burns, chronic linear foreign bodies, and electrical injuries), hyperplastic lesions, and neoplasia. Neoplastic lesions of the tongue are rare and account for only 4% of all oropharyngeal tumors in dogs.[1] Glossectomy includes partial glossectomy (amputation of any portion or all of the free tongue rostral to the frenulum), subtotal glossectomy (amputation of all of the free tongue and a portion of the genioglossus muscle, geniohyoid muscle, or both, caudal to the frenulum), near total glossectomy (resection of 75% or greater of the entire tongue), and total glossectomy.[2]

General Surgical Considerations

Preoperative evaluation of patients with glossal disease should include a complete physical examination, complete blood count (CBC), and serum biochemical profile. Three-view thoracic radiographs, skull radiographs, computed tomographic scans, magnetic resonance imaging, and evaluation of associated lymph nodes by fine needle aspiration or surgical biopsy may be indicated for patients with potential neoplastic lesions. Incisional biopsy of tongue lesions not caused by trauma is strongly recommended to obtain an accurate preoperative diagnosis so that a therapeutic plan and accurate prognosis may be determined. Other diagnostic tests may be indicated to establish the overall general health of the patient, especially geriatric animals prior to anesthesia.

Food should be withheld for 12 hours prior to the surgical procedure. Rapid anesthetic induction and intubation are recommended for oral surgery. Intubation by temporary tracheostomy or pharyngeal intubation may be required depending upon lesion location to allow adequate surgical exposure and manipulation of the tongue. The cuff of the endotracheal tube should be properly inflated to prevent aspiration of blood and lavage fluid during the surgical procedure. The oral cavity should be lavaged to remove any particulate material prior to aseptic preparation. The head should be positioned appropriately for the procedure being performed. Sternal or lateral recumbency is preferred for most glossectomies. Dilute povidine–iodine soap scrub can be used in a three scrub cycle for preparation of the surgical area. Chlorohexidine scrub or solution should not be used on the face to prevent contact with the eyes. The head is draped appropriately for the surgical procedure being performed.

The tongue has an extensive vascular supply and profuse bleeding is commonly encountered and expected during lingual surgery. Hemorrhage can be controlled by use of electrosurgery, lasers, temporary occlusion of the carotid arteries, and

accurate suture placment.[3] All surgery involving the oral cavity is considered contaminated due to the wide variety of microorganisms present in the normal microflora however, systemic antibiotics are generally not indicated due to the tongue's vascularity, the antibacterial properties of saliva, and the presence of immunoreactive cells in the connective tissues.[4] Healing of the tongue is rapid and absorbable monofilament suture such as monocryl or PDS (poliglecaprone 25 or polydioxanone) promotes uncomplicated healing.

Depending on the extent of the surgical procedure being performed, alternative feeding methods may be indicated to provide adequate nutrition post operatively. Animals may be unwilling to eat or the oral cavity and surgical site may be bypassed to promote normal tissue healing. Percutaneously placed esophagostomy and gastrostomy tubes can be easily placed at the time of the glossectomy and maintained until the patient is able to return to oral alimentation (See Chapter 6). We recommend placement of feeding tubes in all patients undergoing major glossectomies (subtotal, near-total, and total). Most dogs will rapidly return to oral alimentation following partial glossectomy.

Surgical Techniques

Partial Glossectomy

A wedge glossectomy can be used to excise lateral lesions of the tongue. Stay sutures can be placed within the tongue to provide traction and improve the surgeon's visualization of the lesion. Pre-placement of wide through and through simple interrupted sutures beyond the line of excision provides rapid hemostasis and tissue apposition. These sutures should be 5 to 10 mm away from the proposed incision line. Full thickness resection of the tissue wedge is performed with a scalpel blade, electrocautery, or laser and the preplaced interrupted sutures are tied. Single interrupted sutures should then be placed between the preplaced sutures to appose the mucosal edges at the incision. A continuous suture pattern can also be used for mucosal apposition. The surgeon should be aware that large wedge excisions will result in lateral deviation of the tongue which may be clinically significant.

A partial transverse or hemi-glossectomy is used for unilateral disease that requires more tissue excision than is possible with a wedge glossectomy (Figures 14-28A and B). Pre-placement of horizontal mattress sutures 5 to 10 mm away from the caudal incision line, 5 to 10 mm apart, aids in providing hemostasis. The lingual artery should be dissected and ligated. The midline incision should be performed along the raphe. Mucosal apposition is achieved with simple interrupted absorbable sutures or a simple continuous suture pattern of polydioxanone or polyglicaprone. A complete transverse glossectomy is used to excise rostral disease that crosses the raphe. The recommended technique is similar to that required for partial transverse glossectomy. The frenulum, if involved in the incision, should be reattached ventrally with mattress sutures.

Subtotal and Near Total Glossectomy

Subtotal glossectomy involves excision of the entire free tongue and a portion of the genioglossus, the geniohyoid muscles, or both, caudal to the frenulum. A near total glossectomy refers to resection of at least 75% of the entire tongue.[2] The principles

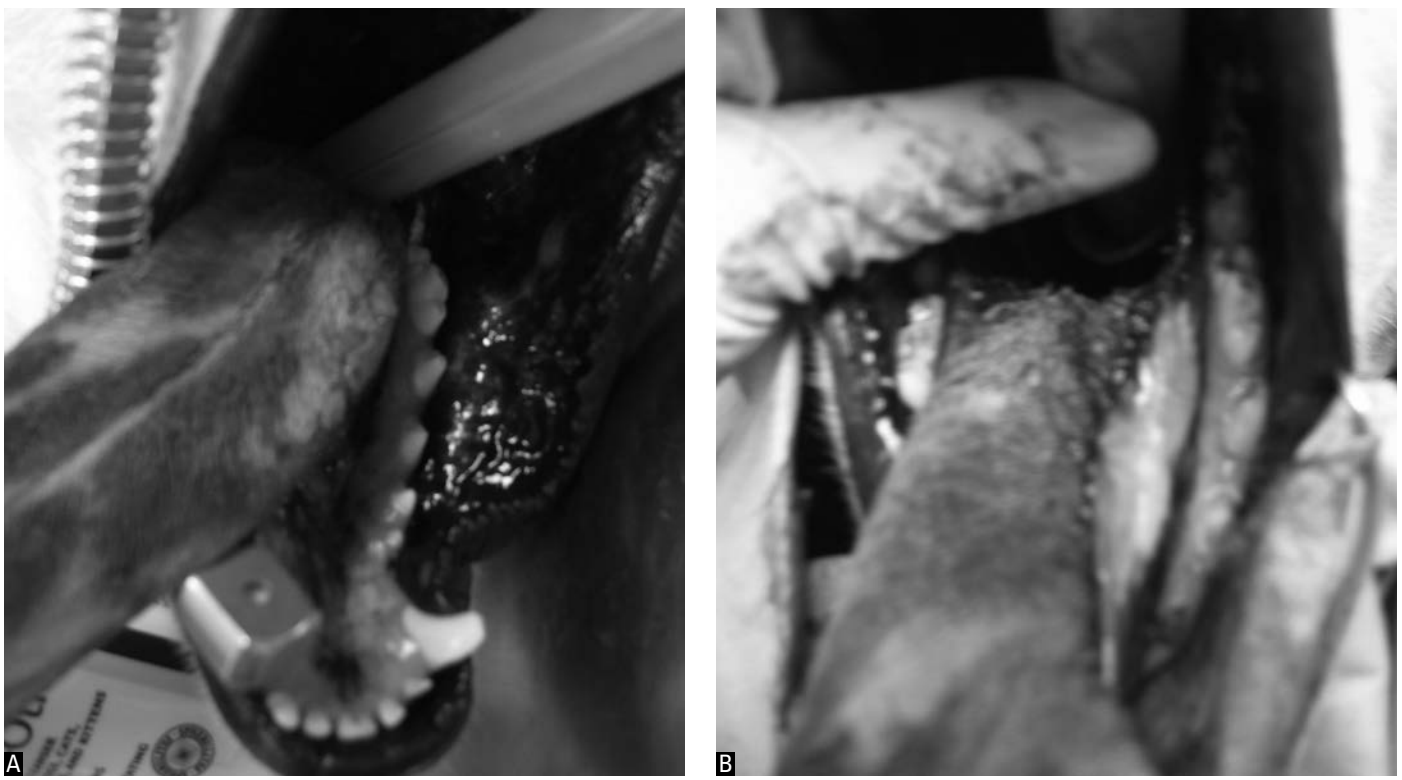


Figure 14-28. A. Preoperative view of a squamous cell carcinoma on the caudolateral aspect of the tongue of an 8-year-old castrated male mixed breed dog. **B.** Postoperative view of the tongue identified in Figure 14-29A, after partial glossectomy.

of hemorrhage control and mucosal apposition described for partial glossectomy should be followed for subtotal and near total glossectomies. Sutures are preplaced through the body of the tongue and the lingual arteries dissected and ligated to prevent excess hemorrhage. Mucosal apposition can be performed with either a simple interrupted or a simple continuous suture pattern using monofilament absorbable suture. Any remaining frenulum should be reattached ventrally to the tongue with mattress sutures (Figure 14-29).

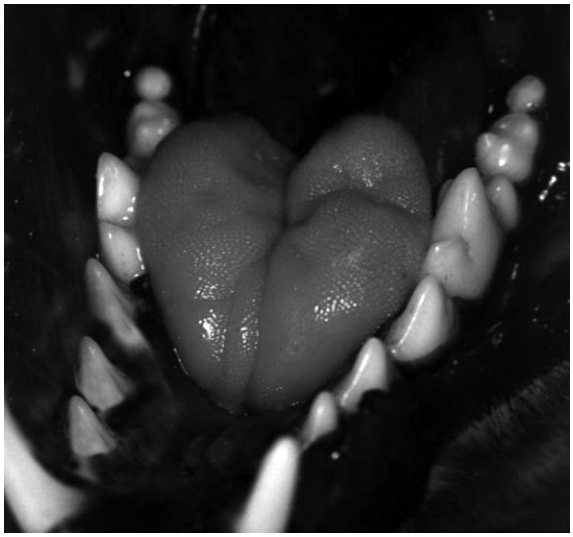


Figure 14-29. Gross appearance of a 5-year-old castrated male Schnauzer 2 years after subtotal glossectomy for chronic glossitis.

Total Glossectomy

A total glossectomy involves amputation or excision of the entire tongue. The only remaining tissue in these cases is the mucosa lining the ventral mandibular floor. If possible this mucosa should be apposed with a simple continuous suture pattern. Hemorrhage should be controlled by ligation of all bleeding vessels, especially the lingual arteries. Dogs are able to learn glutition without a tongue however self-grooming is impossible thus owners should regularly groom the animal to maintain the animal's hair coat.

Postoperative Care and Complications

Analgesics and parenteral fluids are indicated for the first 24 hours postoperatively. The duration of analgesic and fluid therapy depends upon the extent of glossectomy. Antibiotics, if administered are indicated for 24 hours after the surgical procedure and then discontinued unless treating bacterial glossitis. An Elizabethan collar or basket muzzle is often necessary to prevent self-induced trauma to the surgical site. Food and water should not be offered for the first 12 to 24 hours after the procedure. For patients with an esophagostomy or PEG tube, feedings can begin as soon as possible based on tube placement. Patients undergoing major glossectomies (subtotal, near-total, and total glossectomies) may require training to be able to eat effectively orally. Previous reports suggest that chilled meatballs formed from canned dog food can be used to teach the patient how to pick-up the food and move it to the back of their mouths. The patient's muzzle may need to be elevated once the meatball is placed in their mouth to assist in food prehension and swallowing. Once the patient has learned how to pick up and swallow a meatball on their own, they can be encouraged to drink water by placing the meatball in a bowl of water. This will allow them to adapt to having their muzzles under water. Many dogs in previous case reports ultimately learned how to suck in water like a vacuum.[2] Cats are likely to have greater difficulty with prehension following glossectomy and will often require long-term or permanent assisted feeding with a feeding tube.

The surgical incision closure should be monitored for evidence of dehiscence and should be kept clean of food and debris by rinsing the mouth with water daily. Healing of the tongue is generally rapid due to its extensive vascularity. Lateral deformation of the tongue can occur with partial glossectomies, especially wedge recession. Hyperptyalism is a commonly reported complication in human glossectomy patients and has been reported in canine glossectomy patients but the incidence remains unknown.[2,5,6] Complications related to esophagostomy and PEG tubes are a potential and are described elsewhere.

Lip and Cheek

The lips and cheek have an extensive vascular supply with significant collateral circulation. Arterial blood supply to the maxillary lip and cheek is provided by the infraorbital artery which is a direct branch of the maxillary artery. The mandibular lip and cheek are supplied by the mandibular alveolar and facial arteries. This rich blood supply can be used to construct broad based mucogingival advancement or rotation flaps for reconstruction of defects associated with the maxillary and mandibular arcade. These flaps are often required to close defects created following surgical excision of oral tumors and repair of congenital or traumatic defects.[7]

Anatomy

The lips form the rostral and lateral boundaries of the vestibule. The mandibular and maxillary labia meet caudally at an angle, forming the commisure. The philtrum is the deep cleft at the rostral midline union of the maxillary labia. The mandibular labia have firm attachments of the buccal mucosa between the mandibular canine and first premolar. This interdental attachment maintains the position of the mandibular labia and prevents sagging.[8] The cheeks are histologically similar to the lips and are continuous with them. Both have two epithelial surfaces, an outer dermis and an inner mucosa. Between these two layers are two thin muscles, the outer orbicularis oris muscle and the inner buccinator muscle.[8] Other cheek muscles include the platysma, mental buccinator, zygomatic, canine, nasolabial and incisive muscles.[9] Innervation is provided by the facial nerve (motor) and trigeminal nerve (sensory).[9]

Surgical Techniques

Limited information exists in the veterinary literature regarding surgical procedures of the lips and cheek. Information is available regarding surgical treatment of traumatic lip avulsions, reconstructive procedures for maintenance of the lip margin following tumor excision, correction of "tight lip syndrome" in Shar Pei's, anti-drool procedures (cheiloplasty), tissue excision for lip fold dermatitis, surgical correction of dental arcade mucoperiosteal

defects, reconstructive procedures of the eyelid margins and surgical repair of primary cleft palates.

Lip avulsion injuries are generally associated with the rostral mandibular lip and are the result of a shearing injury. Shearing force causes avulsion of the gingival mucosa from its area of insertion on the rostral mandibles just ventral to the incisors. Surgical correction of lip avulsion involves debridement of any devitalized tissue and reattachment of the mandibular skin at the gingival line of the incisors. This can be accomplished by taking large bites of tissue from the avulsed lip with polydioxanone suture and subsequent passage of the suture through holes drilled in the rostral mandible or by encircling the mandibular incisors. Because of the rich blood supply, tissue healing is generally uncomplicated provided appropriate surgical debridement is performed prior to reattachment of the lip.

Lip Margin Reconstruction

Several techniques exist for excision of lip neoplastic lesions and for closure of the resulting defects. In all cases, the mucosa should be anatomically apposed if possible to assure proper cosmetic alignment of the lip. This alignment should be achieved without undue tension on the suture line so that normal function of the jaw is maintained. Full-thickness triangular or wedge resection of the lip allows realignment of the mucosal and lip edges however, the tissue margins obtained with this excision may be inadequate for malignant neoplasms. Full-thickness square or rectangular resection can be performed to obtain a wider tissue margin. The defect created with this technique can be closed in a "Y" fashion or with a full-thickness labial advancement flap (Figures 14-30A-D). Labial advancement or rotational flaps can be mobilized from either the upper or lower lips.

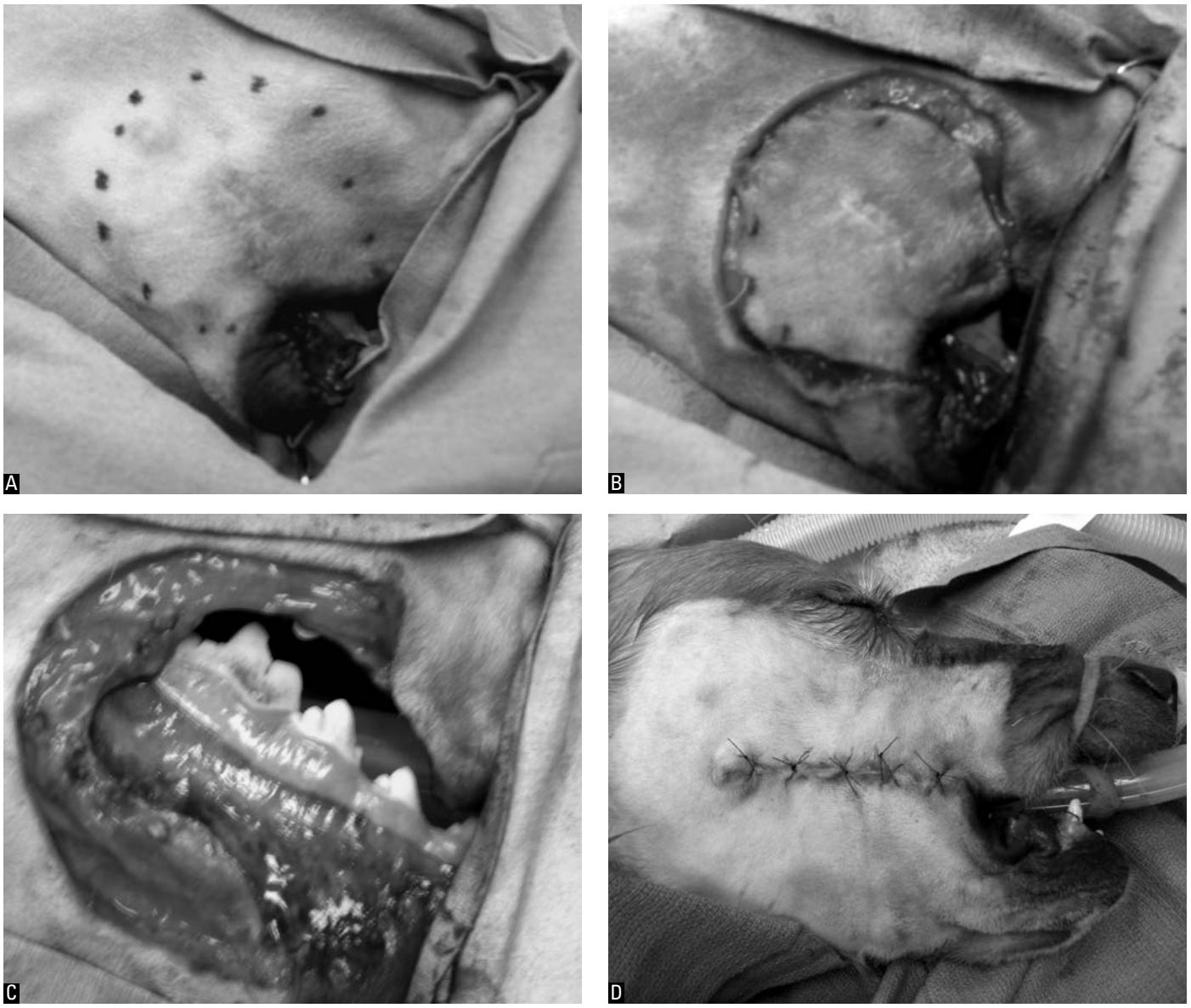


Figure 14-30. A. Preoperative view of a 3-year-old Golden retriever with an incompletely excised grade II mast cell tumor of the cheek. **B.** Intraoperative view of the dog identified in Figure 14-30A with 2 centimeter margins indicated on all sides of the prior incision. **C.** Intraoperative view of the dog identified in 14-30A after complete full thickness labial excision of the mast cell tumor. **D.** Postoperative view of the dog identified in Figure 14-30A after three-layer closure of the surgical defect.

These pedicles are supplied by the superior or inferior labial arteries and veins.[10,11] It is important that lip defects be closed in a two or three-layer closure of the mucosa, fascia and skin. The initial suture should be placed at the labial margin to avoid defects in the lip margin. The mucosal layer is apposed first in either a simple interrupted or simple continuous fashion using absorbable suture. If a muscular fascial plane is present, closure of this tissue with absorbable suture will reduce tension on the defect. Finally, the dermis is apposed.

In the "tight lip syndrome" of Shar Pei's the rostral mandibular skin curls dorsally over the mandibular incisor and canine teeth and can interfere with normal mastication. This condition is best treated at an early age (3 months) as the restriction in jaw movement can interfere with normal development of the mandible. Surgery involves incision of the mandibular skin attachment at the mucogingival junction from the incisors extending to the first premolar bilaterally. The mandiblar skin and its attachments to the mandible are periosteally elevated allowing the mandibular skin to displace ventrally.[12] The wound created is allowed to heal by second intention. As the wound heals, it is important for the veterinarian or owner to digitally break down any adhesions of tissue that may cause adherence of the skin in a restrictive position.[12]

Anti-drool cheiloplasty procedures are most commonly performed on large or giant breed dogs such as Newfoundlands. The goal of surgery is to redirect saliva to the caudal aspect of the oral cavity. The procedure is simple to perform and involves a mucosal and submucosal incision in the buccal surface of the mandibular and maxillary cheek. The mandibular incision is made several centimeters rostral to the oral commisure in the freely moveable gingiva of mandibular cheek. The lower incision is then apposed to a corresponding maxillary incision and the two mucosal edges sutured.[13] The apposition of these two surfaces creates a channel that redirects saliva into the caudal oral cavity where it is swallowed (Figures 14-31A-E).

Lip fold dermatitis and pyoderma is seen in animals with abnormal lip skin confirmation. Redundant folds of mandibular lip skin entrap moisture and saliva creating a local environment conducive to bacterial overgrowth. Spaniel breeds, St. Bernards, and Newfoundlands are breeds commonly affected. Antibiotics are not effective in the long-term resolution of clinical signs. The goal of surgery is to resect redundant folds of mandibular lip tissue while maintaining a normal range of motion in the oral cavity. The affected inflamed or infected tissue is excised longitudinally and the wound closed with simple interrupted sutures (Figure 14-32).

Full thickness rotational flaps based on the lateral maxillary cheek to reconstruct the lower eyelid margins following surgical resection of periocular neoplasms have been previously described in dogs and cats. By transferring the lip margin the lower eyelid margin can be functionally reconstructed.[14,15] Special attention is paid to exact apposition of the reconstructed lip and eyelid margins for functional and cosmetic reasons. It is also important to not excessively rotate the skin flap potentially compromising the subdermal plexus blood supply.

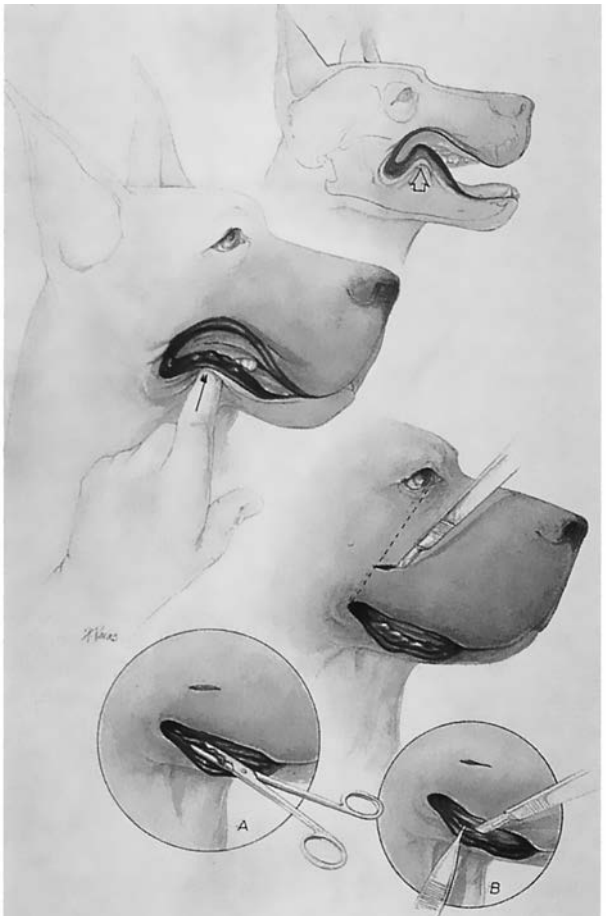


Figure 14-31A. The lower lip, 2 to 3 cm rostral to the commisure, is digitally elevated until the lip is taut when the mouth is fully opened to mark the dorsal extent of the horizontal cheek incision. A full-thickness horizontal cheek incision is completed. The caudal aspect of the incision intersects a line drawn from the medial canthus to the commisure (*dotted line*). *A.* A 2.5-cm long mucocutaneous border is excised from the lower lip. *B.* The incised edge of the lower lip is split in half to form a cutaneous and a mucosal flap.

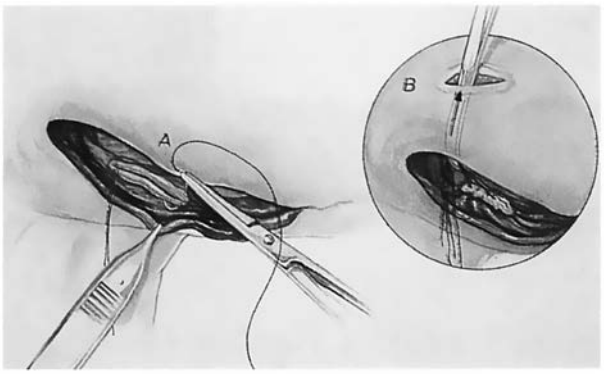


Figure 14-31B. *A.* Stay sutures are placed in the rostral and caudal aspects of the lower lip incision. *B.* The lower lip flaps are pulled through the cheek incision with the stay sutures. From Smeak DD: Antidrooling cheiloplasty clinical results in 6 dogs. J Am Anim Hosp Assoc 25:181, 1989.

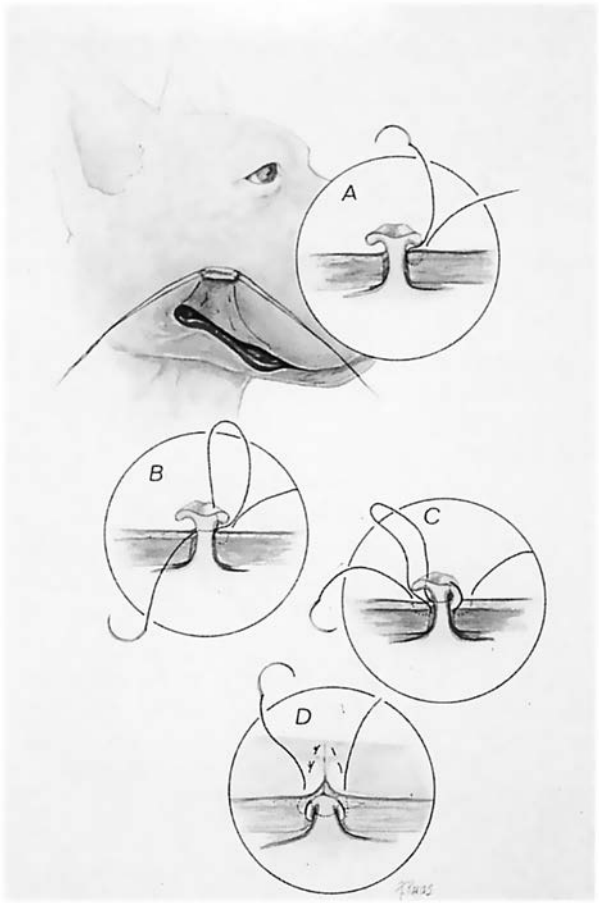


Figure 14-31C. The incised edges of the lower lip and cheek are apposed with horizontal mattress sutures. The needle is passed split thickness through the cheek into the incision *A.* then through the mucosal flap, through the base of the lower lip *B,* up through the cutaneous flap, and finally through the opposite side of the cheek *C.* The needle is reversed and passed through in an opposite direction to complete the pattern. *D.* Two or three mattress sutures appose the lip flaps to the cheek. From Smeak DD: Antidrooling cheiloplasty clinical results in 6 dogs. J Am Anim Hosp Assoc 25:181, 1989.

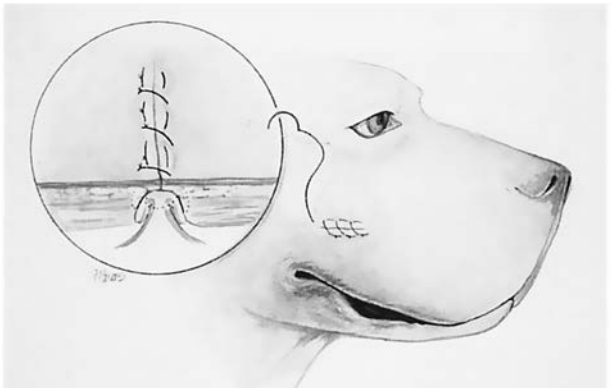


Figure 14-31D. Cheek skin is closed with interrupted sutures to complete the antidrool cheiloplasty. From Smeak DD: Antidrooling cheiloplasty clinical results in 6 dogs. J Am Anim Hosp Assoc 25:181, 1989.

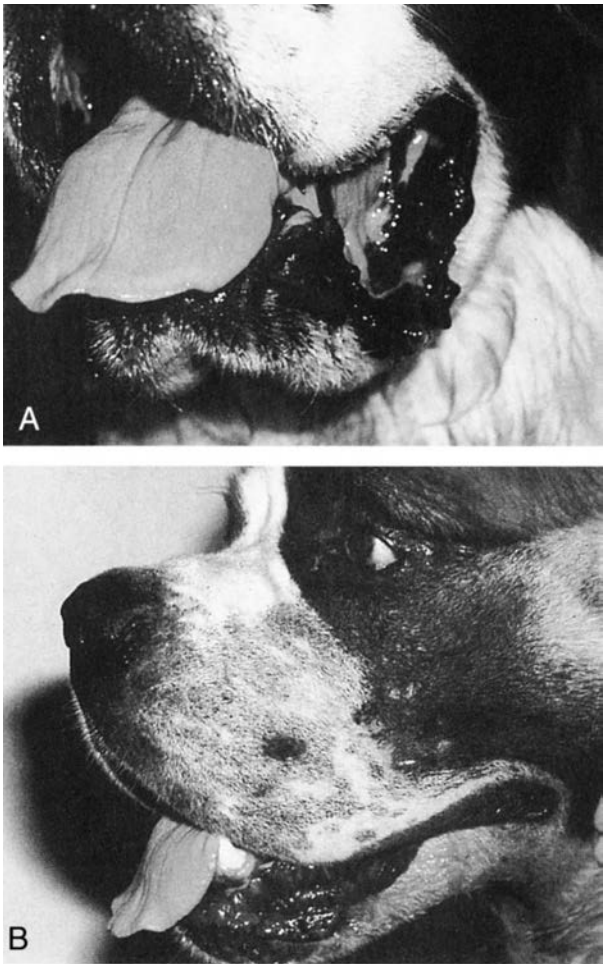


Figure 14-31E. Gross appearance of a patient before and after antidrool cheiloplasty (ADC). *A.* Preoperative appearance. *B.* Appearance after suture removal 24 days after bilateral ADC was performed. Notice the draining wounds around the upper lip incision.



Figure 14-32. Gross appearance of a patient 2 weeks postoperative after a cosmetic cheiloplasty performed following a hemimandibulectomy.

In dolicocephalic breeds following unilateral mandibulectomies, cheiloplasty procedures may be beneficial to maintain the tongue within the oral cavity for cosmetic reasons and to prevent excessive drooling. This is accomplished by performing a full-thickness lip margin excision along the ventral and dorsal borders of the oral commisure. The mandibular and maxillary cheek is then apposed in three layers. Absorbable suture material is used for the buccal mucosa in a simple continuous or interrupted pattern. The deep muscular layer is closed similarly to the mucosa and skin sutures are used for skin apposition. Specific attention must be paid to establishing a balance between restriction of the tongue into the oral cavity and interference with normal eating. (See Figure 14-31).

Postoperative Care and Complications

The specifics of post-operative care following surgery of the lips and cheek are dependent on the site of operation. In all animals, activities such as pulling ropes and chewing bones, sticks and rawhides should be avoided until tissue healing is complete. An Elizabethan collar may be required to prevent self-trauma of the incision. Animals are typically fed a soft diet for two weeks following surgery while tissues heal. During surgery specific attention is paid to prevent excessive restriction of opening of the mouth during resection of lip and cheek tissues. If opening of the mouth is significantly limited because of the necessity to remove large portions of the caudal lip margin a nylon or tape muzzle may be beneficial to protect the surgical site for 3 to 4 weeks following surgery. Another option is suturing buttons along the incision for tension relief. After this time the tissue should be strong enough to tolerate the normal stresses associated with movement of the oral cavity.

References

1. Dorn CR, Priester WA: Epidemiologic analysis of oral and pharyngeal cancer in dogs, cats, horses, and cattle. *J Am Vet Med Assoc* 169(11): 1202, 1976.

2. Dvorak LD, Beaver DP, Ellison GW, et al.: Major glossectomy in dogs: a case series and proposed classification system. *J Am Anim Hosp Assoc* 40(4):331, 2004.

3. Dunning D: Tongue, lips, cheeks, pharynx, and salivary glands. *In*: Slatter D, ed.: Textbook of Small Animal Surgery. Philadelphia: WB Saunders, 2003, 553-561.

4. Harvey CE: Small Animal Denistry. St Louis: Mosby Yearbook, 1993, 301-303.

5. Neverlien PO, Sorumshagen L, Eriksen T, *et al.*: Glycopyrrolate treatment of drooling in an adult male patient with cerebral palsy. *Clin Exp Pharmacol Physiol* 27(4): 320, 2000.

6. Olsen AK, Sjorgren P: Oral glycopyrrolate alleviates drooling in a patient with tongue cancer. *J Pain Symptom Manage* 18(4): 300, 1999.

7. Luskin IR: Reconstruction of Oral Defects using Mucogingival Pedical Flaps. *Clin Tech Small An Prac* 15(4):251, 2000.

8. Pavletic MM: Reconstructive surgery of the lips and cheek. *Vet Clin North Am* 20: 201, 1990.

9. Grandage J. Functional anatomy of the digestive system. In: Slatter D, ed.: Textbook of Small Animal Surgery. Philadelphia: WB Saunders, 2003, 499.

10. Pavletic MM: Plastic surgery of the head. *Proc Am Anim Hosp Assoc* 1987, pp.392397.

11. Smeak DD: Lower labial pedicle rotation flap for reconstruction of large upper lip defects. *J Am Anim Hosp Assoc* 28: 565, 1992.

12. McCoy DE: Surgical treatment of the tight lip syndrome in the Shar-Pei dog. J Vet Dent 14: 95, 1997.

13. Smeak DD: Anti-drool cheiloplasty: Clinical results in six dogs. *J Am Anim Hosp Assoc* 25: 181, 1989.

14. Hunt GB: Use of Lip-to-Lid Flap for Replacement of the Lower Eyelid in Five Cats. *Vet Surg* 35: 284, 2006.

15. Pavletic MM, Nafe LA, Confer AW: Mucocutaneous subdermal plexus flap from the lip for lower eyelid restoration in the dog. *J Am Vet Med Assoc* 180: 921, 1982.

Chapter 15

Pharynx

Cricopharyngeal Dysphagia

Eberhard Rosin

Cricopharyngeal dysphagia, although an uncommon condition, is considered in the differential diagnosis of persistent dysphagia of young dogs. This condition is characterized by inadequate or asynchronous relaxation of the cricopharyngeal sphincter that prevents the normal movement of food from caudal portions of the pharynx into the cranial esophagus. The etiologic basis of this failure of reflex relaxation has not been established. Dogs with cricopharyngeal dysphagia usually have a history of dysphagia persisting since weaning. Attempts to swallow solid food result in anxiety, gagging, and expulsion of food from the mouth by forward movements of the tongue. After repeated ingestion of the masticated food, the entire meal passes into the stomach.

Diagnosis

Except for slight nasal exudate and occasional coughing, physical examination reveals no abnormality. Examination of the pharynx reveals no inflammatory or obstructive lesions. While the patient is under anesthesia, an esophagoscope can be passed into the stomach without difficulty. The resting pressure provided by the closed sphincter, as encountered by passage of the endoscope and as measured by manometry, is normal.

Radiographs of a barium swallow study reveal contrast material remaining in the pharynx. In some dogs, barium is aspirated into the lungs. Fluoroscopic examination of a barium swallow demonstrates normal movement of the barium bolus into the oropharynx by elevation of the tongue and contraction of the pharyngeal musculature. Despite the presence of sufficient force to distend the caudal pharyngeal wall, inadequate or asynchronous relaxation of the cricopharyngeal sphincter prevents normal movement of the barium bolus into the proximal esophagus. The thin stream of barium that passes through the sphincter moves into the stomach with no evidence of failure of reflex relaxation of the gastroesophageal sphincter. This cycle is repeated in rapid succession until all the barium is swallowed. As the epiglottis, which closes the glottis in normal fashion during swallowing attempts, opens during inspiration, the residual barium filling the caudal pharyngeal region may be aspirated into the trachea and discharged by coughing.

Immediate relief of the dysphagia is achieved by cricopharyngeal myectomy. Complete division of muscle fibers of the cricopharyngeal muscle is essential for permanent elimination of the condition.

Technique for Cricopharyngeal Myectomy

The dog is anesthetized, intubated, and placed in dorsal recumbency. A midline incision is made from the cranial aspect of the larynx to the thoracic inlet. Exposure of the trachea and esophagus is by midline dissection of the ventral neck musculature. Partial incision of the insertion of fibers of the sternohyoid muscle on the basihyoid bone may be necessary. The bisected sternohyoid muscle is retracted to expose the trachea. Dissection is continued to the left of the trachea by transection of the insertion of the left sternothyroid muscle to the lateral surface of the thyroid lamina. The left thyroid gland is exposed between the trachea and the sternothyroid muscle. Several small branches of the cranial thyroid artery that supply the upper aspect of the left thyroid gland are ligated and transected (Figure 15-1). The left recurrent laryngeal nerve should be preserved.

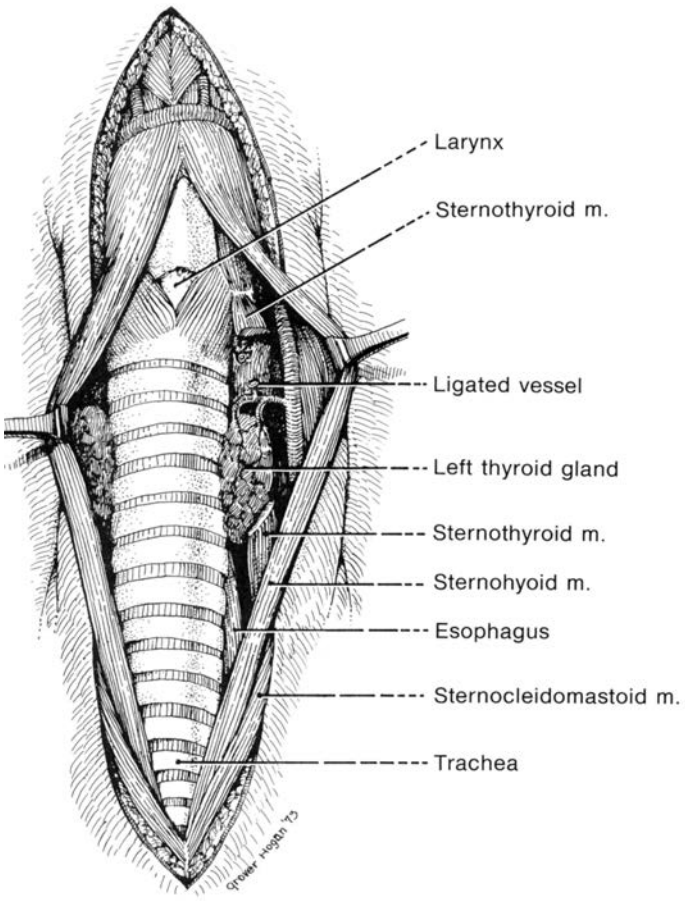


Figure 15-1. Mobilization of the leftside of the trachea and the cranial esophagus.

The cricopharyngeal muscle and dorsal proximal esophagus can be exposed by grasping the larynx and rotating it. The cricopharyngeal muscle can be identified as a bundle of transverse muscle fibers converging on the dorsal midline and blending into the longitudinal muscle fibers of the cranial esophagus. Two parallel incisions, approximately 2 mm apart, are made on the dorsal midline through the cricopharyngeal muscle and onto the cranial esophageal musculature (Figure 15-2). The esophageal mucosa is not incised. The incised muscle fibers are separated from the mucosa and are excised. Bleeding is controlled by use of gauze and pressure; the myectomy is not sutured.

Closure of the incision is initiated by apposition of the sternohyoid muscle with simple interrupted 3-0 absorbable sutures. Suturing the transected insertion of the sternothyroid muscle is not necessary. The subcutaneous tissue and skin are sutured routinely. Although other tissue planes that were separated for exposure are not sutured, seroma formation is uncommon.

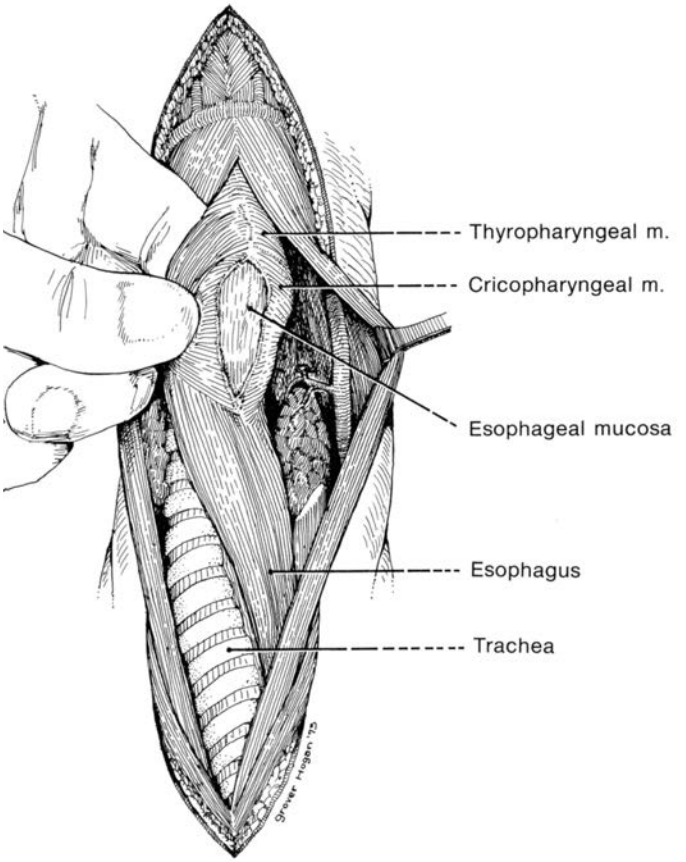


Figure 15-2. Myectomy through the length and thickness of the cricopharyngeal and the cranial esophageal musculature. The esophageal mucosa is not incised.

Postoperative Care

No special postoperative care is required. Patients tolerate solid food the day after the operation. Recurrence of dysphagia because of fibrosis and constriction at the myectomy site is prevented by adequate removal of sphincter muscle fibers during the original surgical procedure.

Editors Note: Suspicion of Cricopharyngeal dysphagia should prompt the primary care veterinarian to refer the case to a specialist. Fluroscopic contrast swallowing studies are indicated to properly diagnose this uncommon condition prior to any surgical intervention.

Suggested Readings

Hurwitz A L, Duranceau A. Upper esophageal sphincter dysfunction: pathogenesis and treatment. Am J Digest Dis 1978;23:275.

Lund WS. The functions of the cricopharyngeal sphincter during swallowing. Acta Otolaryngol (Stockh) 1965;59:497.

Pearson H. The differential diagnosis of persistent vomiting in the young dog. J Small Anim Pract 1970; 11:403.

Rosin E, Hanlon GF. Canine cricopharyngeal achalasia. J Am Vet Med Assoc 1972;160:1496.

Seaman WB. Functional disorders of the pharyngoesophageal junction. Radiol Clin North Am 1969,11:113.

Sokolovsky V. Cricopharyngeal achalasia in a dog. J Am Vet Med Assoc 1967:150:281.

Suter PF, Watrous BJ. Oropharyngeal dysphagias in the dog: a cine-fluorographic analysis of experimentally induced and spontaneously occurring swallowing disorders. I. Oral stage and pharyngeal stage dysphagias. Vet Radiol 1980:21:24.

Warnock JJ, Marks SL, Pollard R, et al: Surgical management of cricopharyngeal dyspahgia in dogs: 14 cases (1989-2001), J Amer Anim Hosp Assoc 223 (10): 1462-1468,2003.

Otopharyngeal/Otic Polyps in Cats

Jacqueline R. Davidson

Introduction

Otopharyngeal polyps, also termed nasopharyngeal polyps or inflammatory polyps, are benign pedunculated growths that arise from the oropharyngeal mucous membranes. The polyp stalk may originate from the nasopharynx, the auditory canal, or the tympanic cavity.[1,2] The polyp may grow into the nasopharynx or tympanic cavity or both. The mucosal lining from the nasopharynx to the tympanic cavity is continuous and histologically similar, so it is difficult to identify the origin of polyps. Polyps are composed of variable amounts of submucosal lymphocytic plasmacytic cellular infiltration with fibroplasia and the epithelium ranges from stratified squamous to ciliated columnar cells.[2,3]

The exact cause of the polyps is unknown. The presence of submucosal inflammatory cells suggests that polyps may arise from infection or chronic inflammation. Polyps are also associated with rhinitis or otitis media, suggesting a viral or bacterial etiology. However, any potential role played by infectious agents remains unclear and it may be that the etiology is multifactorial.[4] Because polyps have been identified in very young kittens, a congenital origin has also been suggested.[5,6]

Otopharyngeal polyps occur in cats of any age, although these animals are often less than two years old and may be seen in kittens as young as 4 weeks of age.[1,5,7,8] There is no apparent sex or breed predisposition. Although polyps are most commonly unilateral they can be bilateral. Polyps have also been reported in dogs, but are less prevalent than in cats.[9-11]

Clinical signs may be present for weeks to years before a polyp is diagnosed, and the signs vary depending on polyp location.[3,12] Polyps in the nasopharyngeal region may cause obstruction resulting in respiratory stridor, dyspnea, dysphagia, or voice changes.

Respiratory distress, cyanosis and syncopal episodes may also occur. Nasopharyngeal polyps may cause signs of upper respiratory tract infection such as sneezing, coughing, and nasal or ocular discharge. The respiratory signs may be mildly responsive

to symptomatic treatment if a secondary bacterial infection is present. Polyps in the external or middle ear may be visible in the external canal and may be associated with infection or cause signs that mimic otitis externa, otitis media, or otitis interna. These signs include head shaking, ear scratching, head tilt, Horner's syndrome, and nystagmus. Ability to hear may be diminished in the affected ear,[13] although this may not be clinically apparent. Any cat with chronic upper respiratory tract disease should be evaluated for polyps. The differential diagnoses include upper respiratory tract infections such as feline calicivirus and feline rhinotracheitis virus, nasal foreign bodies, and nasopharyngeal masses such as cryptococcal granuloma and neoplasms.

In dogs, inflammatory polyps tend to occur in the middle ear rather than the nasophayrngeal region, and they present with clinical signs of otitis media, otitis externa, or bleeding from the external ear canal.[10] The differential diagnoses for signs related to the ear include neoplasia and otitis externa, media, or interna.

Preoperative Considerations

A thorough physical exam should be performed, including complete otoscopic and oropharyngeal evaluations. Polyps may rupture through the tympanic membrane and appear in the external ear canal. Examination of the external ear canal may reveal signs of otitis externa with a visible pink, red or grey, spherical mass occluding the canal. The surface is often smooth and glistens, due to the mucosa that covers the surface. An otoscope or video-otoscope may be needed to visualize a polyp that is causing the tympanic membrane to bulge, or has perforated the membrane and is protruding into the external auditory canal. If the history and physical findings are suggestive of a pharyngeal mass, sedation or general anesthesia is necessary to perform a thorough oral examination. Inspection of the oral cavity may reveal ventral displacement of the soft palate. The nasopharynx can be evaluated by retracting the caudal edge of the soft palate rostrally using a spay hook or stay suture. The nasopharynx can also be visualized by use of a flexible fiberoptic bronchoscope.

Skull radiographs should be performed with the cat under general anesthesia, with particular attention paid to the nasal cavity and middle ear. A nasopharyngeal polyp may be identified as a soft tissue density in the nasopharynx on the lateral radiographic view. Ventrodorsal, oblique lateral, and frontal open-mouth views are recommended to evaluate the osseous and tympanic bulla and petrous temporal bones. Thickening or sclerosis of the osseous bulla and sclerosis of the petrous-temporal bone indicate chronic middle ear involvement. The tympanic bulla may be best evaluated for increased soft tissue density using frontal open-mouth and lateral oblique radiographic views of the skull. Increased soft tissue density may also be seen within the external canal if a polyp is located there. Most cats with polyps have radiographic changes compatible with middle ear infection.

However, radiographic evaluation is not a highly sensitive method for diagnosing otitis media so a high level of suspicion for otitis media should be maintained in cats diagnosed with otopharyngeal polyps even with a lack of radiographic evidence.[2,14] Compared to skull radiographs, both computed tomography and magnetic resonance imaging provide more accurate assessment of soft tissue opacities and changes in the osseous bulla.

Surgical Technique

The treatment of choice is a ventral bulla osteotomy performed on the side associated with the polyp, along with polyp extraction. Regardless of whether the polyp is in the external ear canal or the nasopharynx, a ventral bulla osteotomy should be performed before removing the polyp to facilitate removal of inflammatory tissue and detachment of the pedicle.

Performance of a ventral bulla osteotomy is associated with a lower incidence of otic and possibly nasopharyngeal polyp recurrence, supporting the idea that polyps may originate in the middle ear.[1,2] A bulla osteotomy is recommended even if there is no evidence of bulla abnormalities on the diagnostic images.

To perform a ventral bulla osteotomy, the cat is placed in dorsal recumbency with the head and neck extended. The ventral wall of the tympanic bulla can usually be palpated between the angular process of the mandible and the larynx. A paramedian skin incision is made over the bulla beginning near the angle of the mandible and extending about 6 cm caudally, where the linguofacial vein may be identified. The incision is continued through the subcutaneous tissues and cutaneous muscles. Blunt dissection between the digastric muscle laterally and the hyoglossal and styloglossal muscles medially exposes the bulla, which is palpable cranial to the hyoid apparatus. The hypoglossal nerve, and the lingual artery and vein may be identified on the hyoglossal muscle and are retracted medially. The ventral branch of the external carotid artery is located lateral to the bulla. Self-retaining retractors may be used to maintain exposure, with care taken to avoid the hypoglossal nerve and the vessels. Connective tissue and periosteum is bluntly dissected off the ventral aspect of the bulla using a periosteal elevator. A Steinmann pin is used to create a hole in the ventral bulla. The hole should be large enough to accommodate one jaw of a small rongeurs. The ventral aspect of the bulla is then removed with the rongeurs.

The middle ear of the cat contains a septum that divides the bulla into a small dorsolateral and a larger ventromedial compartment.[15,16] This septum must be removed to gain access to the dorsolateral compartment of the bulla, where the external auditory meatus and the auditory os of the Eustachian tube are located (Figure 15-3). Removal of the septum is performed as described for removal of the ventral bulla. Both compartments of the bulla should be cultured. The bulla should undergo careful inspection and gentle curettage to remove the epithelial lining and any granulation tissue. Aggressive curettage or direct suctioning of the dorsomedial aspect of the bulla should be avoided to reduce the risk of damaging the postganglionic sympathetic nerve fibers, auditory ossicles, semicircular canals, and cochlea. Damage to these structures can result in Horner's syndrome and otitis interna. Any tissue removed from the bulla should be submitted for histologic evaluation. Before closing, the bulla is lavaged with sterile saline. Placement of a surgical drain is probably not necessary, but if one is used it should be placed to exit through a separate stab incision. A closed suction drain may be constructed by cutting the end from a butterfly infusion set[a] and creating several fenestrations in the tubing. Once the drain has been placed in the bulla and the wound has been closed, the needle is inserted into a vacutainer tube to provide

[a]E-Z Set. Becton Dickinson. Sandy, Utah

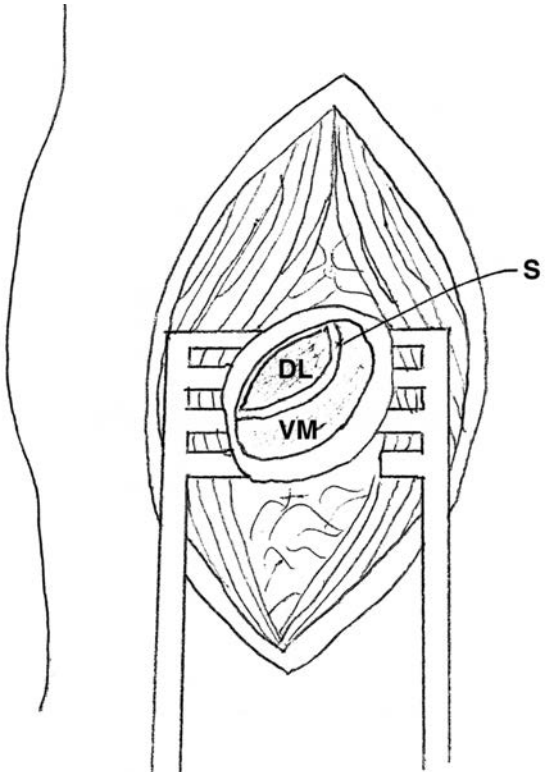


Figure 15-3. Feline bulla. The ventral aspect of the bulla has been removed to gain access to the large ventromedial compartment *(VM).* The ventral aspect of the septum *(S)* has also been removed to gain access to the dorsolateral compartment *(DL).*

suction. This system is preferable to a Penrose drain because the quantity and character of the drainage can be easily monitored. The cutaneous muscles and subcutaneous tissues are sutured with 3-0 or 4-0 absorbable suture material in a simple continuous pattern. The skin may be closed using 4-0 absorbable suture material in a simple continuous intradermal pattern or using 4-0 nylon for external skin sutures. The drain should be sutured to the skin to prevent premature removal, and a bandage is placed around the head to stabilize the vacutainer tube. The vacutainer should be replaced twice daily to ensure it is providing negative pressure. The drain is removed when fluid production is, minimal which is usually within 3 to 7 days. If a Penrose drain is used, it is necessary to cover it with a bandage that is changed daily to monitor any drainage. The skin sutures may be removed 7 to 10 days postoperatively.

Simple traction using an Allis tissue forceps or alligator forceps is usually sufficient to remove the polyp. Hemorrhage is usually minimal and may be controlled by direct pressure. If the polyp is visible in the external canal, it may be extracted by traction after performing a ventral bulla osteotomy. A lateral ear canal resection may be performed to improve exposure, but is rarely necessary. Nasopharyngeal polyps can be removed by traction, using an oral approach. Endoscopy may provide better visualization of the nasopharyngeal region,[17] but is typically not necessary. Retraction of the soft palate rostrally with a spay hook usually provides adequate exposure. If necessary (rarely), exposure may be increased by making a longitudinal incision on the midline of the soft palate (Figure 15-4).



Figure 15-4. A midline incision has been made in the soft palate to improve exposure of a feline nasopharyngeal polyp.

Stay sutures may be used to retract the palate while the polyp is being removed. A three-layer closure is performed on the palate by suturing the nasal mucosa, submucosal tissue and oral mucosa separately using 4-0 or 5-0 absorbable suture material in a simple continuous pattern. The polyp should be submitted for histologic evaluation to confirm the diagnosis.

Surgical complications are related to the ventral bulla osteotomy, and the most common is damage to the postganglionic sympathetic nerve fibers, resulting in Horner's syndrome which is characterized by miosis, ptosis, enophthalmus and prolapse of the third eyelid (Figure 15-5). It usually resolves within one month, although it may be permanent.[2,8] Horner's syndrome is a rare complication in dogs, probably reflecting anatomical differences in the tympanic bulla between dogs and cats. Damage to the round and oval windows or vestibulocochlear apparatus result in vestibular disturbances, which include head tilt, ataxia, and nystagmus. Nystagmus usually resolves within 24 hours, but head tilt or ataxia may persist.[14,16] Damage to the hypoglossal nerve is less common, and results in deficits of swallowing, prehension, and mastication. Facial nerve paralysis has also been reported.[2,3] Deafness is not a reported complication of ventral bulla osteotomy. However, cats who are deaf prior to surgery may not be improved by it.[13]

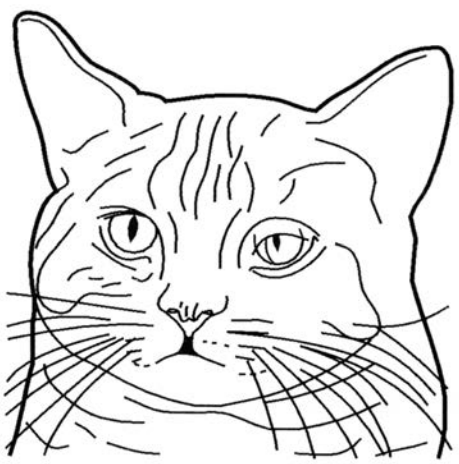


Figure 15-5. A cat with Horner's syndrome after ventral bulla osteotomy. Miosis, ptosis, enophthalmos, and prolapse of the third eyelid are present.

The prognosis is good with complete excision, but recurrence of the polyp may occur from months to years postoperatively.[3,12] Recurrence is less common when surgical removal is combined with bulla osteotomy.[2,14,16] Recurrence is less common for nasopharyngeal polyps than for aural polyps, even if removed by traction with no bulla osteotomy.[19]

References

1. Bradley RL, Noone KE, Saunders GK, et al. Nasopharyngeal and middle ear polypoid masses in five cats. Veterinary Surgery 1985;14:141-144.

2. Kapatkin AS, Matthiesen DT, Noone KE, et al. Results of surgery and long-term follow-up in 31 cats with nasopharyngeal polyps. Journal of the American Animal Hospital Association 1990;26:387-392.

3. Lane JG, Orr CM, Lucke VM, et al. Nasopharyngeal polyps arising in the middle ear of the cat. Journal of Small Animal Practice 1981;22:511-522.

4. Klose TC, MacPhail CM, Schultheiss PC, et al. Prevalence of select infectious agents in inflammatory aural and nasopharyngeal polyps from client-owned cats. Journal of Feline Medicine and Surgery 2010;12:769-774.

5. Brownlie SE, Bedford PGC. Nasopharyngeal polyp in a kitten. Veterinary Record 1985;117:668-669.

6. Stanton ME, Wheaton LG, Render JA, et al. Pharyngeal polyps in two feline siblings. Journal of the American Veterinary Medical Association 1985;186:1311-1313.

7. Parker NR, Binnington AG. Nasopharyngeal polyps in cats: Three case reports and a review of the literature. Journal of the American Animal Hospital Association 1985;21:473-478.

8. Trevor PB, Martin RA. Tympanic bulla osteotomy for treatment of middle-ear disease in cats: 19 cases (1984-1991). Journal of the American Veterinary Medical Association 1993;202:123-128.

9. Fingland RB, Gratzek A, Vorhies MW, et al. Nasopharyngeal polyp in a dog. Journal of the American Animal Hospital Association 1993;29:311-314.

10. Pratschke KM. Inflammatory polyps of the middle ear in 5 dogs. Veterinary Surgery 2003;32:292-296.

11. London CA, Dubilzeig RR, Vail DM, et al. Evaluation of dogs and cats with tumors of the ear canal: 145 cases (1978-1992). Journal of the American Veterinary Medical Association 1996;208:1413-1418.

12. Harvey CE, Goldschmidt MH. Inflammatory polypoid growths in the ear canal of cats. Journal of Small Animal Practice 1978;19:669-677.

13. Anders BB, Hoelzler MG, Scavelli TD, et al. Analysis of auditory and neurologic effects associated with ventral bulla osteotomy for removal of inflammatory polyps or nasopharyngeal masses in cats. Journal of the American Veterinary Medical Association 2008;233:580-585.

14. Remedios AM, Fowler JD, Pharr JW. A comparison of radoigraphic versus surgical diagnosis of otitis media. Journal of the American Animal Hospital Association 1991;27:183-188.

15. Ader PL, Boothe HW. Ventral bulla osteotomy in the cat. Journal of the American Animal Hospital Association 1979;15:757-762.

16. Little CJL, Lane JG. The surgical anatomy of the feline bulla tympanica. Journal of Small Animal Practice 1986;27:371-378.

17. Esterline ML, Radlinsky MG, Schermerhorn T. Journal of Feline Medicine and Surgery 2005;7:121-124.

18. Faulkner JE, Budsberg SC. Results of ventral bulla osteotomy for treatment of middle ear polyps in cats. Journal of the American Animal Hospital Association 1990;26:496-499.

19. Anderson DM, Robinson RK, White RAS. Management of inflammatory polyps in 37cats. Veterinary Record 2000;147:684-687.

Chapter 16

Salivary Glands

Michael D. King and Don R. Waldron

Salivary Gland Disease

Dogs and cats have four pairs of salivary glands of clinical significance. Knowledge of salivary gland and duct anatomy is important from a surgical perspective in treatment of salivary gland disease and to prevent iatrogenic salivary tissue injury during other surgical procedures in the head and cervical areas. The major salivary glands of both the dog and cat are the paired parotid, mandibular, sublingual and zygomatic glands (Figure 16-1).[1] The parotid gland is triangular in shape and closely adjacent to the lateral aspect of the auricular cartilage which makes up the external ear canal. The mandibular gland is a large gland, ovoid in shape, and surrounded by a fibrous capsule which is joined cranially to the sublingual gland. The mandibular gland is positioned dorsal and caudal to the mandibular lymph nodes and masseter muscle, and lateral to the external carotid artery. The monostomatic part of the sublingual gland continues cranially from the mandibular gland, following the mandibular duct, ending on a small papilla adjacent to the cheek teeth. The polystomatic section of the sublingual gland consists of multiple lobules positioned along the mandibular and sublingual salivary ducts; these lobules open separately into the oral cavity adjacent to the tongue. The zygomatic gland corresponds to the dorsal buccal glands in other species, and is located medial to the rostral attachment of the zygomatic arch.[1,2]

Clinical Disease

Disease of the canine and feline salivary glands include salivary mucoceles, neoplasia, sialadenitis, and sialolithiasis.[3] A phenobarbital-responsive sialodenosis and hypersialosis has been described in dogs.[4,5] This condition is characterized by bilateral, painless, and non-inflammatory enlargement of the parotid or mandibular glands. Clinical signs of sialodenosis include weight loss, vomiting, retching and difficulty in swallowing. Response to phenobarbital administration in these cases is usually rapid, though continuous treatment may be required to prevent recurrence.[4,5]

Salivary gland neoplasia is uncommon in the dog and cat.[6,7] Neoplasia has been reported in many breeds, though Siamese cats and Spaniel breed dogs have been overrepresented in some studies.[8,9] The parotid and mandibular glands are most commonly affected, with one study describing mandibular gland neoplasia occurring most often in cats and parotid gland tumors predominating in dogs.[8] Salivary gland tumors in dogs and cats may be simple or complex adenocarcinomas.[10] Definitive treatment involves surgical excision of the tumor and affected gland, with reported median survival times post-surgery for dogs and cats of 550 days and 516 days respectively.[8] Radiation therapy and several chemotherapy protocols have been used in conjunction with surgical excision but haven't been shown to improve survival times.

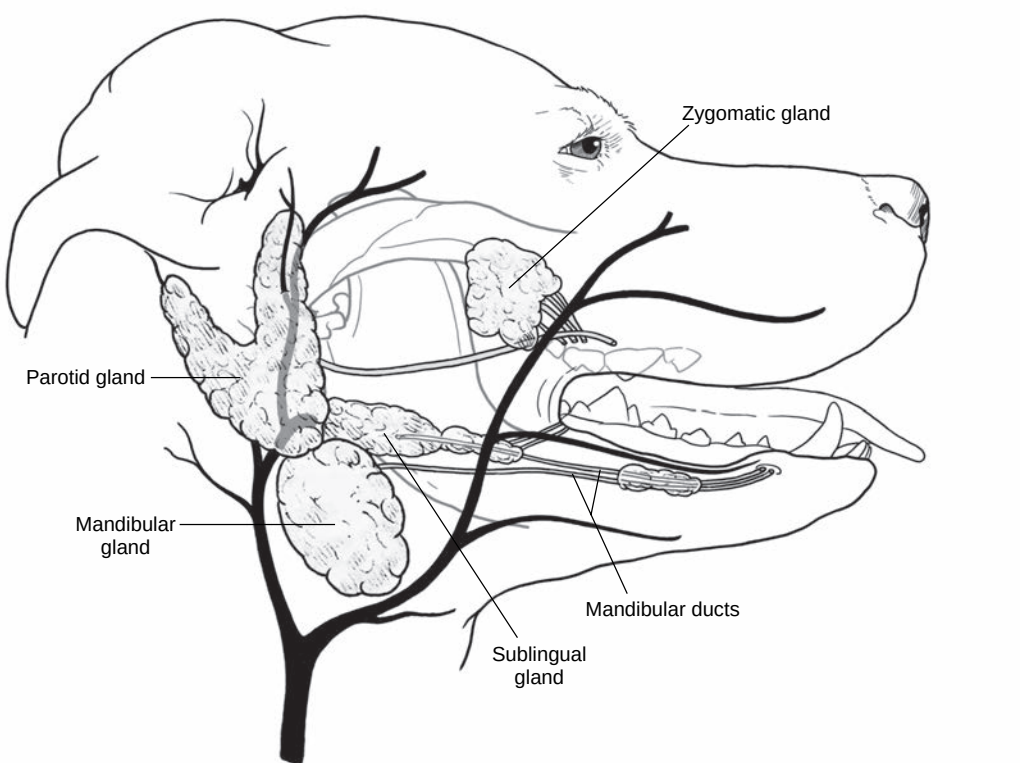


Figure 16-1. The four pairs of salivary glands in the dog and cat.

Salivary mucocele is a collection of saliva within tissues and is the most commonly diagnosed disease of the canine salivary glands. Mucoceles are rarely reported in the feline and have been associated with trauma.[11,12] It is thought that saliva accumulates due to leakage from a damaged salivary gland or duct although the cause of such leakage is unknown. Most mucoceles are associated with the sublingual gland/duct complex and occur in the cranial cervical or intermandibular subcutaneous tissue (cervical mucocele). Intraoral mucoceles associated with sublingual gland/duct defects are uncommon and include sublingual mucocele (ranula) and pharyngeal mucocele. The latter result from saliva accumulating adjacent to pharyngeal and laryngeal structures. Most forms of mucoceles are benign lesions associated with low patient morbidity; however intraoral mucoceles (ranula) may interfere with prehension and pharyngeal mucoceles may cause airway obstruction and dyspnea. Zygomatic gland mucoceles are rare in dogs. These mucoceles cause ophthalmologic signs such as exophthalmos and periorbital swelling.

Diagnosis of a cervical mucocele is usually achieved by aspiration of a thick, honey-colored, or blood-tinged mucoid fluid with a low cell count from the primary cervical swelling. The fluid can be confirmed as saliva by using a mucus-specific stain such as periodic acid-Schiff (PAS). The differential diagnosis for cervical mucocele includes abscess and neoplasia, especially lymphoma. Thyroglossal duct cysts or branchial cysts are rare congenital lesions similar to mucoceles.

The mandibular and sublingual glands and ducts are closely associated anatomically and definitive treatment of cervical, sublingual or pharyngeal mucoceles involves removal of both glands on the affected side.[13] Some authors advocate marsupialization of sublingual and pharyngeal mucoceles in an attempt to allow continuous drainage of the accumulated swelling. However, without concurrent removal of the affected glands marsupialization alone may lead to recurrence.[14,15] Determination of which side to operate in cases of cervical mucoceles is usually apparent or made during physical examination. If mucocele lateralization is not apparent, displacement of the mucocele may produce a swelling within the oral cavity, adjacent to the tongue on the affected side. Alternatively, placing the animal in dorsal recumbency when the animal is anesthetized usually results in the mucocele shifting laterally towards the affected side. Sialography has been recommended by some authors and can demonstrate a defect in the duct or glands radiographically, allowing accurate identification of which side is affected however, this requires cannulation of the sublingual ducts, which is difficult and time consuming.[13,15] Exploratory surgery is performed in some cases to confirm the affected side. Careful examination of the mucocele during surgery may allow identification of a small communication with the affected gland. In rare cases, when no side can be identified, removal of the mandibular and sublingual glands bilaterally can be performed with no deleterious effects to the dog.[16]

Surgical Technique

Mandibular and Sublingual Salivary Gland Excision

The patient is anesthetized and positioned in lateral recumbency with a pad positioned under the neck. The lateral aspect of the facial area from mid-mandible to the mid-cervical area is clipped and prepared for aseptic surgery. A skin incision is

made extending from the angle of the mandible caudally over the jugular vein and its bifircation (Figure 16-2). Subcutaneous tissue and platysma muscle are incised and the division of the jugular vein to the ventral linguofacial and dorsal maxillary veins is identified. Careful hemostasis using electrocautery and ligation is essential during surgery to maintain visibility within the surgical field. The mandibular gland is located just medial and cranial to the jugular vein bifurcation. The surgeon should not confuse the mandibular lymph nodes which are located ventrally to the linguofacial vein with the salivary gland complex. The nodes are smaller and are not lobulated as is the mandibular gland. An incision is made into the fibrous capsule of the mandibular gland and the gland dissected free with a combination of sharp and blunt dissection. Blood supply to the mandibular gland is located medial and dorsally and cauterization or ligation of the vascular supply is recommended. The mandibular gland is exteriorized and lateral traction used to allow dissection of the associated sublingual gland cranially to the level of the digastricus muscle. The sublingual gland dissection is completed with a combination of digital blunt dissection and a Kelly hemostat. Dissection is continued dorsal and cranial to the digastricus muscle, until the lingual nerve is identified rostrally and all glandular tissue is isolated (Figure 16-3). The mandibular and sublingual ducts are ligated caudal to the lingual nerve and the glandular complex removed. Inadvertent avulsion of the glandular complex sometimes occurs during dissection. If the avulsion occurs rostral to the lingual nerve no further action is necessary. If avulsion occurs caudal to the lingual nerve an effort is made to completely excise glandular tissue to the level of the lingual nerve. Suction is used to remove all mucus and saliva from the mucocele and a passive or active drain placed in the mucocele prior to closure and maintained for 2 to 3 days. Subcutaneous tissues and platysma are closed with absorbable suture, and skin closed routinely. The drain should be covered with a bandage, and removed once there is minimal discharge from the surgical wound.

Zygomatic Gland Excision

Zygomatic gland mucoceles are uncommonly diagnosed. Definitive therapy consists of zygomatic gland excision and drainage of the mucocele. The patient is anesthetized and placed in lateral recumbency with the head supported by a pad. An incision is made along the dorsal rim of the zygomatic arch and the palpebral fascia and retractor anguli muscle are incised and reflected dorsally (Figure 16-4A-F). The periosteum of the zygomatic arch is incised and reflected ventrally, allowing visualization of the dorsal aspect of the zygomatic gland. Further visualization is obtained by partially removing the dorsal half of the zygomatic arch with an osteotome or rongeurs, and by gentle dorsal retraction of the globe. The zygomatic gland is then bluntly dissected free, with care to avoid a branch of the deep facial vein ventrally. The mucocele is then drained and the surgical site lavaged with sterile saline. If the section of removed zygomatic arch is intact, it can be secured in place with suture through pre-drilled holes in the bone. The cut ends of the retractor anguli muscle are apposed, and the palpebral fascia is sutured to the zygomatic periosteum with absorbable suture material. Subcutaneous tissues and skin are closed routinely.

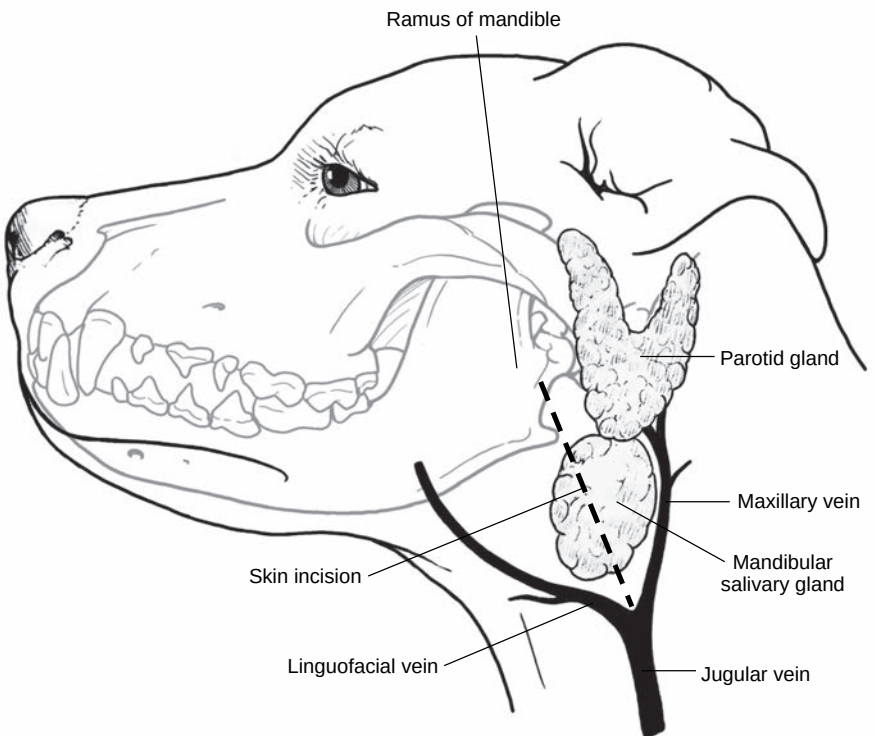


Figure 16-2. A skin incision is made from the angle of the mandible extending caudally over the bifurcation of the jugular vein.

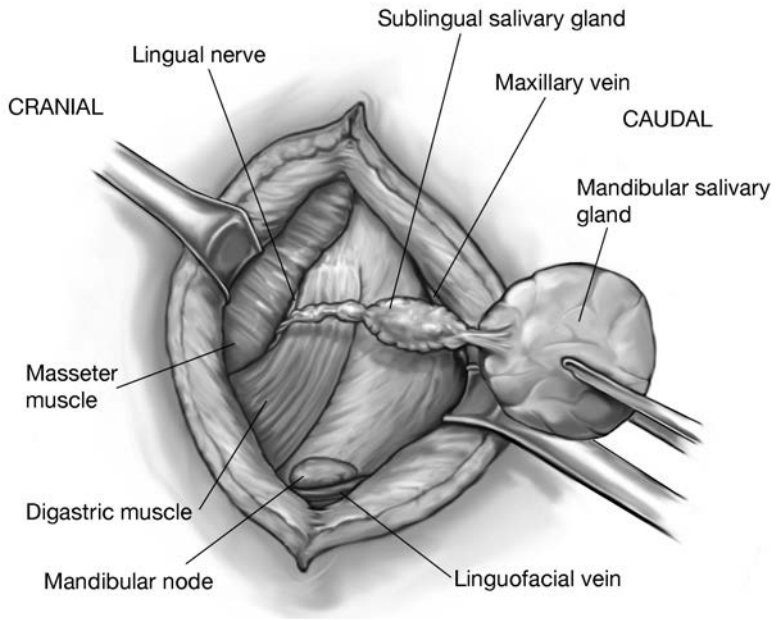


Figure 16-3. The mandibular and sublingual salivary gland complex is dissected and exteriorized after capsular incision. Caudal traction on the glandular complex assists in exposing the rostral sublingual complex to the level of the lingual nerve.

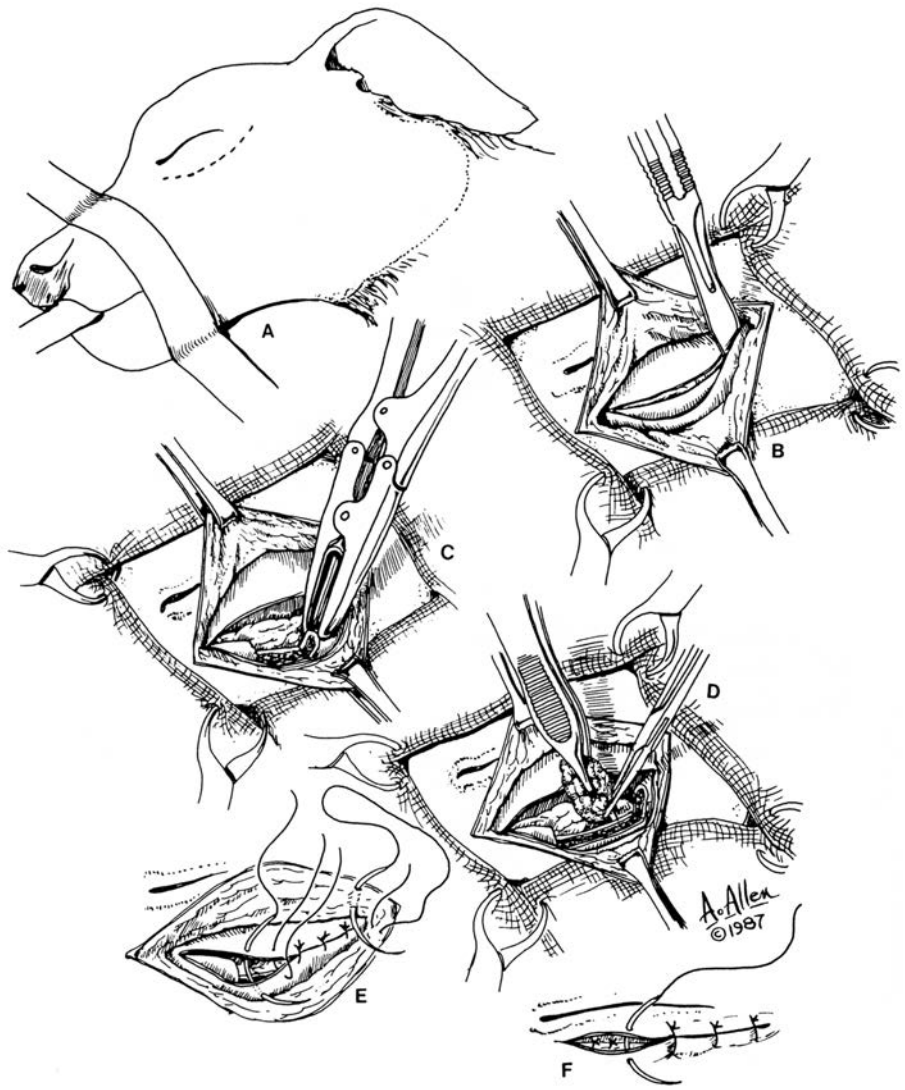


Figure 16-4A-F. Zygomatic sialodenectomy.

References

1. Dyce KM, Sack WO, Wensing CJG: The Head and Ventral Neck of the Carnivores, in Textbook of Veterinary Anatomy (ed 2). Philadelphia, Pennsylvania, W.B. Saunders, 1996, pp 367-391.

2. Evans HE, deLahunta A: The Head, in Miller's Guide to the Dissection of the Dog (ed 4). Philadelphia, Pennsylvania, W.B. Saunders, 1996, pp 250-309.

3. Spangler WL, Culbertson MR: Salivary gland disease in dogs and cats: 245 cases (1985-1988). J Am Vet Med Assoc 198:465-469, 1991.

4. Stonehewer J, Mackin AJ, Tasker S, et al: Idiopathic phenobarbital-responsive hypersialosis in the dog: an unusual form of limbic epilepsy? J Small Anim Pract 41:416-421, 2000.

5. Boydell P, Pike R, Crossley D, et al: Sialadenosis in dogs. Journal of the American Veterinary Medical Association 216:872-874, 2000.

6. Withrow SJ. Cancer of the salivary glands. In Small Animal Clinical Oncology. SJ Withrow (ed).4th ed. Philadelphia, WB Saunders, 2007, 476-477.

7. Morrison WB. Cancers of the head and neck. In Cancer in Dogs Cats, Medical and Surgical Management, Morrison WB ed., Philadelphia, Williams and Wilkins, 1998, 513-514.

8. Hammer A, Getzy D, Ogilvie G, et al: Salivary gland neoplasia in the dog and cat: survival times and prognostic factors. J Am Anim Hosp Assoc 37:478-482, 2001.

9. Karbe E, Schiefer B: Primary salivary gland tumors in carnivores. Can Vet J 8:212215, 1967.

10. Carberry CA, Flanders JA, Harvey HJ, et al: Salivary gland tumors in dogs and cats: a literature and case review. Journal of the American Animal Hospital Association 24:561-567, 1988.

11. Feinman JM: Pharyngeal mucocele and respiratory distress in a cat. J Am Vet Med Assoc 197:1179-1180, 1990.

12. Martin CL, Kaswan RL, Doran CC: Cystic lesions of the periorbital region. Compendium on Continuing Education for the Practicing Veterinarian 9:10221025, 1028-1029, 1987.

13. Smith MM: Surgery of the canine salivary system. Compendium on Continuing Education for the Practicing Veterinarian 7:457-462, 464-465, 1985.

14. Harvey HJ: Pharyngeal mucoceles in dogs. J Am Vet Med Assoc 178:1282-1283, 1981.

15. Hoffer RE: Symposium on surgical techniques in small animal practice. Surgical treatment of salivary mucocele. Vet Clin North Am 5:333-341, 1975

16. Waldron DR, Smith MM: Salivary mucoceles. Probl Vet Med 3:270-276, 1991.

Chapter 17

Esophagus

Management of Esophageal Foreign Bodies

Michael S. Leib

Introduction

Most foreign material ingested by dogs and cats will either pass uneventfully through the gastrointestinal tract, cause mild vomiting and/or diarrhea, or be dissolved by gastric acid.[1] However, foreign bodies that lodge in the esophagus should be considered an emergency. The longer entrapped foreign bodies are present, the greater the chance of severe esophageal wall damage and possible perforation.[2] Sharp pointed objects can penetrate the esophageal wall leading to mediastinitis or occasionally broncho-esophageal fistula.[3] The most commonly encountered esophageal foreign bodies are bones, rawhide chew toys, dental chews such as Greenies®, fish hooks, and hairballs.[4]

Because of indiscriminate eating habits, swallowing of incompletely masticated food, and exposure to dental cleaners, foreign bodies occur more commonly in dogs than cats.[3,5,6,7] Hairballs vomited from the stomach can obstruct the esophagus in cats. Foreign bodies can occur in any age animal, but are most common in young dogs, or those frequently given bones or rawhide chew toys.[8] Foreign body entrapment may be more common in small dogs and terrier breeds.[3,4]

Pathophysiology

The esophagus is very distensible and most ingested foreign objects are passed into the stomach. Foreign bodies commonly lodge where the esophagus is restricted from distending: the thoracic inlet, base of the heart, or diaphragmatic hiatus. The entrapped foreign body stimulates secondary peristalsis, which can augment pressure necrosis of the esophageal wall.[9,10] Even though the esophagus is lined by tough stratified squamous epithelium, erosion, ulceration, and perforation can develop if the foreign body is not promptly removed. Fish hooks can lodge anywhere within the esophagus but the pharyngeal portion of the esophagus and heart base are most common.[6]

Clinical Signs

The most common clinical signs associated with esophageal foreign bodies are regurgitation, excess salivation, anorexia, odynophagia, and respiratory signs due to aspiration pneumonia. Foreign body ingestion may be observed or suspected by the owner. Clinical signs develop acutely. With obstructive lesions regurgitation of water occurs and dehydration can quickly develop. Perforation of the esophageal wall may result in pyrexia and depression. Mediastinitis with extension into the pleural cavity will lead to pleural effusion and progressive respiratory distress.

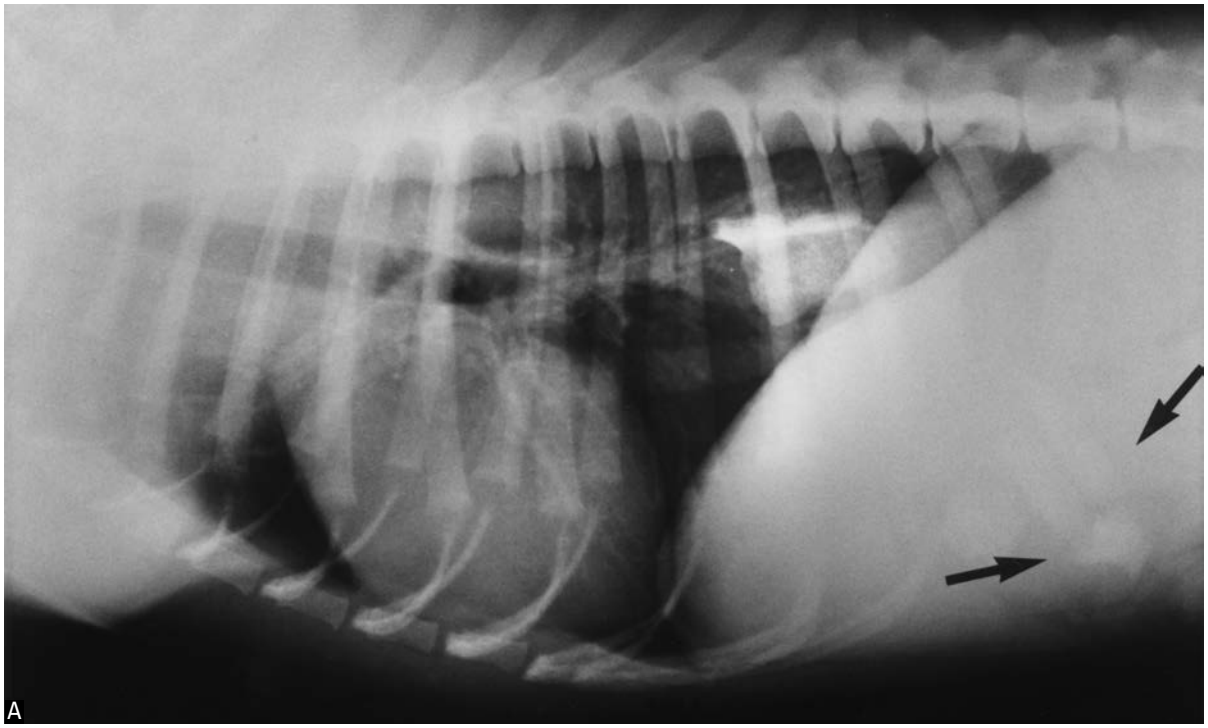


Figure 17-1A. Lateral survey thoracic radiograph from a 7 month old male West Highland white terrier showing a bone density cranial to the diaphragmatic hiatus. Several other bone fragments are visible in the stomach (arrows).

Diagnosis

Most esophageal foreign bodies are radiodense and clearly visible on survey radiographs (Figures 17-1A and B). Other common radiographic findings include a soft tissue density surrounding the foreign body (fluid in the esophagus, thickened wall, or localized mediastinitis) and air-filled dilated esophagus cranial to the foreign body.[11] Thin poultry bones can be difficult to visualize as they silhouette with ribs and vertebrae.

Although difficult to diagnose in cases with large entrapped bones, the presence of mediastinitis radiographically suggests esophageal perforation. Radiographic findings associated with mediastinitis include: increased mediastinal opacity and widening, extensive fluid density surrounding the foreign body, loss of detail around the mass, or obliteration of the shadow of the caudal vena cava.[3]

If perforation has occurred, thoracic radiographs taken after esophagoscopy may demonstrate pneumomediastinum. If perforation is suspected on survey radiographs, but cannot be confirmed, an iodine contrast study should be performed. Aqueous organic iodide contrast at 0.5-1.0 ml/kg can be administered.[12] Contrast studies should be performed after foreign body removal, because when the foreign body is still in place it may obstruct the perforation site, blocking leakage of contrast.[3]

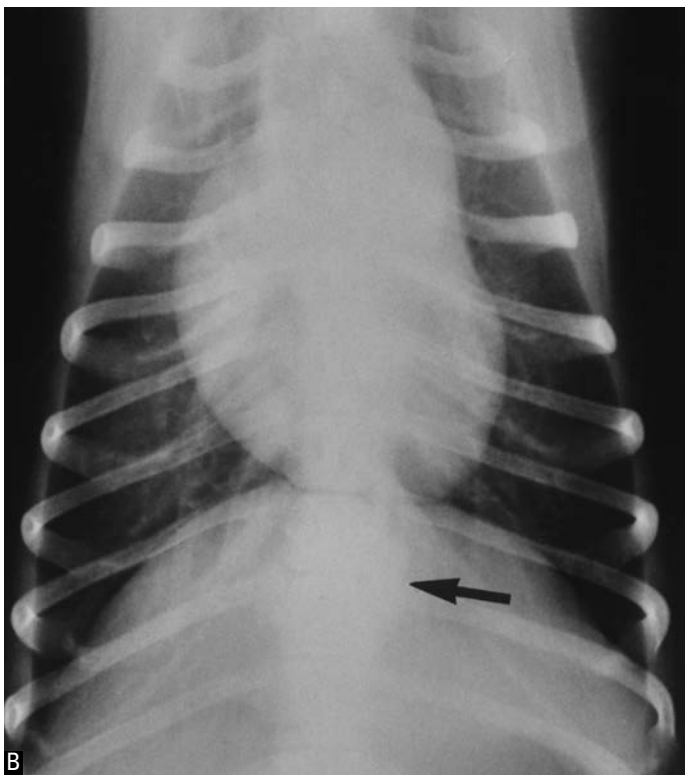


Figure 17-1B. Ventrodorsal survey thoracic radiograph from the same dog in figure 17-1A. The bone is difficult to see (arrow) because it is superimposed over the vertebral bodies.

Treatment

Most esophageal foreign bodies can be successfully removed endoscopically (Figure 17-2).[11] If foreign bodies cannot be endoscopically grasped and extracted from the esophagus, they can often be carefully pushed into the stomach with an orogastric tube under endoscopic visualization. In the stomach, gastric acid



Figure 17-2. Endoscopic appearance of a bone lodged within the esophagus.

will dissolve most bones, or foreign bodies can be removed via celiotomy and gastrotomy, or endoscopically, as more room is available for endoscopic manipulation.[5,9,11] Pushing an impacted foreign body into the stomach with an orogastric tube without endoscopic visualization should be performed carefully or not at all, because of the risks of severe mucosal damage or esophageal perforation. Surgery of the esophagus should be avoided if possible because of difficult exposure within the thorax, post-operative morbidity, and frequent complications. Surgical removal is indicated if a foreign body cannot be removed or pushed into the stomach, if the entire tip of a fishhook has penetrated the esophageal wall, or if esophageal perforation is present. A highly successful method of foreign body retrieval using forceps under fluoroscopic guidance has been reported, but is not practical for most practitioners.[4]

Large foreign bodies may be so tightly lodged within the esophagus, that flexible endoscopic forceps cannot grasp the object tightly enough for removal. These foreign bodies can often be retrieved using a rigid uterine or rectal biopsy forceps passed along the side of a flexible endoscope.[2] During removal, large foreign bodies may lodge at the pharynx, but can be delivered by grasping with curved carmalt forceps. Foreign bodies can also be removed using a rigid endoscope and rigid forceps.[5,6,8,11]

Esophagoscopy

To perform esophagoscopy, the animal should be positioned in left lateral recumbency.[13] A mouth speculum must be placed on the left upper and lower canine teeth to protect the endoscope. The tongue should be grasped and the head and neck extended by an assistant. A flexible endoscope is passed over the base of the tongue, through the pharynx dorsal to the endotracheal tube, and into the proximal esophagus. Lubrication is generally not necessary.

The esophageal mucosa is usually collapsed and appears in longitudinal folds.[14-16] It should be distended by insufflating air. The endoscope tip should be centralized within the lumen by adjusting the control knobs. Only minor tip adjustments are necessary, as the esophagus is a relatively straight tube. By advancing the endoscope only when the lumen is clearly visible, the endoscopist can dramatically reduce the risk of esophageal perforation. The endoscope should be advanced until the foreign body is visible. The mucosa surrounding the foreign body should be carefully inspected for erosion, ulceration, or perforation. If perforation is present or suspected, air insufflation should be limited, to avoid producing pneumomediastinum and possibly pneumothorax. Attempts should be made to gently slide the endoscope past the foreign body. This will allow assessment of mucosa not initially visible and help to plan foreign body extraction. The shape, contour, and composition of the foreign body will dictate the type of forceps necessary for extraction. The most helpful forceps are the rat-tooth, wire snare, 4-wire basket, and Roth net.

The foreign body forceps should be passed through the endoscope's biopsy channel into the lumen of the esophagus and opened by an assistant. An edge of the foreign body should be grasped and the forceps closed. The forceps should be withdrawn to pull the foreign body close to the endoscope's tip. Air should be insufflated during withdrawal of the endoscope to help dilate the esophagus and prevent damage to the esophageal mucosa as the foreign body is withdrawn.

Fishhooks can be difficult to remove, especially if embedded or if they are treble-barb hooks.[6] If the tip of the hook is protruding into the lumen, it can be grasped and the entire hook pulled through the mucosa and removed. If the tip of the hook is not visible but appears to be embedded only in the mucosa or submucosa, the hook can be gently torn through the mucosa, creating a superficial laceration that usually heals without complication.[6] If the hook appears to have passed through the esophageal wall, it should be surgically removed.

Hairballs, or trichobezoars, which occur most often in cats, often tear apart when grasped with foreign-body-retrieval forceps. Because of their tendency to fragment, hairballs may require multiple passes with extraction forceps to completely remove them. In addition, because of space limitations, it is usually not possible to place a wire snare or basket around the center of an esophageal hairball. In some cases, it is easier to push the hairball into the stomach for easier endoscopic manipulation, and where the hairball can be firmly grasped and removed. Esophageal perforation and resulting mediastinitis is a severe complication of esophageal foreign bodies. Small perforations can be managed medically by treating esophagitis, while large perforations require surgical repair and drainage.[8]

Mild esophagitis and erosions will heal quickly without complications. Food should be withheld for 24 hours followed by frequent feeding of small quantities of a gruel diet for 2-3 days. The gruel can be gradually thickened, the meal volume increased, and the feeding frequency decreased if regurgitation does not occur. Moderate or severe esophagitis and ulceration require more intensive medical management and a longer period of "resting the esophagus" by withholding oral food intake. In some cases, a percutaneous gastrostomy tube can be placed to provide nutrition while promoting esophageal healing and bypassing the esophagus. Cimetidine (10 mg/kg TID), ranitidine (2 mg/kg BID or TID), or famotidine (0.5 mg/kg BID) or a proton pump antagonist such as omeprazole (1 mg/kg SID) should be given to reduce gastric acid production and prevent further esophageal damage

from gastroesophageal reflux. Metoclopramide (0.2-0.4 mg/kg TID) can help increase gastroesophageal tone and reduce gastric reflux. Sucralfate suspension can bind to and coat eroded or ulcerated esophageal mucosa (1 gm/25 kg TID-QID). If severe mucosal damage is present, broad-spectrum antibiotics should be given for 1-2 weeks. Medical treatments should be continued for 1 week after normal feeding has been resumed. After the esophagus has healed, oral feeding can be started as described above. Until oral feeding begins, medications (except sucralfate) must be given parenterally or via the PEG tube.

Prognosis

The overall prognosis is good, but is dependent on the type of foreign body, the duration of time present, the degree and severity of esophageal damage, and the development of perforation.[4] The longer a foreign body is impacted within the esophagus, the harder it is to remove and the greater chance for perforation. Large perforations warrant a poor prognosis, despite aggressive surgical care.[3] Most cases with esophagitis, that receive appropriate medical care, will heal without complications.[8,10] Stricture formation following foreign body retrieval of bones is uncommon and is more likely following perforation or when severe damage to the esophageal wall has occurred, or after impaction of a dental chew.[7] Animals with severe esophagitis or ulceration should be endoscopically reevaluated in 7-10 days to assess stricture formation, which if present can be dilated with balloon catheters.

References

1. Leib M. Diseases of the esophagus. In: Leib M, Monroe W, eds. Practical Small Animal Internal Medicine. Philadelphia: W B Saunders; 1997:633-652.

2. Jones BD. Management of Esophageal Foreign Bodies. In: Kirk RW, Bonagura JD, ed. Current Veterinary Therapy XI. Philadelphia: W B Saunders Company; 1992:577-580.

3. Parker NR, Walter PA, Gay J. Diagnosis and Surgical management of esophageal perforation. J Am Anim Hosp Assoc 1989;25:587-594.

4. Moore A. Removal of oesophageal foreign bodies in dogs: use of the fluoroscopic method and outcome. J Sm Anim Pract 2001;42:227-230.

5. Pearson H. Symposium on Conditions of the Canine Oesophagus - I Foreign Bodies in the Oesophagus. J Sm Anim Pract 1966;7:107-116.

6. Michels GM, Jones BD, Huss BT, et al. Endoscopic and surgical retrieval of fishhooks from the stomach and esophagus in dogs and cats: 75 cases (1977-1993). J Am Vet Med Assoc 1995;207:1194-1197.

7. Leib MS, Sartor LL, Esophageal foreign body obstruction caused by a dental chew treat in 31 dogs (2000-2006). J Am Vet Assoc 2008; 232:1021-1025.

8. Ryan WW, Greene RW. The Conservative Management of Esophageal Foreign Bodies and Their Complications: A Review of 66 Cases in Dogs and Cats. J Am Anim Hosp Assoc 1975;11:243-249.

9. Spielman BL, Shaker EH, Garvey MS. Esophageal foreign body in dogs: a retrospective study of 23 cases. J Am Anim Hosp Assoc 1992;28:570-574.

10. Zimmer JF. Canine Esophageal Foreign Bodies: Endoscopic, Surgical, and Medical Management. J Am Anim Hosp Assoc 1984;20:669-677.

11. Houlton EF, Herrtage ME, Taylor PM, et al. Thoracic oesophageal foreign bodies in the dog: a review of ninety cases. J Sm Anim Pract 1985;26:521-536.

12. Moon M, Myer W. Gastrointestinal contrast radiology in small animals. Sem Vet Med Surg 1986;1:121-143.

13. Leib MS. Endoscopic Examination of the Dog and Cat. In: Jensen SL, Gregersen H, Moody FG, Shokouh-Amiri MH, eds. Essentials of Experimental Surgery: Gastroenterology. Amsterdam: Harwood Academic Publishers; 1994.

14. Tams TR. Esophagoscopy. In: Tams TR, ed. Small Animal Endoscopy. St. Louis: C V Mosby; 1990:47-88.

15. Guilford WG. Upper gastrointestinal endoscopy. Vet Clin North Am: Sm Anim Pract 1990;20:1209-1227.

16. Guilford W, Jones BD. Gastrointestinal endoscopy of the dog and cat. Vet Med Rep 1990;2:140-150.

Hiatal Hernia Repair

Ronald M. Bright

Introduction

The hiatus of the esophagus is that portion of the diaphragm that allows the esophagus and vagus nerves to pass between the thoracic and abdominal cavities. A hiatal hernia (HH) can allow the protrusion of an abdominal structure(s) through an enlarged hiatus and into the thoracic cavity. The most common HH in the dog and cat is the axial hiatal hernia, which implies a cranial displacement of the gastroesophageal junction through the hiatus into the caudal mediastinum[1] (Figure 17-3A). Various amounts of stomach may reside within the thorax as well as other viscera that may move cranially. Most of the time this is a "sliding" hiatal hernia whereby the viscera is not fixed and moves back and forth between the thorax and abdomen.

Paraesophageal hernias occur when the esophagaogastric junction remains in its normal position below the diaphragm. (Figure 17-3B). However, the fundus and other parts of the stomach as well as other abdominal viscera can move through the hiatus into the mediastinum alongside the esophagus.

Hiatal hernias can be congenital or acquired, although the congenital type may not become symptomatic until adulthood.[2,3] There appears to be a congenital predisposition in the Chinese Shar Pei breed. This breed has also been shown to have an increased incidence of esophageal motility disorders and esophageal redundancy, although these can be incidental radiographic findings not associated with any clinical signs.[4,5] Acquired hiatal hernias are often associated with some form of trauma although there is some evidence to suggest that they can occur in dogs and cats with no history of trauma but in association with cardiopulmonary, neuromuscular, or metabolic disease.[6]

Pathophysiology

The terminal esophagus (abdominal portion) incorporates the lower esophageal sphincter (LES) and extends approximately 2 cm below the diaphragm. Normally, the LES relaxes to allow a bolus of food or liquid to pass into the stomach and quickly closes to prevent excessive gastroesophageal reflux (GER). Any change to the normal anatomic relationship between the LES, the hiatus, and the phrenicoesophageal ligament can disrupt the high pressure zone (unrelated to the cranial displacement

of the LES) and contribute to excessive GER by impairing the competency of the sphincter.[7,8] Other anatomic factors that may contribute to excessive GER include the loss of the oblique angle at which the stomach and esophagus join and the distortion of the muscular sling produced by the lesser curvature of the stomach.[8] In most cases of hiatal hernia in the dog and cat, a primary disorder of the LES is unlikely.[7]

Trauma, a well-recognized cause of acquired HH, may result in weakening of the attachments at the hiatus. Hiatal hernias have been seen associated with chronic diaphragmatic herniation.[2,9] However, non-traumatic causes may be related to the "bellows" effect of the thorax.[6] Brachycephalic breeds such as the Bulldog have been shown to have a relationship between more severe forms of the brachycephalic syndrome and hiatal hernias.[6] It is speculated that severe inspiratory disorders can result in negative intraesophageal and intrapleural pressure, leading to the esophagus and stomach being drawn into the thorax, worsening a mild preexisting hiatal hernia and associated signs.[6,10]

The esophagitis that results from HH and GER is caused by the reflux of acidic gastric contents along with pepsin. Esophagitis can induce vomiting (less likely) or regurgitation. The regurgitation is usually intermittent and the contents of the regurgitated material can be blood-tinged and contain undigested food, clear liquid, and foam.

Differential diagnoses for reflux esophagitis associated with HH would include congenital megaesophagus, and acquired megaesophagus due to dysautomonia, myasthenia gravis, neoplasia, foreign bodies, lead poisoning, hypothyroidism, hypoadrenocorticism, and polymyositis.

Diagnosis

To some degree, signalment is important as the Chinese Shar Peis and English bulldogs appear to be predisposed to HH.[4,6] However, most animals with the congenital form of HH will have signs before they are 1 year of age, although diagnosis may be delayed.[11] Animals with the acquired form of HH may develop signs at any age.

Not all animals with a HH are symptomatic and hernias may be identified on thoracic radiographs as incidental findings.[2] Animals with symptomatic HH will consistently have regurgitation and pain from esophagitis, may have hypersalivation, anorexia, and aerophagia. Odonydysphagia, chronic weight loss, and a soft moist cough may be seen. Coughing may indicate aspiration which in severe cases results in aspiration pneumonia.

Physical examination signs may be limited to increased lung sounds (if aspiration is a problem), a thin body condition, and possibly hypersalivation. In addition, the affected animal may be febrile and dehydrated.

The most helpful diagnostic tools are radiography and endoscopy. Survey radiographs of the thorax usually demonstrate a megaesophagus and an abnormal soft tissue density in the caudodorsal thorax. With sliding hernias, however, repeat radiographs may be necessary to finally demonstrate the displaced viscera. The gas within the stomach will help identify any gastric displacement and pneumonia may be seen.

A barium contrast esophagram should be performed as it helps identify the gastroesophageal junction and/or gastric rugal folds. The degree of megaesophagus can be defined better with the aid of contrast material. Fluoroscopy is useful in demonstrating the intermittent (sliding) nature of the hernia. The presence of

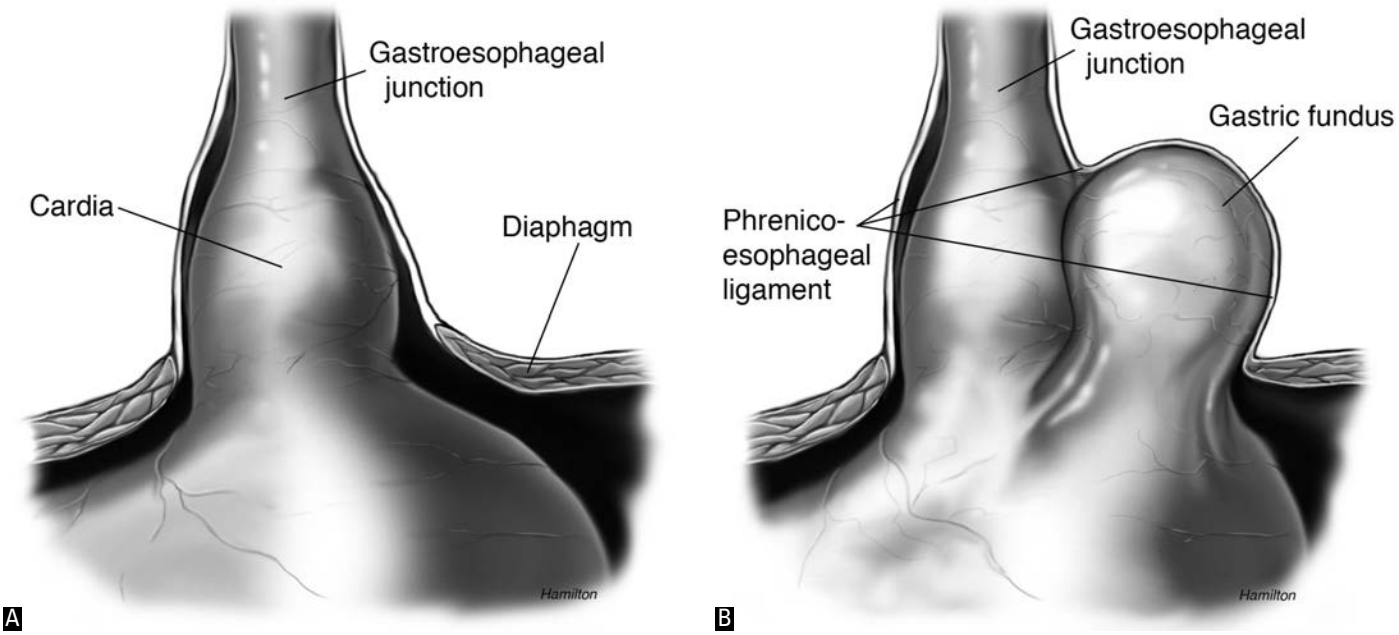


Figure 17-3. A. The "sliding" axial hernia allows the distal esophagus, gastroesophageal junction, and a portion of the stomach to protrude into the thorax. **B.** The paraesophageal hernia allows the protrusion of viscera through a diaphragmatic defect adjacent to the hiatus. The gastroesophageal junction remains fixed in position.

gastroesophageal reflux and the severity of hypomotility can also be analyzed. If a paraesophageal hernia is present, the gastroesophageal junction remains in its normal position while the stomach and other displaced viscera are displaced cranially into the thorax along with and adjacent to the distal esophagus.

Endoscopy will assist in identifying not only the HH but secondary inflammatory changes of the distal esophagus as well. Endoscopy may demonstrate enlargement of the hiatal opening, cranial displacement and dilatation of the cardia, and rugal folds of the stomach.[12] Visualization of the cardia and gastroesopahgeal junction is often easiest with the scope in the retroflex position.[12]

Medical Therapy

The goal of medical therapy is to alleviate the signs caused by reflux esophagitis and any aspiration pneumonia that may be present. Animals with minimal symptomatology may benefit from dietary modification alone. Modification should include a soft diet low in fat, decreasing the volume of food given at each meal while increasing the frequency of feeding, and feeding from an elevated position. Some obese animals will also benefit by losing weight.

In those cases that fail to respond to dietary changes, raising the gastric pH with an H2-receptor antagonist will help neutralize the effects of gastric secretions on the esophageal mucosa and decrease the esophagitis. The improvement in esophagitis indirectly helps increase the tone of the LES thereby diminishing the amount of GER. A proton-pump inhibitor (omeprazole, Prilosec, Astra Zeneca) can be substituted for the H2-receptor antagonist. A prokinetic drug such as metoclopramide (Reglan, Wyeth Pharmaceuticals) or cisapride can be used to help increase the LES tone and hasten gastric emptying resulting in less GER. Cytoprotective agents such as sucralfate (Carafate, Hoechst Marion Roussel) has been shown to be effective by coating the distal esophagus and providing protection against the effects of gastric acid, pepsin, and bile salts. This is given as a slurry or suspension when used for esophagitis.

If the hiatal hernia is small and there is minimal displacement of abdominal contents, the reflux esophagitis is not severe and medical treatment alone is often effective. However, animals that remain symptomatic in spite of aggressive medical therapy will require surgical intervention. Some owners may also choose surgery initially because of their inability to comply with the rigorous requirements of medical therapy.

Surgical Therapy

Veterinary surgeons have historically performed plication of the gastric fundus around the distal esophagus to reverse the effects on GER caused by a hiatal hernia.[3,10] However, Prymak and colleagues advised against this as a component of surgical therapy for hiatal hernia since a LES disorder is not thought to be the primary problem associated with an HH.[7] Surgical repositioning of the displaced stomach and gastroesophageal junction to its normal abdominal location, reduction in size of the esophageal hiatus by plication of the lumbar crus of the diaphragm, and esophagopexy/gastropexy are the procedures associated with the greatest degree of success and fewest complications.[7]

A cranial midline celiotomy is performed to access the cranial abdomen, diaphragm, and distal esophagus. The stomach and esophagus are gently retracted caudally while standing on the left side of the animal that is placed in dorsal recumbency. An assistant maintains slight caudal traction on the stomach and esophagus that helps reposition the distal esophagus below the diaphragm. The small intestine is packed in warm saline-soaked laparotomy pads outside the abdominal cavity to the right of the midline. The triangular ligament of the liver is incised and the liver lobes retracted laterally toward the right side of the abdomen to aid in visualization of the esophageal hiatus. The ventral portion of the esophagus is carefully dissected away from the phrenicoesophageal ligament to allow the caudal portion of the esophagus and the LES to be withdrawn into the abdomen. During this dissection, the ventral trunk of the vagus nerve and blood vessels should be avoided. The right and left crura of the diaphragm are then approximated (hiatal plication) with polypropylene or monofilament synthetic suture to reduce the hiatus to a diameter of 1-2 cm, or to the size, which would allow the passage of one finger adjacent to the esophagus.[7] Polypropylene or a monofilament synthetic suture is preferred for the plication (Figure 17-4A).

The esophagus is then "fixed" to the diaphragm to maintain the LES in the abdominal cavity caudal to the esophageal hiatus. This esophagopexy is accomplished by placing 2 sutures on each side of the hiatal opening between the diaphragm and the tunica muscularis along the ventrolateral surface of the esophagus, again taking care to avoid the vagus nerve (Figure 17-4B). Finally, a left-sided incisional gastropexy is performed while the fundus is under a slight amount of caudal traction. The incision on the abdominal wall is made slightly caudal to the incision on the fundus of the stomach so that when traction is applied to the fundus, the two incisions will be in alignment. In cats, the abdominal wall incision for gaqstropexy is placed more caudally to ensure a moderate amount of traction on the fundus when the abdominal wall and gastric incision are aligned.

Postoperative Care

The animal is maintained on medical therapy and special feeding techniques as described under medical therapy for 2-3 weeks postoperatively. If aspiration pneumonia is a concurrent problem, antibiotics, coupage, oxygen therapy, and nebulization may be necessary. Some degree of regurgitation may continue postoperatively but usually resolves in 3-7 days. If reflux esophagitis is severe, a tube gastrostomy can be performed at the time of hiatal hernia repair and the animal fed in this manner until regurgitation is absent and esophagitis has decreased. Resolution of the megaesophagus and improved esophageal motility has been documented as early as 7 days after hiatal hernia correction.[7]

In most cases, the prognosis following hiatal hernia correction is good. Some animals may still require feeding from an elevated position and small frequent feedings especially if there is a generalized gastrointestinal motility disorder.[13]

In some cases where resolution of clinical signs is not complete, a primary LES disorder may exist. These cases may benefit from

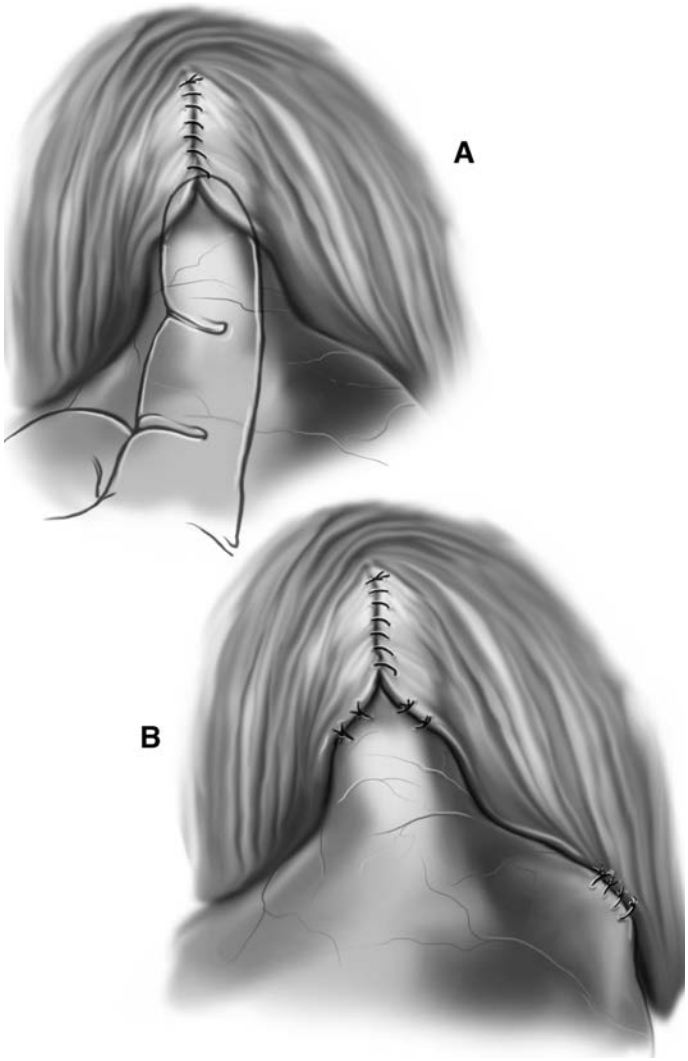


Figure 17-4. A. The stomach and distal esophagus are returned to their normal position. The hiatus is plicated to within 1-2 cm of the esophagus which allows a finger to slide between the hiatus and the esophagus. **B.** An esophagopexy is done by placing sutures between the tunica muscularis of the esophagus and the diaphragmatic portion of the hiatal ring. Lastly a left side gastropexy is done while the fundus has a small amount of caudal traction applied to it.

a fundoplication which is a valvuloplasty technique designed to increase the tone of the LES and decrease reflux.[3,14] This procedure is technically demanding and requires an experienced surgeon to achieve good results. This surgery may also be associated with serious complications such as gastric dilation, stricture, and dysphagia.[15-19]

References

1. Kelly KA. Physiology of the gastrointestinal tract. New York: Raven Press, 1981, 281.

2. Lorinson D, Bright RM. Long-term outcome of medical and surgical treatment of hiatal hernias in dogs and cats: 27 cases (1978-1996). J Am Vet Med Assoc 213: 381, 1998.

3. Ellison GW, Lewis DD, Phillips L et al: Esophageal hiatal hernia in small animals: literature review and a modified surgical technique. J Amer Anim Hosp Assoc 23:391, 1987.

4. Stickle R, Sparschu G, Love N et al. Radiographic evaluation of esophageal function in Chinese Shar Pei pups. J Amer Vet Med Assoc 201:81, 1992.

5. Sivacolundhu RK, Read RA, Marchevsky AM. Hiatal hernia controversies-a review of pathophysiology and treatment options. Aust Vet J 80:48, 2002.

6. Hardie EM, Ramirez III O, Clary EM et al. Abnormalities of the thoracic bellows: Stress fractures of the ribs and hiatal hernia. J Vet Intern Med 12: 279, 1998.

7. Prymak C, Saunders HM, Washabau RJ. Hiatal hernia repair by restoration and stabilization of normal anatomy: an evaluation in four dogs and one cat. Vet Surg 18:386, 1989.

8. Henderson RD. Gastroesophageal function in hiatus hernia. Can J of Surg 15:63, 1972.

9. Pratschke KM, Hughes JML, Skelly C, et al. Hiatal herniation as a complication of chronic diaphragmatic herniation. J Small Anim Pract 39:33, 1998

10. Sontag SJ, O'Connell S, Khandewal S et al. Most asthmatics have gastrointestinal reflux with or without bronchodilator therapy. Gastroenter 99:613, 1990.

11. Hedlund CS. Hiatal hernia. In Fossum TW, ed.: Small Animal Surgery 2nd ed. Philadelphia. Mosby, Inc, 2002: p 326.

12. Johnson SE, Sherding RG: Diseases of the esophagus and disorders of swallowing. In Birchard SJ & Sherding RG eds. Saunders Manual of Small Animal Practice 2nd ed. Philadelphia. W B Saunders 2000 p 727.

13. Knowles KE, O'Brien DP, Amann FJ. Congenital idiopathic megaesophagus in a litter of Chinese shar peis: clinical, electrodiagnostic, and pathologic findings. J Amer Anim Hosp Assoc 26:313, 1990

14. Prymak C: Esophageal hiatal hernia repair In Bojrab MJ, ed. Current techniques in small animal surgery. 4th ed. Baltimore. Williams and Wilkins, 1998, p 197.

15. Gaskell CJ, Gibbs C, Pearson H: Sliding hiatal hernia with reflux esophagitis in two dogs. J Small Anim Pract 15:503, 1974.

16. Waldron DR, Moon M, Leib MS, et al. Esophageal hiatal hernia in two cats. J Small Anim Pract 31:259, 1990.

17. Earlam RJ, Ellis FH. Repair of experimental hiatal hernia in dogs. Arch Surg 95:585, 1967.

18. Donahue PE, Bombeck CT. The modified Nissen fundoplication reflux presentation without gas bloat. Chir Gasroenterol 11:15, 1977.

19. Stanghellini V, Malagelada JR. Gastric manometric abnormalities in patients with dyspeptic symptoms after fundoplication. Gut 27:790, 1985.

Chapter 18

Exploratory Celiotomy

Harry W. Boothe, Jr.

Introduction

Exploratory celiotomy or laparotomy is a commonly performed major surgical procedure in small animals. Performing a celiotomy is similar to performing a physical examination and the veterinary surgeon should be thorough, efficient, and consistent when performing surgery to avoid missing disease within the abdominal cavity. Exploratory celiotomy may be indicated for diagnostic, prognostic, or therapeutic purposes. Ideally, exploratory celiotomy provides an opportunity for both a definitive diagnosis and therapeutic intervention. While noninvasive or minimally invasive methods for evaluating many abdominal tissues have been described, complete exploratory celiotomy with biopsy of appropriate tissues/organs remains an efficient method of assessing the abdominal cavity.

This chapter reviews the principles of exploratory celiotomy with emphasis placed on selected biopsy techniques in small animals, including indications, decision-making, timing and specific surgical techniques.

Indications

Indications for exploratory celiotomy include abnormal accumulations of fluid or objects within the abdominal cavity or abdominal viscera, nonresponsive pain, major organ disruption, nonresponsive dystocia, and abnormal discharges originating from an abdominal tissue. Additionally, exploratory celiotomy is indicated whenever abdominal contents can be evaluated most effectively by inspection and palpation, or when diagnosis is dependent on microbiologic testing or biopsy and histologic analysis of relatively inaccessible regions of the abdomen. Many disease processes are indications for exploratory celiotomy however, trauma, foreign body, and neoplasia are probably the most common reasons for performing surgery.

Decision-Making

Decision-making and surgical judgment are an important part of the surgical process. When to perform surgery, when and what tissues to biopsy, and how to provide therapeutic intervention should be carefully considered preoperatively to produce the best results for the patient.

Timing

When to perform exploratory surgery is one of the most critical decisions to be made. Surgery should be timed to maximize the potential for success, both diagnostically and therapeutically, and to minimize patient risk and morbidity. The chronology of changing historical and physical findings is usually helpful in deciding when to perform surgery and minimizing patient risk and morbidity.[1] Timing is particularly critical when dealing with a septic or traumatized patient.[2] Delay in performing surgery often reduces the potential for success; however, deciding to perform surgery too quickly may result in an inappropriate or unneeded surgical procedure and more trauma to the patient.

Diagnostic peritoneal lavage can reduce uncertainty concerning when to perform an exploratory celiotomy; particularly in abdominal trauma situations.[3,4] The presence of abdominal sepsis is a clear indication for exploratory surgery. Indications of sepsis include free air within the abdomen seen radiographically or the presence of intracellular bacteria on cytologic specimens. While few absolutes guide the surgeon regarding the timing of surgery beyond those relating to a septic abdomen, exploratory celiotomy generally should be performed as soon as it is clear that the patient with abdominal disease is not responding sufficiently to therapy. Additionally, exploratory celiotomy should be scheduled to allow the surgeon adequate time to properly perform all surgical procedures appropriate to the case.

Determining when and what tissues to biopsy during an exploratory celiotomy are also important decisions. Historical and physical findings, preoperative blood work, and imaging studies should guide the surgeon as to which body systems should be sampled. Gross surgical findings also influence the decision of which tissues are to be sampled; all abnormal tissues that cannot be definitively assessed grossly should have biopsies evaluated histologically. Generally, one or more body systems are identified presurgically as target tissues for both careful evaluation and possible biopsy or culture. The sequence of tissue/organ biopsy should be influenced by the contamination potential associated with each biopsy procedure. Procedures with lower risk of contamination such as kidney biopsy are performed first, while those with higher risks of contamination such as intestinal biopsy are performed last.

Biopsy of appropriate tissues and submission of tissue samples for histologic examination should be considered a routine part of most exploratory celiotomies. With the exception of intestinal foreign bodies or hemorrhage secondary to trauma, histologic evaluation of tissues is indicated, particularly when a definitive surgical diagnosis is not apparent at the time of surgery. If the surgeon relies on gross evaluation and interpretation alone (without biopsy) during exploratory celiotomy a correct definitive diagnosis will be missed in many cases.

Aerobic and anaerobic bacterial cultures may be indicated in cases of abscessation, peritoneal fluid accumulation, prostatic disease, hepatobiliary disease, or renal disease. Urine cultures are commonly performed when urinary tract infection may be present.

Therapeutic Intervention

Therapeutic intervention during exploratory celiotomy is directed toward the lesions identified during the procedure. Specific therapeutic goals of exploratory celiotomy include hemorrhage control, correction of contaminating sources, correction of causes of pain, removal of mass lesions or obstructions, and elimination of abnormal fluid accumulations. By effective decision-making and appropriate time management during exploratory celiotomy, there is an opportunity for the veterinary surgeon to

achieve both a definitive diagnosis and provide an appropriate therapeutic procedure for a specific disease process.

Surgical Techniques

Technical considerations when performing a celiotomy include appropriate patient preparation, proper positioning for surgery, surgical approach, equipment needs, method of exploration, biopsy techniques, intra-operative peritoneal lavage, and wound closure.

Patient Preparation and Positioning

The patient is prepared for surgery so that surgical options are maximized for any disease process encountered. Liberal clipping of hair and aseptic preparation is performed over an area extending beyond the limits of the ventral abdomen. Poor or incomplete patient preparation is unacceptable since it could limit surgical options or result in incomplete surgical evaluation, or contamination of the surgical field. In most cases, the patient is positioned in dorsal recumbency on a level table. Centering the animal in dorsal recumbency without lateral "leaning" is important in approaching the ventral midline with the least tissue trauma. Slight downward tilting of either end of the surgical table may be helpful, particularly during surgical exploration.

Surgical Approach

The standard surgical approach for exploratory celiotomy is the ventral midline approach. To examine the abdomen completely, a skin incision is made from the xiphoid process to just cranial to the pecten (pubis). The skin incision is extended parapreputially in the male dog to properly expose the caudal abdominal cavity. Occasionally, extension of the midline incision paracostally may improve visualization of the craniodorsal abdomen (especially liver and diaphragm). The paracostal incision is initiated at the xiphoid process and continued parallel and 3 to 4 cm caudal to the costal arch, and ends level with the tip of the last rib. The abdominal incision may be modified to accommodate specific tissues of interest; however, a large enough skin incision is imperative so as to not compromise appropriate exploration of the abdomen. On entrance into the abdominal cavity the prominent fatty falciform ligament is found between the xiphoid process and umbilicus. Excision of the falciform ligament from its peritoneal attachment by electrocautery or sharp dissection improves visibllity of the cranial abdomen and permits precise closure of the abdominal wall at the completion of the procedure.

Equipment Needs

Surgical instrumentation required for exploratory celiotomy is minimal beyond that of a standard soft tissue surgical pack. Useful additional surgical instruments that should be available include tissue retractors, suction (including tip, tubing, and apparatus), noncrushing intestinal and vascular forceps, and electrocautery. Self-retaining abdominal retractors (e.g.[a] Balfour retractor) markedly improve visibility and access to the peritoneal cavity (Figure 18-1). Balfour retractors are placed with moistened laparotomy sponges positioned to protect the abdominal wall. Suction permits removal of blood, exudate, and



Figure 18-1. The use of Balfour retractors placed over moistened laparotomy sponges is shown. Self-retaining retractors improve visibility and access to the peritoneal cavity.

lavage fluid from the abdominal cavity. A Poole suction tip[b] is usually most effective in body cavities.[5]

Properly placed noncrushing intestinal forceps will assit the solo surgeon in decreasing spillage of intestinal contents while minimizing intestinal trauma during biopsy, enterotomy, or intestinal resection and anastomosis. Hemostatic forceps may provide short-term hemorrhage control until definitive hemostasis is achieved by ligation or electrocautery. Electrocautery is a secure and efficient method of hemostasis when used on smaller vessels. Inappropriate use of electrocautery may result in delayed hemorrhage or an increased rate of wound infection.[5]

Method of Exploration

The technique used in abdominal exploration should be the same regardless of the clinical signs of the patient.[6] After entry into the peritoneal cavity; samples of free peritoneal fluid, if present, are collected for microbial culture. Small amounts of transudate are commonly seen in young animals and are normal. The abdomen is scanned for obvious lesions initially and sources of active hemorrhage or gastrointestinal leakage are identified and treated immediately. Lesions that do not involve active hemorrhage or gastrointestinal leakage are initially ignored in favor of a complete exploration of the abdomen.

The surgeon should perform a thorough, systematic exploration of the abdomen.[1,6-10] Abdominal tissues are evaluated for location, size, shape, color, consistency, and surface contour. Tissues or fluid accumulations are cultured, if indicated, at the time of biopsy sample collection. The cranial aspect of the abdomen is

[a] Balfour retractor, V. Mueller, Baxter Healthcase Corp, McGaw Park, IL. 60085. [b] Poole suction tip, Cardinal Health, McGaw Park, IL 60085.

examined first by evaluating the caudal surface of the diaphragm while carefully retracting the liver lobes caudally. Each liver lobe should be inspected and gently palpated for mass lesions. The hepatic hilus, including the gall bladder, hepatic ducts, hepatic artery, and terminal portal vein branches are examined while gently retracting the stomach caudally. Bile duct patency can be checked if indicated, by attempting to gently express gall bladder contents into the duodenum. Observe and palpate the biliary tract including the bile duct as it traverses the hepatoduodenal ligament. The stomach is thoroughly palpated from the gastroesophageal junction and cardia to the pylorus, including all anatomic surfaces and the greater and lesser omentum.

The spleen is exteriorized to thoroughly evaluate the parenchyma for mass lesions and its vascularity visually and by palpation. Siderotic plaque is commonly seen and appears as grey to greenish colored plaques on the splenic edges. These plaques are regarded as normal and do not require biopsy. Next, inspect and gently palpate the pancreatic body and left pancreatic limb as it extends along the caudal surface of the stomach. Identify and grasp the descending colon and use the mesocolon as an anatomic retractor for abdominal contents by positioning the colon ventrally and to the right. Colonic retraction exposes and allows examination of the left paravertebral region, including the left kidney and proximal ureter, left adrenal gland, aorta, and left ovary and uterine horn.

The spleen is returned to the abdomen or exteriorized and wrapped in a moistened laparotomy pad, which facilitates evaluation of the intestines. The small intestine is evaluated by assessing mesenteric arterial pulsations and peristaltic activity. Examination is initiated at the pylorus, and the duodenum is retracted to evaluate the right pancreatic limb. The pancreas should be gently palpated for the presence of mass lesions. Use the mesoduodenum as a retractor by positioning the duodenum ventrally and to the left side of the abdominal cavity. This maneuver permits examination of the right paravertebral region, including the portal vein, caudal vena cava, celiac artery, epiploic foramen, hepatic lymph nodes, right kidney and proximal ureter, and right ovary and uterine horn. The right adrenal gland can be palpated just dorsal to the caudal vena cava and medial to the right kidney. Trace the duodenum distally to the duodenocolic ligament, which limits exteriorization of the caudal duodenal flexure and proximal jejunum. The surgeon should carefully visualize and palpate the distal duodenum and jejunum, ileum, cecum, and colon.

Evaluate the mesentery of the intestine and its associated lymph nodes, vascularity, and lacteals. Finally, the caudal abdomen, including the distal colon and associated lymph nodes, urinary bladder, distal ureters, proximal urethra, regional lymph nodes (medial iliac, sacral, and hypogastric), prostate and ductus deferens, or uterine body and vagina are visualized and gently palpated.

Biopsy Techniques

After a thorough and systematic abdominal examination, appropriate tissues are biopsied or specific surgical therapeutic intervention is performed. Biopsies of the liver, intestine, lymph node, and kidney are most commonly performed during exploratory celiotomy.

Liver

Liver samples for biopsy may be obtained by various methods.[11-13] One of the simplest and most frequently performed is the "guillotine" method.[11] A loop of monofilament absorbable synthetic suture material is placed around a peripheral portion of a liver lobe and the ligature tightened to cut through and crush the hepatic parenchyma and rest on the hepatic vessels and biliary ducts. A scalpel blade or scissors is used to excise the hepatic tissue approximately 5 mm distal to the ligature.

Another hepatic biopsy method is the finger or instrument fragmentation technique.[12] This method is also limited to sampling the edge of a liver lobe. The proposed biopsy site is isolated from the remaining lobe by carefully crushing hepatic parenchyma using an instrument (e.g., Crile hemostatic forceps[c]) or tips of the thumb and index finger. Parenchymal crushing exposes blood vessels and bile ducts to the isolated section. Ligatures of synthetic absorbable suture material are placed on exposed blood vessels and bile ducts in the isolated lobar section. The exposed vessels and ducts are divided distally to the ligatures and the hepatic sample excised.

Wedge resection of peripheral hepatic tissue is another biopsy option.[12] The proposed biopsy site is isolated by placing and tying one or two rows of full-thickness horizontal mattress sutures of synthetic absorbable suture material in the liver. The biopsy specimen is excised by sharp dissection distal to the sutures. If necessary, additional horizontal mattress sutures may be placed near the incised edge of the liver lobe to achieve hemostasis.

A more versatile hepatic biopsy method involves use of a cutaneous biopsy punch.[d] Any portion of the liver may be sampled; however, smaller, partial thickness samples are obtained.[11] The biopsy punch is placed into the lesion or hepatic tissue and the biopsy obtained by twisting the instrument to free the tissue specimen. Avoid excessive tissue penetration to preserve larger vessels located in the deeper hepatic parenchyma. Hemostasis is achieved by inserting either a topical hemostatic agent (e.g., absorbable gelatin sponge[e]) or a vascularized omental tag into the biopsy defect.[11]

Intestine

Selected upper and lower intestinal regions are accessible to mucosal endoscopic biopsy,[14] however full-thickness surgical intestinal biopsy samples may be taken from any site. Relative advantages of endoscopic, laparoscopic-assisted, and surgical biopsies have been described.[15-17] Principles of intestinal biopsy collection during exploratory celiotomy include the collection of multiple samples along its length, full-thickness sample collection, and protection of the properly-closed biopsy site.[18,19] Technical surgical considerations include closure technique and incisional protection method.

A cutaneous punch[d] is used to penetrate full-thickness into the lumen and obtain the sample.[20] The intestinal defect is closed

[c] Crile hemostatic forceps, Cardinal Health, McGaw Park, IL 60085. [d] Baker's 6 mm biopsy punch, Baker Cummings, Key Pharmaceuticals, Miami, FL 33169. [e] Gelfoam, Pharmacia & Upjohn Company, Kalamazoo, MI 49001.



Figure 18-2. A disposable cutaneous punch (6 mm in dogs and 4 mm [shown here] in cats) is used to obtain an intestinal biopsy sample. The circular defect is closed transversely with simple interrupted sutures using 4 monofilament synthetic suture material.

in a single layer with an appositional suture pattern (e.g., simple interrupted) and monofilament synthetic absorbable suture material (e.g., polydioxanone). Transverse closure of the circular defect is recommended.[21] Leak testing of the biopsy site(s) is performed by isolation of the biopsy site with fingers or Doyen clamps and injection of saline into the isolated intestinal segment.[22] Intestinal incision protection can be provided by using greater omentum or a serosal patch to reinforce the closure technique.[19,23] Greater omentum is placed over the biopsy site if normal wound healing is expected. A serosal patch is performed by placing an adjacent intestinal loop onto the biopsy site and placing serosal to serosal sutures when delayed wound healing is anticipated (e.g., hypoproteinemia, peritonitis).[17,23]

Lymph Node

The following abdominal lymph nodes are frequently biopsied during abdominal surgery: medial iliac, mesenteric (jejunal), pancreaticoduodenal, and colic lymph nodes. Mesenteric (jejunal) lymph nodes may yield less definitive information.[24] While results of fine-needle lymph node aspiration correlate well with those of lymph node histology in small animals with solid tumors, incisional or excisional lymph node biopsy samples are preferred because they provide morphologic information.[25] The blood supply to adjacent tissue (intestine) is carefully preserved when excising a lymph node. Divide the blood supply to the lymph node between sutures, and carefully dissect the lymph node from adjacent tissues.[26,27] The lymph node is handled gently to avoid creation of tissue artifact.

Kidney

Biopsy of the kidney is frequently performed to provide both diagnostic and prognostic information.[27] Surgical biopsy methods include needle biopsy and wedge resection. The needle biopsy technique is less traumatic but yields smaller specimens. The needle[f] is placed through the renal capsule at the caudal aspect of the kidney and directed within the cortex toward the cranial pole. Remove the biopsy needle and apply digital pressure or an interrupted suture over the needle puncture site to achieve hemostasis.

Kidney wedge biopsy yields larger specimens but has a higher risk of hemorrhage. A wedge-shaped segment of renal cortex is excised using a scalpel blade. The defect is closed using mattress sutures of synthetic absorbable suture material placed through the renal capsule and parenchyma. If necessary, the greater omentum may be incorporated into the closure to provide hemostasis and cover the biopsy defect.

Intraoperative Peritoneal Lavage

Following abdominal exploration, specimen collection, and therapeutic intervention, the peritoneal cavity should be lavaged prior to closure. Intraoperative peritoneal lavage using relatively large volumes (1 to 3 L) of warm, isotonic solution assists in contaminant removal (e.g., soft tissue fragments, bacteria, fibrin, fat) and patient warming.[29,30] Use of lavage in patients with intra-abdominal infections is controversial, use in patients experiencing trauma or operative contamination seems appropriate.[29] All lavage fluid should be evacuated by suction prior to body wall closure, as residual saline solution impairs peritoneal defense mechanisms.[29]

Different agents (antimicrobials, antiseptics, or anticoagulants) have been added to peritoneal lavage fluid to reduce the incidence or severity of peritoneal contamination and improve survival.[5] Of these agents, anticoagulants have shown the most benefit and fewest complications.[31,32] Heparin has a beneficial therapeutic effect in experimental canine peritonitis by preventing further fibrin deposition thus reducing fibrinous bacterial entrapment.[30] The net beneficial effect is improved clearance of bacteria from the peritoneal cavity.[30] Heparin may be added to the lavage fluid at a dose of 100 u/kg.

Abdominal Closure

The abdominal wall is closed at the completion of abdominal exploration and after lavage fluid evacuation. Abdominal wall closure technique recommendations are based on biomechanical information of healing abdominal incisions in the dog.[33] Sutures should incorporate approximately 8 mm of tissue on each side of the wound. Sutures should incorporate the linea alba and external fascial sheath of the rectus abdominis muscle only, not muscle or peritoneum (Figure 18-3).[34,35] Incorporating the internal fascial sheath of the rectus abdominis muscle does not yield additional wound strength and is not recommended.[34] Suture tightness should be appropriate for wound edge apposition however excessively tight sutures yield lower long-term wound strength.[36] Either a continuous or interrupted suture pattern is performed using appropriate sized synthetic absorbable or nonabsorbable suture material.[34,37,38] The subcutaneous tissue and skin are closed in a routine fashion.

Summary

Exploratory celiotomy is a commonly performed procedure in small animals. When properly timed and performed, exploratory celiotomy can provide definitive diagnostic, prognostic, and therapeutic intervention to the patient. Critical decisions to be

[f] Coaxial achieve, Cardinal Health, McGaw Park, IL 60085.

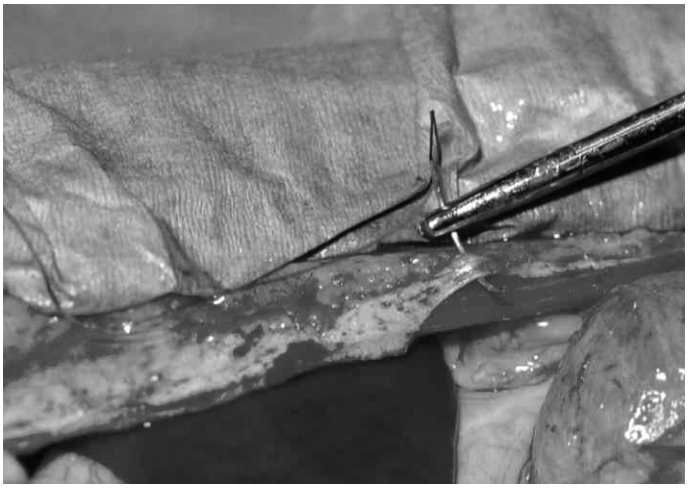


Figure 18-3. Closure of the abdominal wall is shown. Sutures should incorporate approximately 8 mm of fascia on each side of the wound.

made include why, when, and how to perform abdominal exploration, associated biopsy techniques, and the performance of specific surgical procedures.

References

1. Crane SW: Exploratory celiotomy in the diagnosis of gastrointestinal diseases. Vet Clin North Am Small Anim Pract 13:477, 1983.

2. Brasmer TH: D is for digestive; E is for excretory. Major Probl Vet Med 2:137, 1984.

3. Crowe DT, Jr, Crane SW: Diagnostic abdominal paracentesis and lavage in the evaluation of abdominal injuries in dogs and cats: Clinical and experimental investigations. J Am Vet Med Assoc 168:700, 1976.

4. Kolata RJ: Diagnostic abdominal paracentesis and lavage: Experimental and clinical evaluations in the dog. J Am Vet Med Assoc 168:697, 1976.

5. Toombs JP, Clarke KM: Basic operative techniques, In Slatter D, ed.: Textbook of Small Animal Surgery 3rd ed. Philadelphia: WB Saunders Co., 2003, p 199.

6. Vaughn JH: The exploratory laparotomy, In Anderson NV, ed.: Veterinary Gastroenterology. Philadelphia, Lea & Febiger, 1980, p 108.

7. Pearson H: Exploratory laparotomy. Vet Annual 24:250, 1984.

8. White NA II: Surgical exploration of the equine intestinal tract for acute abdominal disease. Compend Contin Educ Pract Vet 10:955, 1988.

9. Boothe HW: Exploratory laparotomy in small animals. Compend Contin Educ Pract Vet 12:1057, 1990.

10. Boothe HW, Slater MR, Hobson HP, et al.: Exploratory celiotomy in 200 nontraumatized dogs and cats. Vet Surg 21:452, 1992.

11. Martin RA, Lanz OI, Tobias KM: Liver and biliary system, In Slatter D, ed.: Textbook of Small Animal Surgery 3rd ed. Philadelphia: WB Saunders Co., 2003, p 708.

12. Bjorling DE: Partial hepatectomy and hepatic biopsy, In Bojrab MJ, ed.: Current Techniques in Small Animal Surgery 4th ed. Philadelphia: Williams & Wilkins, 1998, p 287.

13. Osborne CA, Hardy RM, Stevens JB, Perman V: Liver biopsy. Vet Clin North Am Small Anim Pract 4:333, 1974.

14. Anderson NV: Biopsy of the gastrointestinal system. Vet Clin North Am Small Anim Pract 4:317, 1974.

15. Hall EJ: Clinical laboratory evaluation of small intestinal function. Vet Clin North Am Small Anim Pract 29:441, 1999.

16. Rawlings CA, Howerth EW, Bement S, Canalis C: Laparoscopic-assisted enterostomy tube placement and full-thickness biopsy of the jejunum with serosal patching in dogs. Am J Vet Res 63:1313, 2002.

17. Shales CJ, Warren J, Anderson DM, et al.: Complications following full-thickness small intestinal biopsy in 66 dogs: a retrospective study. J Small Anim Pract 46:317, 2005.

18. Burrows CF: Chronic diarrhea in the dog. Vet Clin North Am Small Anim Pract 13:521, 1983.

19. Brown DC: Small intestines, In Slatter D, ed.: Textbook of Small Animal Surgery 3rd ed. Philadelphia: WB Saunders Co., 2003, p 644.

20. Keats MM, Weeren R, Greenlee P, et al.: Investigation of Keyes skin biopsy instrument for intestinal biopsy versus a standard biopsy technique. J Am Anim Hosp Assoc 40:405, 2004.

21. Matz BM, Boothe HW, Wright JC, Boothe DM. Effect of enteric biopsy closure orientation on enteric circumference and volume of saline needed for leak testing. Can Vet J 2014;55(1): 1255.

22. Saile K, Boothe HW: Saline volume necessary to achieve predetermined intraluminal pressures during leak testing of small intestinal biopsy sites in the dog. Vet Surg 39:900, 2010.

23. Crowe DT, Jr: The serosal patch: Clinical use in 12 animals. Vet Surg 13:29, 1984.

24. Burkhard MJ, Meyer DL: Invasive cytology of internal organs: Cytology of the thorax and abdomen. Vet Clin North Am Small Anim Pract 26:1203, 1996.

25. Langenbach A, McManus PM, Hendrick MJ, et al.: Sensitivity and specificity of methods of assessing the regional lymph nodes for evidence of metastasis in dogs and cats with solid tumors. J Am Vet Med Assoc 218:1424, 2001.

26. Fossum TW: Lymph node biopsy, In Bojrab MJ, ed.: Current Techniques in Small Animal Surgery 4th ed. Philadelphia: Williams & Wilkins, 1998, p 703.

27. Perman V, Stevens JB, Alsaker R, Osborne CA: Lymph node biopsy. Vet Clin North Am Small Anim Pract 4:281, 1974.

28. Osborne CA, Stevens JB, Perman V: Kidney biopsy. Vet Clin North Am Small Anim Pract 4:351, 1974.

29. Schein M, Saadia R, Decker G: Intraoperative peritoneal lavage. Surg Gynecol Obstet 166:187, 1988.

30. Nawrocki MA, McLaughlin R, Hendrix PK: The effects of heated and room-temperature abdominal lavage solutions on core body temperature in dogs undergoing celiotomy. J Am Anim Hosp Assoc 41:61, 2005.

31. Hau T, Simmons RL: Heparin in the treatment of experimental peritonitis. Ann Surg 187:294, 1978.

32. Maleckas A, Daubaras V, Vaitkus V, et al.: Increased postoperative peritoneal adhesion formation after the treatment of experimental peritonitis with chlorhexidine. Langenbecks Arch Surg 389:256, 2004.

33. Rosin E, Richardson S: Effect of fascial closure technique on strength of healing abdominal incisions in the dog: A biomechanical study. Vet Surg 16:269, 1987.

34. Rosin E: Closure of abdominal incisions, In Bojrab MJ, ed.: Current Techniques in Small Animal Surgery, 4th ed. Philadelphia: Williams & Wilkins, 1998, p 327.

35. Karipineni RC, Wilk PJ, Danese CA: The role of the peritoneum in the healing of abdominal incisions. Surg Gynecol Obstet 142:729, 1976.

36. Stone IK, von Fraunhofer JA, Masterson BJ: The biomechanical effects of tight suture closure upon fascia. Surg Gynecol Obstet 163:448, 1986.

37. Johnston DE: Reflections on suturing. Compend Contin Educ Pract Vet 11:56, 1989.

38. Crowe DT, Jr: Closure of abdominal incisions using a continuous polypropylene suture: Clinical experience in 550 dogs and cats. Vet Surg 7:74, 1978.

Chapter 19

Stomach

Principles of Gastric and Pyloric Surgery

Maria A. Fahie

Introduction

The surgeon should consider specific principles of surgery to produce the best clinical outcome in animals undergoing surgical procedures of the stomach and pylorus. These principles are applicable to surgery involving all of the gastrointestinal tract although only procedures involving the stomach and pylorus will be described in this chapter (Table 19-1).

Table 19-1. Considerations in Gastric Surgery

Anatomical knowledge	Suture material and pattern
Potential secondary metabolic disease	Suture pattern
Neoplastic disease	
Prophylactic antibiotic administration	Stapling devices
Approach (ventral midline celiotomy)	Omental patching
Aseptic technique	Abdominal lavage
Atraumatic tissue handling	Postoperative pain management
Palpation techniques for foreign bodies	Postoperative alimentation/ nutrition

Anatomy

The stomach has a rich blood supply derived from the celiac artery. Branches of the left and right gastric, splenic and left and right gastroepiploic arteries provide the main blood supply to the stomach (Figure 19-1). Innervation of the stomach is an important anatomical consideration since its disruption intraoperatively could lead to postoperative gastric and biliary tract dysmotility. The primary innervation is parasympathetic, from the vagus nerve. The dorsal and ventral vagus trunks pass through the esophageal hiatus. The ventral trunk branches to supply the lesser curvature, pylorus and liver. The dorsal trunk supplies the lesser curvature, ventral stomach wall, and then follows branches of the celiac and cranial mesenteric arteries. Sympathetic gastric innervation stems from the celiacomesenteric plexus with fibers following the gastric branches of the celiac artery (Figure 19-2). The spinal ganglia responsible for gastric innervation can span from C2 to L5, and peak from T2 to T10.

The cardia of the stomach and pylorus are relatively fixed in place by the esophagus and hepatoduodenal ligament while the mid-portion of the stomach is more mobile.

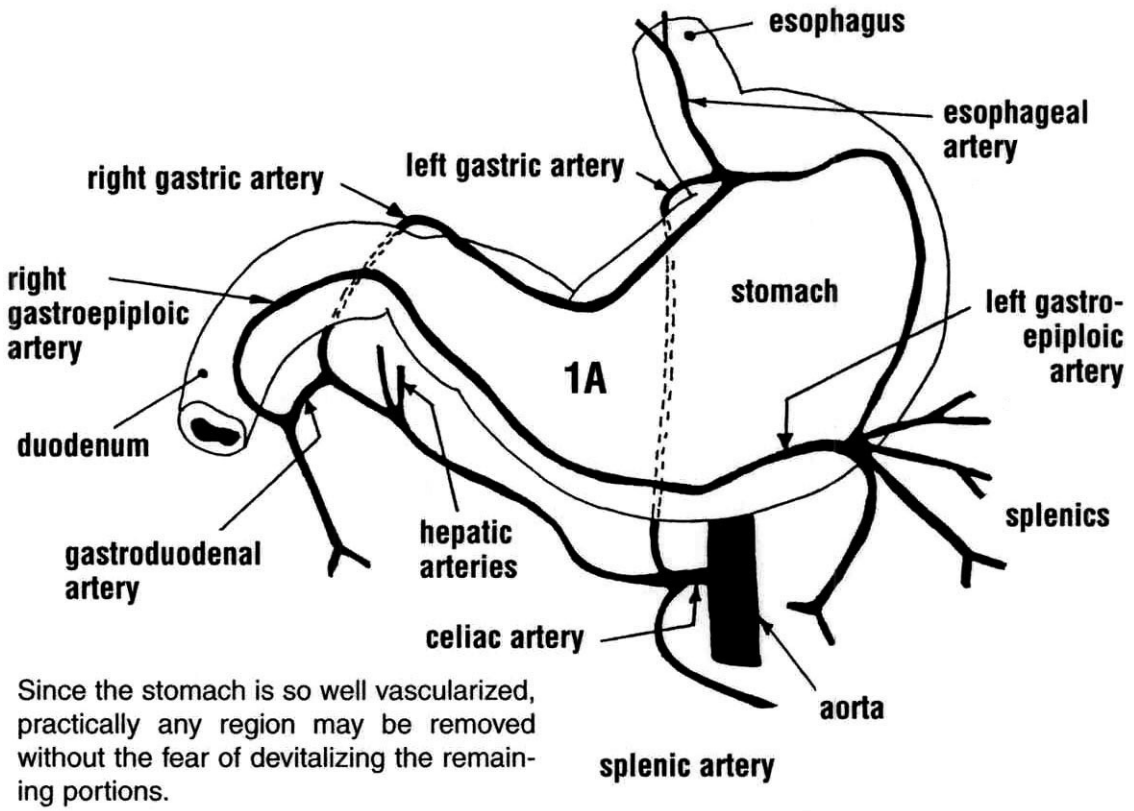


Figure 19-1. Pertinent gastric arterial anatomy. Reprinted with permission from: Anderson S, Gill P, Lippincott L, Somerville M, Shields S, Balfour R, Wilson E. Dimensions in Surgery: Partial Gastrectomy. Pulse (an official publication of the Southern California Veterinary Medical Association): May, 2002.

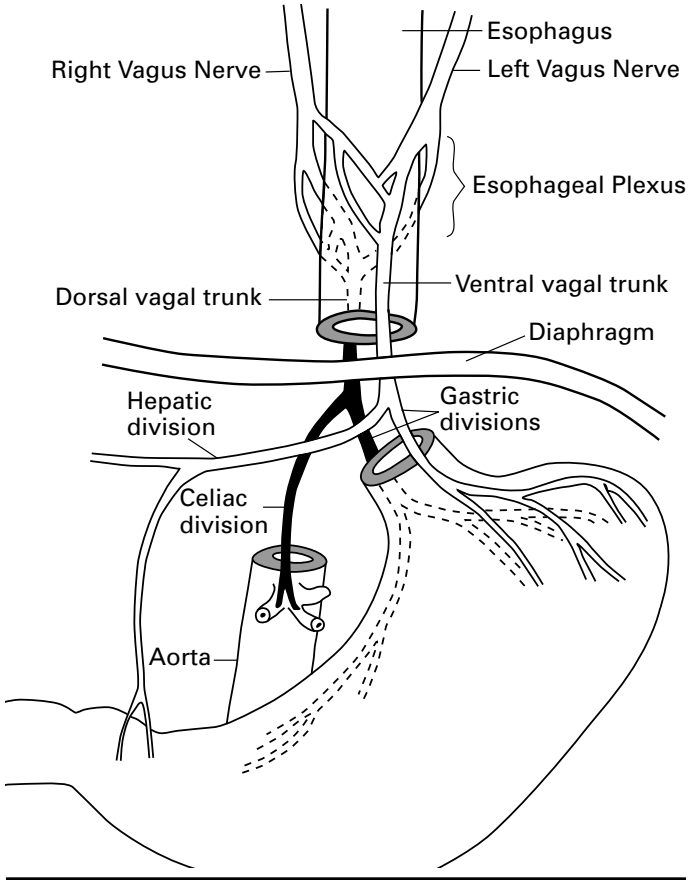


Figure 19-2. Gastric innervation.

In deep chested dogs, access to the stomach and pylorus can be limited by its omental and mesenteric attachments including the hepatoduodenal ligament, a part of the lesser omentum. This structure contains the hepatic arteries, lymphatics, vagus nerve branches, portal vein and bile duct, therefore its incision is associated with risk of damage to those structures (Figure 19-3). Exposure to the stomach is best enhanced by increasing the length of the abdominal wall incision cranially to the xiphoid cartilage of the sternum, and caudally past the umbilicus. When extending cranially, avoid inadvertent incision of the diaphragm resulting in iatrogenic pneumothorax. Exposure can also be enhanced with devices such as a Balfour abdominal retractor.

Metabolic Abnormalities

Animals that require gastric surgery have clinical signs such as vomiting, anorexia, dehydration, abdominal pain, and gastric distension. Medical management of these clinical signs may be necessary pre and postoperatively and may include antisecretory agents (H_2 receptor antagonists), proton pump inhibitors, mucosal protectants, prostaglandin analogues, prokinetic agents and/or antiemetic agents. With acute or chronic vomiting, fluid and electrolyte abnormalities and dehydration are common and should be corrected by intravenous fluid administration prior to anesthesia and surgery if possible. Serum chemistries and electrolyte levels should be obtained prior to surgery. Potassium loss in vomitus and urine can lead to hypokalemia. Hypochloremia can result due to loss of chloride-rich gastric secretions. Hypochloremia can also be exacerbated in hypokalemic patients with reduced renal nephron reabsorption of chloride. The acid-base status of the patient can be normal if loss of gastric hydrochloric acid and bicarbonate-rich duodenal fluid is simultaneous. Metabolic acidosis can be present due to dehydration, prerenal azotemia, and lactic acidosis from compromised tissue perfusion. Hypochloremic metabolic alkalosis indicates severe loss of gastric content and is most indicative of gastric outflow obstruction.

Neoplastic Disease

Dehiscence risk could be higher in patients with neoplasia undergoing gastrotomy for biopsy, although a study of 53 cats with alimentary LSA were not at higher risk.

Prophylactic Antibiotic Administration

Prophylactic antibiotic administration is controversial, since gastric content is generally not high in bacterial numbers in contrast to other regions of the small and large intestine. Opening the gastric lumen is considered a clean-contaminated surgical procedure. Factors that should prompt the surgeon to consider administration of antibiotics include geriatric or debilitated patients, prolonged intraoperative time or compromised aseptic technique. The choice of a specific antimicrobial drug should be based on the organisms within the lumen of the incised organ, or present on the skin at the ventral midline incision site. The duration of antibiotic administration depends upon whether the agent is being administered prophylactically or therapeutically. For prophylactic administration, the antibiotic is given immediately preoperatively (induction of general anesthesia) and continued for the first 12 hours postoperatively. For therapeutic use, the duration of administration should be based upon the pharmacokinetics of the agent used and may extend 10 to 14 days. Cephalexin (22 mg/kg IV or PO TID) is an easily administered, economical antibiotic that provides an adequate spectrum for most gastric procedures.

Approach

The surgeon should perform complete abdominal exploration prior to all gastric procedures in order to determine the extent of the primary disease process or to identify other disease. A ventral midline celiotomy incision is made, beginning at the xiphoid cartilage cranially and extending at minimum to the region of the umbilical scar caudally. An incision extending more caudally is necessary in some cases to perform complete exploration of all abdominal structures. The falciform ligament is prominent in the cranial aspect of the incision and can be either excised or retracted to aid the surgeon's visualization of abdominal structures and make closure of the incision more precise. Branches of the internal thoracic and cranial epigastric artery supply the cranial aspect of falciform tissue near the xiphoid and need to be ligated for hemostasis if it is excised. Smaller vascular branches running perpendicular to the linea into the falciform fat can be ligated or cauterized with electrocautery for hemostasis. Moistened laparotomy pads are placed to protect the edges of the abdominal wall, and self-retaining abdominal retractors such as Balfour abdominal retractors or blunt Weitlaner retractors are used to enhance visualization of the abdominal cavity. The surgeon must carefully avoid damage to the bile duct as it traverses the hepatoduodenal ligament (Figure 19-3). The surgeon should examine all

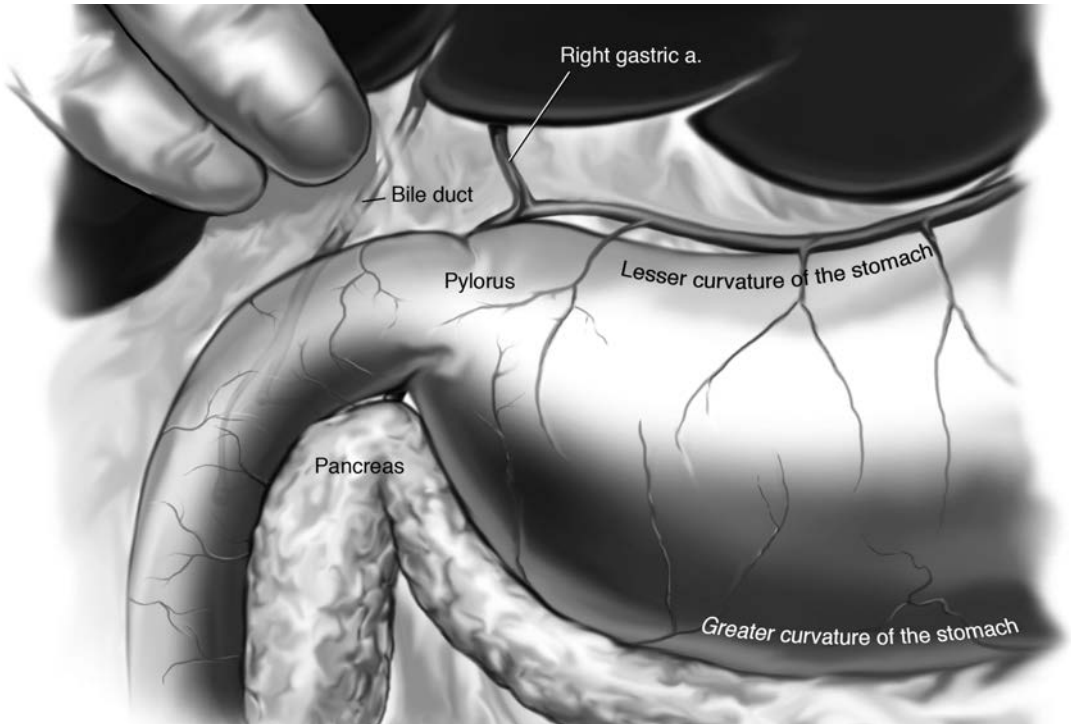


Figure 19-3. Anatomy of the bile duct. It is important to avoid damage to the bile duct as it traverses the hepatoduodenal ligament.

abdominal organs and the entire gastrointestinal tract prior to gastrotomy or enterotomy to reduce manipulation of these potentially contaminated tissues within the abdomen.

Aseptic Technique

The surgeon may use several techniques to decrease contamination of the abdominal cavity and incision during gastrointestinal surgery. Contamination of the abdomen after gastrotomy can be reduced by double-gloving. The surgeon wears an extra one-half sized larger pair of gloves during gastrointestinal tract surgery and removes the contaminated outer gloves prior to abdominal lavage and closure. Contamination of the abdomen by gastric content is reduced by packing off the stomach from the abdominal cavity with laparotomy pads. The stomach is exteriorized as much as possible from the abdomen by placement of stay sutures or Babcock forceps on the serosal surface. Stay sutures are positioned around proposed gastrointestinal incisions to maintain gentle tissue traction and to aid luminal visualization and prevent spillage of luminal contents. The stay sutures should be placed with a substantial (1cm) full-thickness inclusion of gastric wall to prevent accidental tissue tearing as tissues are manipulated. Frequent reapplication of warm saline to exposed tissues and the laparotomy pads is performed intraoperatively and prevents dessication of tissues. After closure of the gastric wall, contaminated laparotomy pads or sponges are removed and replaced. The abdomen is lavaged with warm saline to remove blood clots, tissue debris and to reduce bacterial numbers. Contaminated instruments are discarded and clean instruments used for abdominal wound closure.

Atraumatic Tissue Handling

Gastric tissues can be friable and atraumatic tissue forceps or an assistant's fingers induce less tissue trauma than some surgical instruments during tissue manipulation. Surgical instruments that are valuable for gastric surgery include DeBakey tissue forceps, Babcock forceps and Doyen intestinal forceps. As an alternative to Doyen forceps, Allis tissue forceps can be modified by placing moistened gauze sponges around the arms of the instrument to be applied to tissue. The thickness of the gauze determines the amount of pressure applied. Bobby pins can also be sterilized and used as atraumatic intestinal forceps if an assistant's fingers are not available.

Palpation of Gastric Foreign Bodies

Gastric foreign bodies can be difficult to palpate if there is excessive gastric content and/or if the object is relatively thin, flat and lying against the gastric wall. Gastric contents can be removed by orogastric tube passage and flushing intraoperatively prior to gastrotomy. Alternatively, contents can be carefully removed with suction after gastrotomy, using a Yankaeur or Poole suction tip. If necessary, the surgeon can manually remove gastric content using care to prevent spillage into the abdomen. Gentle and thorough palpation of the entire stomach will permit foreign body location and removal. Palpation of the dorsal gastric surface is aided by digitally creating a fenestration in the greater omentum adjacent and caudal to the greater curvature. If a gastric foreign body is retrieved intraoperatively, the entire intestinal tract should be carefully examined and gently palpated to ensure that no other foreign material is present that could cause an intestinal obstruction. Foreign bodies located in the caudal esophagus can sometimes be removed safely by a gastrotomy incision. Sterile water-soluble lubricant can be used to protect the esophageal and gastric mucosal surfaces during gentle digital palpation and retraction to move the object into the stomach.

Suture Material and Pattern

Many gastric closure techniques are described in the literature including: single-layer appositional or inverting, double layer-inverting or appositional seromuscular (excluding the mucosal layer); and double-layer, appositional and inverting full-thickness closure. The goal of gastric closure is a leak-proof seal with sufficient strength to heal. The submucosal layer, with its abundant collagen, offers the most strength for suture and should be incorporated in all types of closure. A potential justification for exclusion of the gastric mucosal layer is the potential for some types of suture material to wick gastric fluid to the serosa and peritoneum. An advantage of closure of the mucosal layer is reduced postoperative mucosal hemorrhage into the gastric lumen. The classic closure of a hollow viscus using a double-layer inverting pattern such as a Cushing pattern, followed by a Lembert pattern, is widely used and successful. Inverting closure patterns can be difficult to perform if gastric tissue is thickened, and can compromise lumen diameter compared with appositional patterns. Alternatively, some surgeons prefer to close the mucosa with a simple continuous appositional pattern followed by a Cushing pattern as the 2nd layer of closure. It is recommended that the surgeon apply additional throws to each end of continuous suture patterns (5 to 6 throws of suture) to ensure knot stability.

The ideal suture material for gastric closure is monofilament, absorbable [poliglecaprone 25-Monocryl™ (Ethicon, Somerville, NJ), glycomer 631-Biosyn™ (Syneture/Covidien, Norwalk, CT), polydioxanone-PDS II™ (Ethicon, Somerville, NJ) or polytrimethylene carbonate-Maxon™ (Davis & Geck, Chicago, IL)] with a tapered needle, usually 2-0 to 4-0 in size. Based on the speed of gastric tissue healing, there is little justification for use of non-absorbable suture materials. Pyloric obstruction following closure of a gastrotomy incision with polypropylene has been described. Recent studies of absorbable knotless barbed suture material demonstrated comparable bursting strength and closure time for gastrotomy.

Stapling Devices

Stapling devices provide a stronger anastomosis with shorter surgical time compared to hand suturing, however their use may be cost-prohibitive for some patients and procedures. Stapling devices should be considered for partial gastrectomy and/or gastroduodenostomy (Billroth I) diversion procedures. The linear thoracoabdominal (TA™ 30, 55, 90; (USSC, Tyco Healthcare Group LP, Norwalk, CT) and gastrointestinal anastomosis (GIA™ 60, 80; USSC, Tyco Healthcare Group LP, Norwalk, CT) are the most versatile stapling devices for gastric procedures. The TA applies a double staggered row of staples. The GIA applies two double staggered rows of staples and cuts between them.

Omental Patching

The potential benefit of enhanced vascular supply to healing gastric tissue is realized. In most cases, the omentum can be easily advanced over the incision site and tacked to the surrounding gastric serosa with a few simple interrupted sutures of monofilament absorbable.

Abdominal Lavage

Abdominal lavage is indicated following gastric procedures to dilute and/or remove any gastric content spillage. Any gastric incision sites should be lavaged locally after closure, while the stomach is still exteriorized from the abdomen. Prior to abdominal incision closure, copious abdominal irrigation is recommended with warm, isotonic, crystalloid solution such as 0.9% saline or lactated ringer's solution. Lavage should continue until the fluid collected is clear. The preferred temperature of lavage fluid should approximate normal body temperature 38.5°C (101.3°F). In hypothermic patients, fluid at 43°C (110°F) successfully increased body temperature during 2 to 6 minutes of lavage.

Postoperative Pain Management

Appropriate postoperative pain management is being recognized as a key factor in the successful recovery of surgical patients. In gastric surgery patients, nonsteroidal antiinflammatory agents and morphine derivative agents may have undesirable effects on gastric mucosa and gastrointestinal tract motility. Tramadol hydrochloride 50 mg (Tramadol®, 1-2 mg/kg PO-TID, Mutual Pharmaceutical Co. Inc., Philadelphia, PA) may provide necessary pain relief without the side effects discussed above. Maropitant, a neurokinin receptor antagonist and substance P blocker, may provide pain relief and anti-emetic benefits. (Cerenia™, 2-8 mg/kg PO once daily for up to 5 days or injectable, Zoetis, Florham Park, NJ). Gabapentin, an anticonvulsant and analgesic through incompletely understood mechanisms, may also be well tolerated. (Neurontin™, 10-20 mg/kg PO once to twice daily, Pfizer, New York, NY). The proper combination of medications, light activity and appropriate nutrition is necessary for a gradual return to normal function.

Postoperative Alimentation and Nutrition

The benefit of early introduction of nutrients on wound healing is realized. Complications including mucosal atrophy, ileus, and sepsis from bacterial translocation through the intestinal wall are all associated with malnutrition. Decisions regarding diet choice and initiation of oral alimentation must be made considering the preoperative condition, intraoperative findings and surgical procedures performed. Auscultation of gut sounds within 24 hours postoperatively is a positive indication that gastrointestinal motility is resuming. For a simple gastrotomy patient, oral alimentation can begin with water and/or a bland gruel within 24 hours postoperatively, provided no vomiting has been noted. Some patients undergoing gastric surgery might require an alternate route for alimentation postoperatively. Ultimately, this should be anticipated preoperatively, so that the feeding tube placement can occur simultaneously with surgery. In order to bypass the stomach, a jejunostomy tube might be indicated. Research suggests that intrajejunal nutrition enhances the gastrointestinal tract barrier and does not exacerbate pancreatitis. Intravenous total parenteral nutrition is another option but not as successful to prevent mucosal atrophy or increased collagen deposition. Supplementation of vitamin B12 (cyanocobalamin injection) should be considered in gastrectomy and gastroduodenostomy patients, since deficiency and anemia could result. The mechanism underlying the deficiency is the

reduction in numbers of parietal cells to secrete intrinsic factor, which is crucial for vitamin B12 to complex with and become absorbed in the intestine.

Suggested Readings

Bright RM, Jenkins C, DeNovo RC. Pyloric obstruction in a dog related to gastrotomy incision closed with polypropylene. J Small Anim Pract 1994; 35 (12): 629-632.

Clark GN. Gastric surgery with surgical stapling instruments. Vet Clin North Am Small Anim Pract 1994;24:279-304.

Clark GN, Pavletic MM. Partial gastrectomy with an automatic stapling instrument for treatment of gastric necrosis secondary to gastric dilatation-volvulus. Vet Surg 1991: Jan-Feb; 20(1):61-8.

Coolman BR, Ehrhart N, Marretta SM. Use of skin staples for rapid closure of gastrointestinal incisions in the treatment of canine linear foreign bodies. J Am Anim Hosp Assoc. 2000 Nov-Dec;36(6):542-7.

Radlinsky MG. Digestive System. In: Fossum, TW ed. Small Animal Surgery, 4th ed. WB Saunders, Philadelphia, 2013, pp 461-497.

Khurana RK, Petras JM. Sensory innervation of the canine esophagus, stomach and duodenum. Am J Anat 1991,192: 293-306.

Nawrocki MA, McLaughlin R, Hendrix PK. The effects of heated and room temperature abdominal lavage solution on core body temperature in dogs undergoing celiotomy. J Am Anim Hosp Assoc, 41, 1, 61-67, 2005.

Qin HL, Su ZD, Hu LG, et al. Effect of early intrajejunal nutrition on pancreatic pathological features and gut barrier function in dogs with acute pancreatitis. Clinical Nutrition, 21, 6, 2002 469-473.

Cornell K. Stomach. In: Tobias K, Johnston S eds. Veterinary Surgery Small Animal. WB Saunders, Philadelphia, 2012, pp 1484-1512.

Ross WE, Pardo AD. Evaluation of an omental pedicle extension technique in the dog. Vet Surg, 22, 1, 37-43, 1993.

Seim III HB, Bartges JW. Enteral and Parenteral Nutrition. In, Handbook of Small Animal Gastroenterology (2nd ed), 2003, 416-462.

Smith MM, Waldron DR. Approach to the Stomach and Approach to the Pylorus. In: Atlas of Approaches for General Surgery of the Dog and Cat. Philadelphia: WB Saunders, 1993, 184-189.

Tsukamoto M, Enjoji A, Ura K, Kanematsu T. Preserved extrinsic neural connection between gall bladder and residual stomach is essential to prevent dysmotility of gall bladder after distal gastrectomy. Neurogastroenterol Mot 2000, 12: 23-31.

Ehrhart NP, Kaminskaya K, Miller JA, Zaruby JF. In vivo assessment of absorbable knotless barbed suture for single layer gastrotomy and enterotomy closure. Vet Surg 42 (2013) 210-216.

Ellison GW. Complications of gastrointestinal surgery in companion animals. Vet Clin Small Anim 41 (2011) 915-934.

Smith AL, Wilson AP, Hardie RJ, Krick EL, Schmiedt CW. Perioperative complications after full-thickness gastrointestinal surgery in cats with alimentary lymphoma. Vet Surg 40 (2011) 849-852.

Gastrotomy

Maria A. Fahie

Indications

The most common indication for gastrotomy is for identification and removal of suspected foreign bodies or for gastric biopsy. Postoperative peritonitis and stricture are rare in simple gastrotomy patients.

In medium to large patients, with relatively small and smooth gastric foreign bodies, removal can occur with induction of vomiting. Alternatively, gastric lavage or endoscopy can be performed with general anesthesia. A recent retrospective study of 102 dogs undergoing endoscopic removal of esophageal and gastric foreign bodies (FB) concluded a low complication rate provided patients were > 10kg and did not have sharp bone FB or FB present for more than 3 days.

Surgical Technique

The optimal location for gastrotomy is the fundus region, avoiding branches of the left and right gastric and gastroepiploic arteries and associated nerves. Babcock forceps or stay sutures are placed 1-2 cm from each end of the planned gastrotomy site and used to maintain tissue tension to facilitate the incision (Figure 19-4). A scalpel blade (No. 10, 11, or 15) is used to make a controlled full-thickness stab incision. Alternatively, the scalpel blade can be used to make a partial-thickness incision through the serosa, muscularis and submucosa, and the mucosal incision performed alone using a similar blade technique. Metzenbaum scissors can be used to extend the stab incision as indicated in the individual case. Hemostasis is achieved using hemostats or electrocautery. Gastric contents are removed as needed in order to retrieve the foreign body or identify the lesion that prompted the gastrotomy. If a linear foreign body is identified, the section within the stomach should not be detached until the distal extent within the small intestine has been identified via enterotomy. Gastric biopsy is indicated in all cases requiring gastrotomy, whether or not gross abnormalities are detected. A full-thickness strip of tissue can be excised along the gastrotomy incision and submitted for histopathologic analysis.

Closure

Prior to closure, all potentially contaminated instruments, suture material, sponges, drapes and gloves are discarded and replaced. In general, I prefer a two layer gastric closure with a simple continuous appositional pattern using monofilament absorbable suture material usually 2-0 or 3-0 in size. The first layer incorporates the mucosa and the second layer incorporates the submucosa, muscularis and serosa. If there is concern that suture material exposed within the gastric lumen can wick fluid or contaminants into the gastrotomy incision or peritoneal space, then another closure pattern should be chosen. A double layer inverting pattern, such as continuous Cushing or Lembert, can be placed incorporating only the submucosa, muscularis and serosa (Figure 19-4).

Alternatively, stapling devices such as disposable skin staples (4.8 mm by 3.4 mm), or a linear stapling device (TA™) can be used. The primary advantage is reduction in operative time and strength of tissue apposition compared with hand suturing techniques. The primary disadvantage is cost and availability of stapling equipment. Considering these factors, the benefit of staplers is probably limited to larger gastrotomy incisions. The skin stapling technique is described as a double-layer closure, with mucosa/submucosa apposed using a simple continuous pattern of monofilament, absorbable suture material, and serosa/muscularis apposed using skin staples placed at 3 mm intervals facilitated by

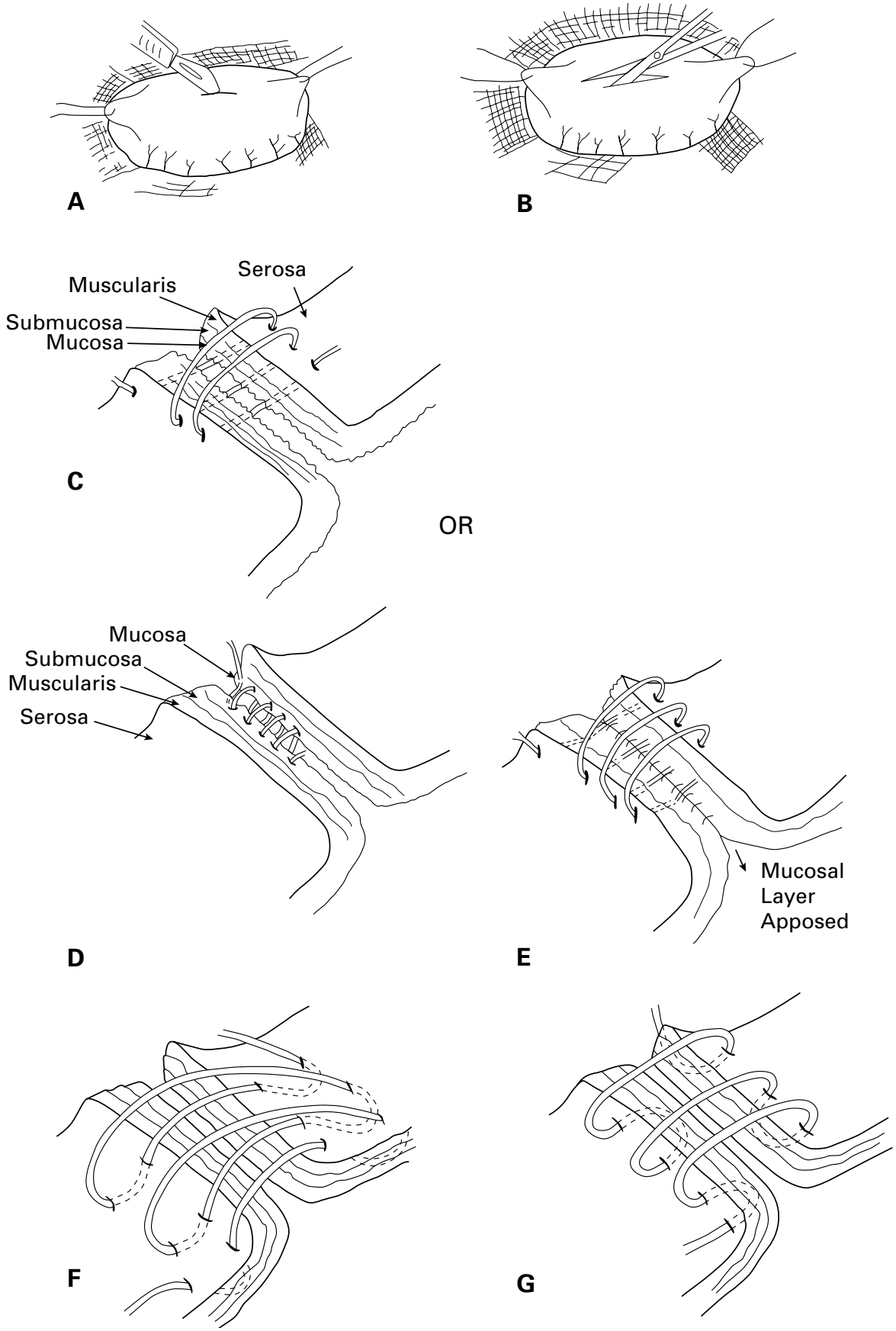


Figure 19-4. Gastrotomy. **A.** Stay sutures allow gentle tissue traction. An inverted #10, 11 or 15 blade is used to make a full-thickness stab incision into the stomach. A partial thickness initial incision is also acceptable. **B.** Extension of the incision with Metzenbaum scissors. **C.** Single-layer closure using a simple continuous appositional pattern incorporating mucosa, submucosa, muscularis and serosa simultaneously. **D.** Alternatively, a double-layer closure can be performed with the initial step of mucosal apposition using a simple continuous pattern. **E.** The second step is submucosal, muscularis and serosal apposition using a simple continuous suture pattern. **F.** Inverting Lembert pattern. **G.** Inverting Cushing pattern.

traction on stay sutures at each end of the incision. A TA™ can be applied to the gastrotomy site, providing an everted closure of all tissue layers at once, with a double staggered row of staples.

Suggested Readings

Gianella P, Pfammatter NS, Burgener IA. Oesophageal and gastric endoscopic foreign body removal: complications and follow-up of 102 dogs. Journal of Small Animal Practice 2009, 50: 649-654.

Partial Gastrectomy (Full-Thickness)

Maria A. Fahie

Indications

Benign gastric neoplasia, such as adenomatous polyps or leiomyoma, can be excised via partial full-thickness gastrectomy. Gastric ulcers that are not amenable to medical management can be excised via partial gastrectomy. Malignant gastric neoplasia (adenocarcinoma, leiomyosarcoma, lymphosarcoma and fibrosarcoma) has often metastasized to local lymph nodes, liver or lungs by the time of diagnosis. Partial gastric resection can only be considered palliative in these patients, since long term prognosis is guarded to grave. Up to 75% of the gastric fundus can be removed without significantly affecting food passage.

Surgical Technique

Abdominal exploration is always indicated prior to partial gastrectomy to evaluate the extent or presence of metastatic or other disease processes. The gastric abnormality to be resected is identified by visualization and palpation and an appropriate surrounding margin of grossly normal tissue is planned. Stay sutures facilitate exposure and manipulation. The vascular supply to the region will include branches of the left and right gastric and gastroepiploic vessels depending on the location of the lesion. Those branches supplying the area to be resected are identified and ligated. The stomach has extensive collateral circulation, therefore ligation of the vascular supply to the region of abnormal tissue can generally be performed without compromise to remaining gastric tissue. Atraumatic intestinal forceps, stay sutures, or assistant's fingers can be used to isolate the tissue that will be remaining. Carmalt forceps can be placed along the margin of the tissue to be resected in order to prevent abdominal contamination with gastric contents. The tissue is incised, removed and submitted for histopathologic analysis.

Closure

For lesions of the lesser curvature, closure of the remaining defect can be performed with hand suturing or stapling techniques similar to those described in the preceding gastrotomy section. Closure of U-shaped defects is facilitated by suturing the appropriate

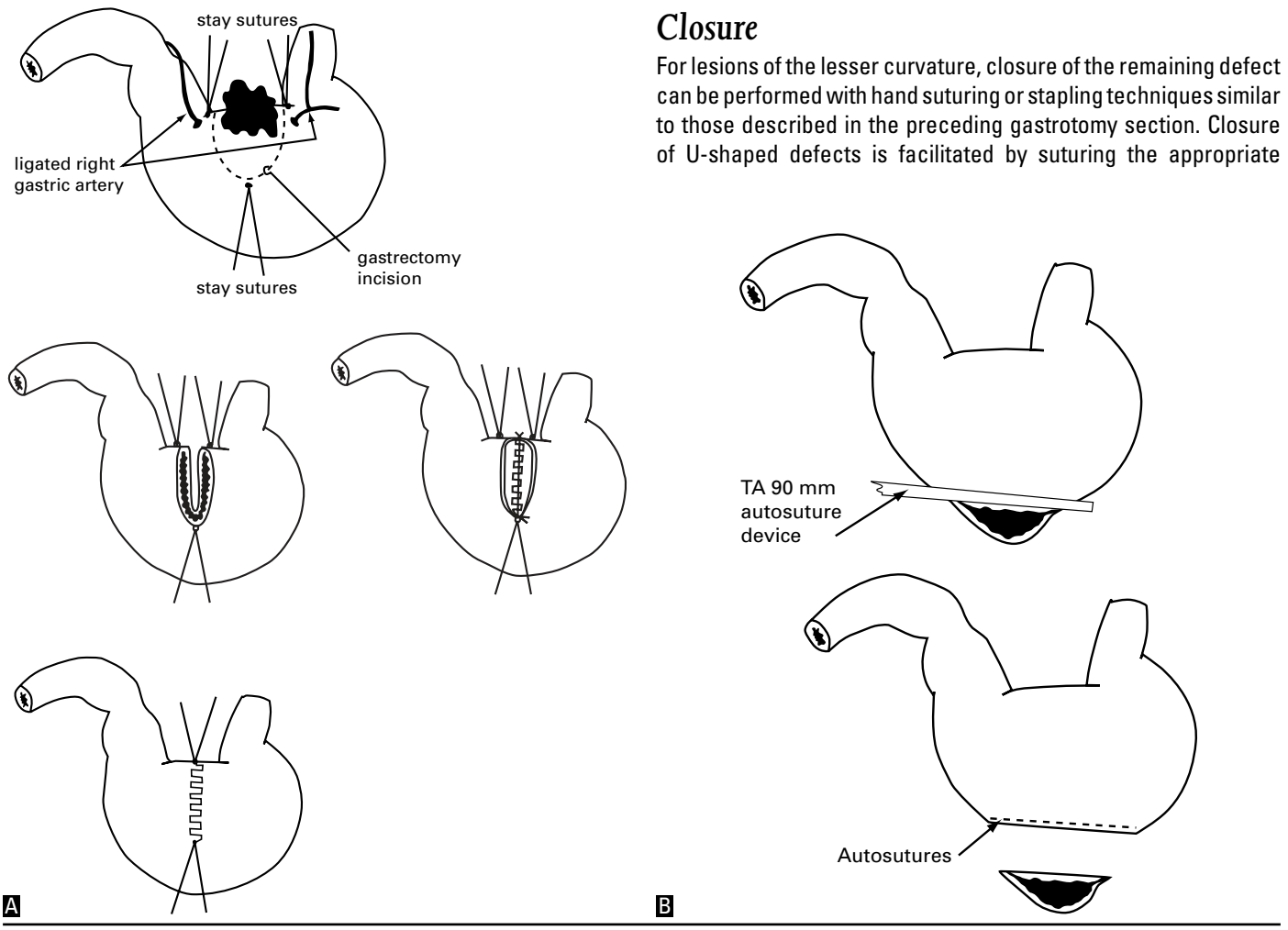
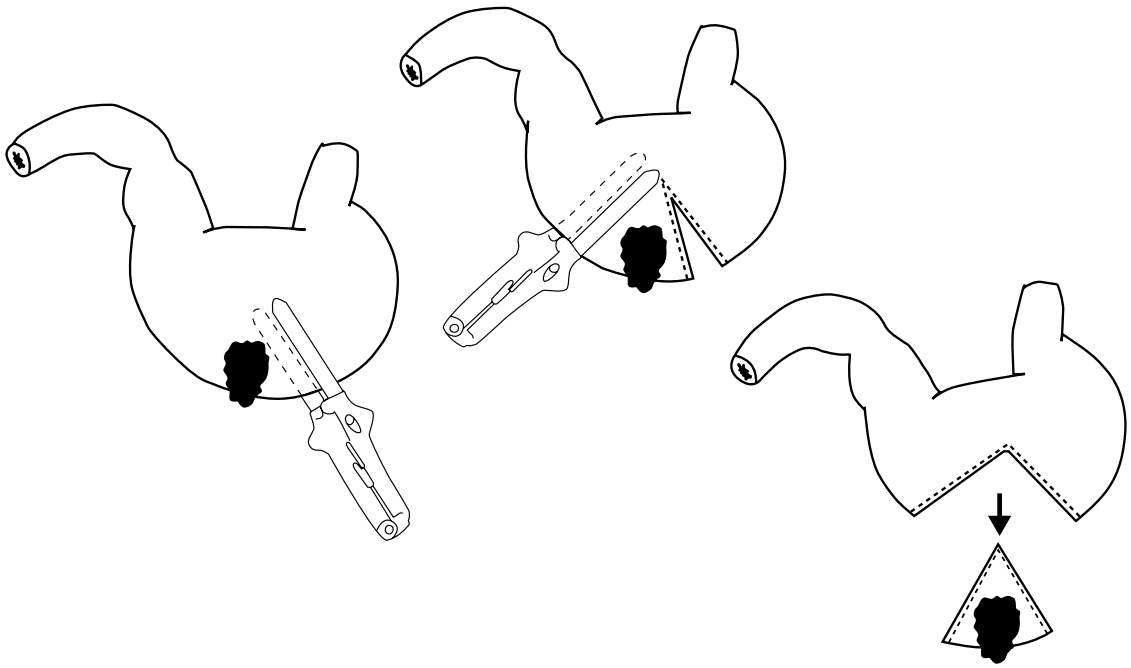


Figure 19-5. A. Hand suturing for closure of partial gastrectomy of lesser curvature. **B.** Linear stapling device for closure of partial gastrectomy of greater curvature.



C

Figure 19-5C. GIA stapling device for closure of partial gastrectomy on greater curvature. Figures 19-5A-C reprinted with permission from: Anderson S, Gill P, Lippincott L, Somerville M, Shields S, Balfour R, Wilson E. Dimensions in Surgery: Partial Gastrectomy. Pulse (an official publication of the Southern California Veterinary Medical Association): May, 2002.

sequence of tissue layers, beginning with the serosal, muscularis and submucosal layers of the dorsal surface of the stomach first which is the deepest layer intraoperatively. Next, the mucosal layer of the dorsal surface, continued to the mucosal layer of the ventral surface. Finally, the serosal, muscularis and submucosal layers of the ventral surface of the stomach. (Figure 19-5A). For lesions of the greater curvature, closure can be performed by hand-suturing similar to as described for gastrotomy. Alternatively, a linear stapling device can be employed (Figure 19-5B). A Carmalt forcep should be placed on the tissue to be resected prior to excision to prevent gastric spillage. An omental patch can be anchored to the stapling site, simply by mobilizing some omental adipose tissue and suturing it to the gastric serosa with several simple interrupted sutures. A GIA™ (USSC, Tyco Healthcare Group LP, Norwalk, CT) stapling device could also be used (Figure 19-5C). This device incises and applies a double layer staggered staple line on each side of the incision. The primary advantage is reduced risk of gastric spillage since the resected tissue also has a double row of staggered staples.

Suggested Readings

Tobias KM. Surgical stapling devices in veterinary medicine: A review. Vet Surg 36 (2007) 341-349.

Partial-Thickness Resection via Gastrotomy Incision

Maria A. Fahie

Indications

This procedure is indicated for mobile, sessile or pedunculated mucosal masses in the cardia or fundus regions.

Surgical Technique

The stomach is exteriorized and isolated from the remainder of the abdominal contents with moistened laparotomy pads. Stay sutures are placed 1 to 2 cm from the ends of the planned gastrotomy. The gastrotomy incision is made in the body of the fundus, directly opposite the mass and midway between the greater and lesser curvature, avoiding gastric arteries and associated nerves (Figure 19-6). The mass is located and a stay suture is placed within it to

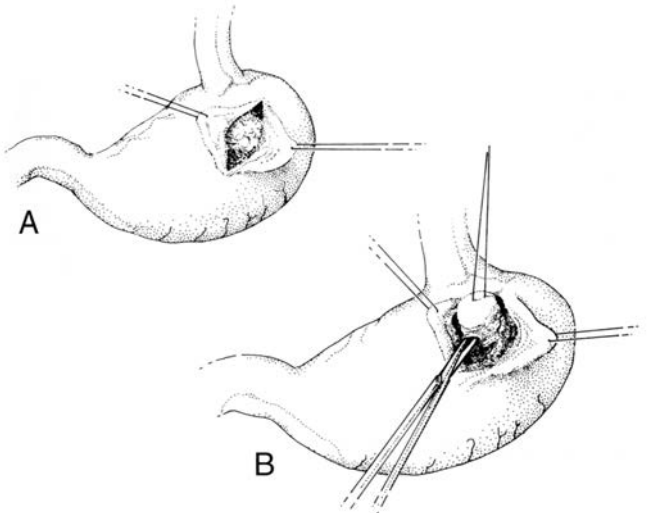


Figure 19-6. Partial thickness submucosal resection of midbody and cardia gastric lesions via gastrotomy. **A.** The gastrotomy incision is made in the fundic region avoiding gastric arteries and nerves. Stay sutures are placed to facilitate manipulation of the incision and avoid spillage of gastric contents. **B.** A stay suture is placed within the mass and traction is applied to allow transection of the surrounding mucosa and submucosa. Closure of the remaining mucosal/submucosal defect should begin prior to complete transection of the mass. A simple continuous appositional or inverting pattern is appropriate.

allow application of traction and to facilitate transection of the surrounding mucosa and submucosa.

Closure

The mucosal closure is initiated prior to completion of transection of the mass, and performed in stages as the mass is gradually transected. A simple continuous appositional or inverting pattern with monofilament absorbable 3-0 or 4-0 suture material is appropriate. The gastrotomy incision is closed as described previously.

Suggested Readings

Kerpsack SJ, Birchard SJ. Removal of leiomyomas and other noninvasive masses from the cardiac region of the stomach. J Am Anim Hosp Assoc. 1994: Sept/Oct, 30; 500-504.

Swann HM, Holt DE. Canine gastric adenocarcinoma and leiomyosarcoma: a retrospective study of 21 cases (1986-1999) and literature review. J Am Anim Hosp Assoc 2002 Mar-Apr;38(2):157-64.

Y-U Antral Flap Pyloroplasty

Maria A. Fahie

Indications

Delayed gastric emptying necessitates medical management with dietary and prokinetic therapy. In some cases, pyloroplasty is indicated in patients with gastric outflow obstruction and delayed gastric emptying due to congenital or acquired pyloric stenosis from benign proliferative disease of antral and pyloric mucosa (chronic hypertrophic pyloric gastropathy). Breeds with a predisposition to this congenital condition include some brachycephalic dogs (English bulldog, Boston terrier, Boxer) and the Siamese cat. Patients with acquired disease are usually middle-aged or geriatric small breeds such as the Lhasa apso, Shih tzu and Maltese. A study of 45 primarily geriatric patients demonstrated an 85% good to excellent response to surgical management of their hypertrophic disease.

Other intramural causes of acquired lesions affecting gastric outflow include neoplasia, foreign body, hypertrophic or eosinophilic gastritis and antral polyps. Extramural lesions of the liver or pancreas can also compress the pyloric region and affect gastric outflow. Pyloroplasty would not be recommended in those patients with malignant, inflammatory or extramural disease.

Pyloroplasty involves a full-thickness incision and reorientation of the pyloric tissue performed to increase the diameter of the gastric outflow tract. I recommend the Y-U antral flap pyloroplasty procedure, instead of pyloromyotomy (Fredet-Ramstedt) or transverse pyloroplasty (Heineke-Mikulicz), since the Y-U pyloroplasty allows for more resection of hypertrophied pyloric mucosa while significantly expanding the diameter of the gastric outflow tract and decreasing gastric emptying time.

Diagnostics to confirm gastric outflow obstruction are crucial and should include contrast radiographs, abdominal ultrasound and gastroduodenoscopy. Retention of a barium meal in the stomach can be difficult to interpret on contrast radiographic studies, since there is a wide range of gastric emptying times reported in normal dogs (5 to 15 hours). Generally, retention > 8-10 hours is considered prolonged and indicative of gastric outflow obstruction. Abdominal ultrasound can identify intramural submucosal/muscularis abnormalities not necessarily visible on radiographs or with endoscopy. Gastroduodenoscopy provides further detail regarding mucosal causes of pyloric obstruction. If pyloroplasty is performed in a patient without diagnostically confirmed gastric outflow obstruction, the procedure can actually cause delayed gastric emptying by overstimulation of the enterogastric reflex from the early passage of hyperosmolar gastric content into the duodenum. Diagnosis of delayed gastric emptying provides the greatest challenge to the surgeon. A review of diagnostic techniques is recommended.

Surgical Technique

The pylorus and pyloric antrum are identified and isolated using a combination of moistened laparotomy sponges and stay sutures. The pyloric ring is identified by palpation. Using a #10 scalpel blade, a "Y" shaped incision is made in the serosa with the base of the "Y" (Figure 19-7A) just oral to the pyloric ring, and each arm of the "Y" being 3 to 5 cm in length. The incision is extended into the gastric lumen through an initial stab incision with the scalpel blade, and extension with scissors. To facilitate advancement of the antral flap, and alleviate continued obstruction from proliferative pyloric mucosa, a rectangular shaped segment of the exposed hypertrophied pyloric ring tissue can be elevated submucosally, from the portion of the pylorus that is exposed by your incision, but not from the flap to avoid disruption of its vascular supply. Excised tissue can be submitted for histopathology. The muscularis and serosal layers (Figure 19-7B) remain intact, and the hypertrophied mucosal/submucosal layers (between e & f) are excised.

Closure

The mucosal/submucosal edges remaining after excision of proliferative tissue (e and f) are apposed in a simple continuous suture pattern with monofilament 3-0 or 4-0 absorbable material. The "Y" shaped incision is then sutured closed to form a "U" shaped incision (Figure 19-7C). Care should be taken to contour the tip of the flap to a "U" shape rather than a pointed "V" shape, since the vascular supply to the point may not be adequate. The most distal suture should be placed initially, to ensure proper flap advancement and placement. The remainder of the tissue can be closed using simple interrupted or continuous appositional sutures, both incorporating all 4 tissue layers (mucosa, submucosa, muscularis, serosa) simultaneously.

Postoperative Care

Appropriate postoperative management depends on the patient's preoperative status. Intravenous fluids should be chosen based on the patient's hydration status, electrolyte levels and acid-base status, and continued postoperatively until adequate oral alimentation is possible. Medical management of vomiting may be indicated. If there is no vomiting, a low-fat diet can be initiated on the first postoperative day to enhance gastric emptying.

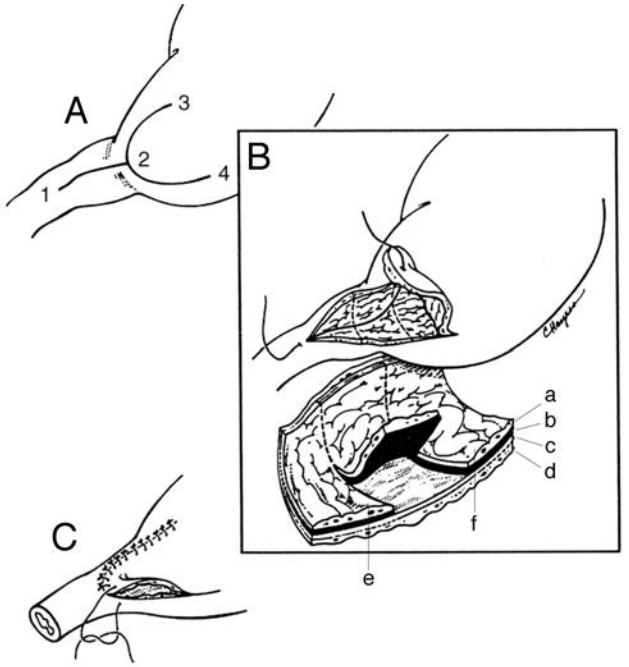


Figure 19-7. Y-U Antral Flap Pyloroplasty. **A.** The base of the "Y" incision extends slightly onto the stomach side of the pyloric ring (1-2). Each limb of the "Y" (1-2, 2-3, 2-4) is approximately 3 to 5 cm in length. **B.** a= sub-serosa, b=muscularis, c=submucosa, d=mucosa, e+f= proliferative tissue located in strip between these two letters; Pyloric submucosal resection of hypertrophied mucosal tissue. **C.** The pyloroplasty incision is closed by advancing the antral flap toward the duodenum, suturing tissue in region #2 to that of region #1. Tissue apposition can be performed using a simple continuous or simple interrupted approximating suture pattern.

Suggested Readings

Allen FJ, Guilford WG, Robertson IG, Jones BR. Gastric emptying of solid radiopaque markers in healthy dogs. Veterinary Radiology and Ultrasound 1996: 37;5:336-344.

Arnbjerg J. Gastric emptying time in the dog and cat. J Am Anim Hosp Assoc 1992: Jan-Feb(28):77-81.

Bright RM, Toal R, Denovo RC, McCracken M, McLauren JB. Effects of the Y-U pyloroplasty on gastric emptying and duodenogastric reflux in the dog. Vet 16 (1987) 392-397.

Burns J, Fox SM. The use of a barium meal to evaluate total gastric emptying time in the Dog. Vet Radiol 1986:27(6):169-72.

Matthiesen DT, Walter MC. Surgical Treatment of chronic hypertrophic pyloric gastropathy in 45 dogs. J Am Anim Hosp Assoc 1986:Mar/Apr:22:241-247.

Miyabayashi T, Morgan JP. Gastric emptying in the normal dog. A contrast radiographic Technique. Vet Radio 1984;25(4):187-91.

Rivers BJ, Walter PA, Johnston GR, Feeney DA, Hardy RM. Canine gastric neoplasia: Utility of ultrasonography in diagnosis. J Am Anim Hosp Assoc 1997;33:144-55.

Stanton ME, Bright RM, Toal R, DeNovo RC, McCracken M, McLauren JB. Effects of the Y-U pyloroplasty on gastric emptying and duodenogastric reflux in the dog. Vet Surg 1987;16(5):392-7.

Matthiesen DT, Walter MC. Surgical treatment of chronic hypertrophic pyloric gastropathy in 45 dogs. J Am Anim Hosp 1986; Mar-Apr (22): 241-247.

Papageorges M, Breton L, Bonneau NH. Gastric Drainage Procedures: Effects in normal dogs I. Introduction and description of surgical procedures. Veterinary Surgery 1987: 16;5:327-331.

Papageorges M, Breton L, Bonneau NH. Gastric Drainage Procedures: Effects in normal dogs II. Clinical observations and gastric emptying. Veterinary Surgery 1987: 16;5:332-340.

Papageorges M, Breton L, Bonneau NH. Gastric Drainage Procedures: Effects in normal dogs III. Postmortem evaluation. Veterinary Surgery 1987: 16;5:341-345.

Sanchez-Margallo FM, Soria-Galvez F, Ezquerra-Calvo LJ, Uson-Gargallo J. Comparison of ultrasonographic characteristics of the gastroduodenal junction during pyloroplasty performed laparoscopically or via conventional abdominal surgery in dogs. AJVR 64 (2003) 1099-1104.

Wyse CA, McLellan J, Dickie AM, et al. A review of methods for assessment of the rate of gastric emptying in the dog and cat: 1898-2002. J Vet Intern Med 2003:17:609-621.

Billroth I (Gastroduodenostomy)

Maria A. Fahie

Indications

Patients with gastric outflow obstruction due to malignant or inflammatory disease (such as adenocarcinoma or severe gastric ulceration) are candidates for pyloric resection and gastroduodenostomy. However, in a review of 24 dogs undergoing pylorectomy with gastroduodenostomy, median survival time with malignant neoplasia was only 33 days. Preoperative weight loss and malignant neoplasia are associated with shortened survival. Hypoalbuminemia and anemia occurred postoperatively in about 62 and 58% of dogs respectively. The goal of gastroduodenostomy is removal of the entire pylorus without disruption of surrounding structures including the extrahepatic biliary tree, or the biliary and pancreatic duct apertures at the major duodenal papilla. If this is not possible, a gastroduodenostomy procedure should not be performed. Gastrojejunostomy (Billroth II) with cholecystoduodenostomy and possible pancreatic enzyme replacement would be necessary for reconstruction after such an extensive resection. The gastroduodenostomy (Billroth I) requires less diversion from normal physiologic conditions compared with gastrojejunostomy (Billroth II) and as a result, there are fewer long term potential complications. In humans, there are fewer problems with gastritis, pancreatic function impairment and lower esophageal sphincter impairment in patients having gastroduodenostomy compared to those having gastrojejunostomy. In a study of 21 dogs having gastroduodenostomy for resection of adenocarcinoma and leiomyosarcoma, postoperative survival ranged from 3 days to 10 months due to recurrence of preoperative clinical signs. A recent retrospective study indicated that preoperative weight loss and diagnosis of malignant neoplasia were significant risk factors that shortened survival time post pylorectomy and gastroduodenostomy. Hypoalbuminemia and anemia commonly contributed to postoperative morbidity.

Approach and Asepsis

In performing gastroduodenostomy, the approach and aseptic technique are similar to that described in the preceding

gastrotomy section. It is crucial to identify and avoid the common bile duct prior to ligation or transection of any structures (See Figure 19-3). Division of the duodenocolic ligament will enable cranial displacement of the caudal duodenal flexure and facilitate approximation of the duodenum and stomach for gastroduodenostomy post-resection of affected tissues.

Surgical Technique

It is important to perform a complete abdominal exploratory to determine the extent of disease prior to gastric diversion procedures. The affected gastric region is identified by visualization and palpation. A surrounding margin of grossly normal tissue is planned. A minimum of 1 cm of duodenum must be maintained orad to the major duodenal papilla in order to avoid postoperative bile and pancreatic duct obstruction. The gastroduodenal artery, biliary tract, hepatic arteries and pancreas must be identified and avoided during manipulations. The vascular supply to the affected region is ligated in a fashion similar to that for a partial gastrectomy procedure (Figure 19-5). Atraumatic forceps are placed on the gastric and duodenal tissue that will remain. Carmalt forceps can be placed on the tissue to be resected. The pylorus is resected and submitted for histopathologic analysis.

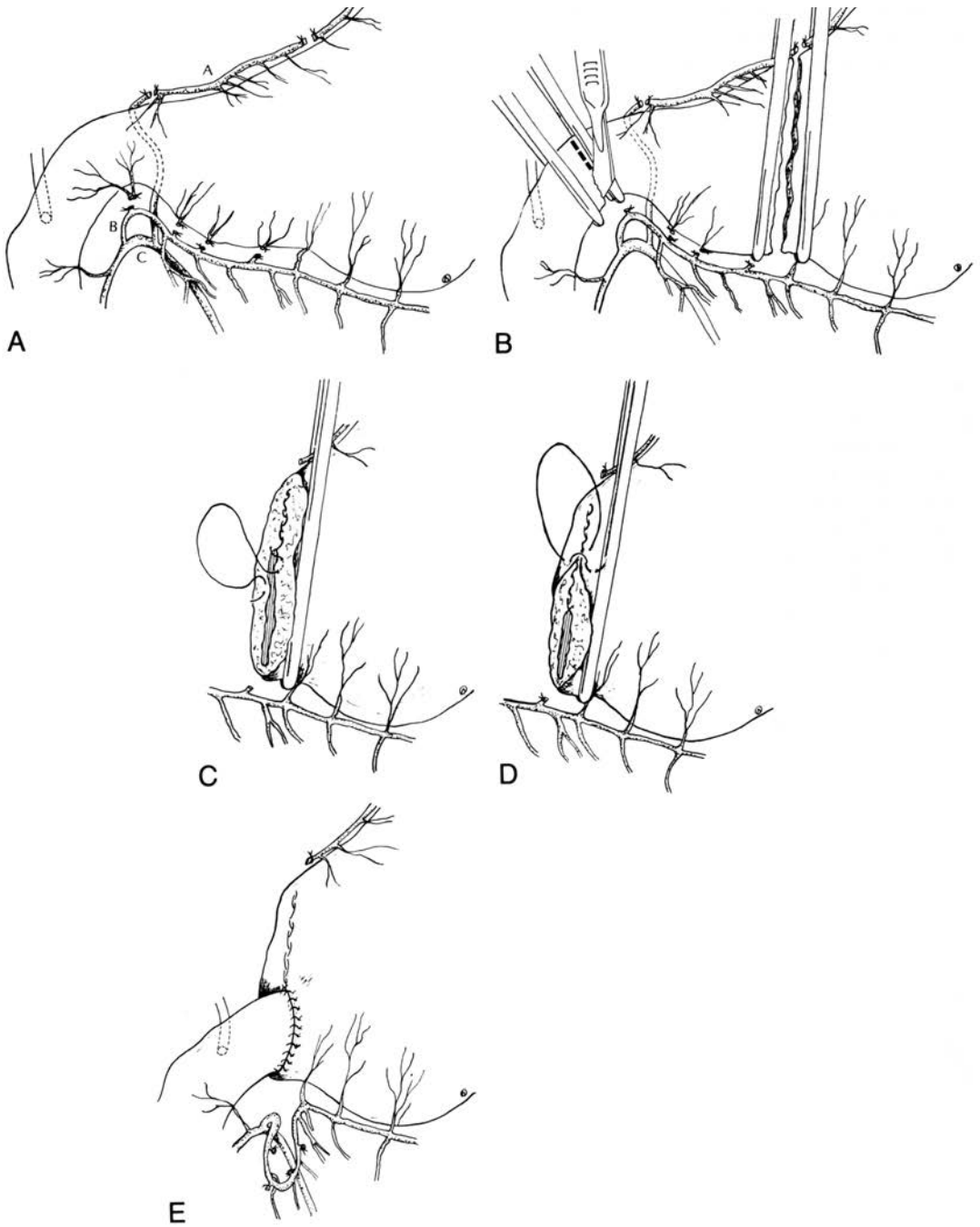


Figure 19-8. Gastroduodenostomy (Billroth I)- Hand suturing **A.** Arteries to be ligated are right gastric (A) and right gastroepiploic (B); avoid the gastroduodenal artery (C). **B.** Excision of pyloric sphincter and canal. **C.** Apposition of gastric mucosa in simple continuous or inverting Cushing or Lembert pattern. **D.** Apposition of gastric seromuscular layers in simple continuous or inverting Cushing or Lembert suture pattern. **E.** Completed anastomosis between stomach and duodenum.

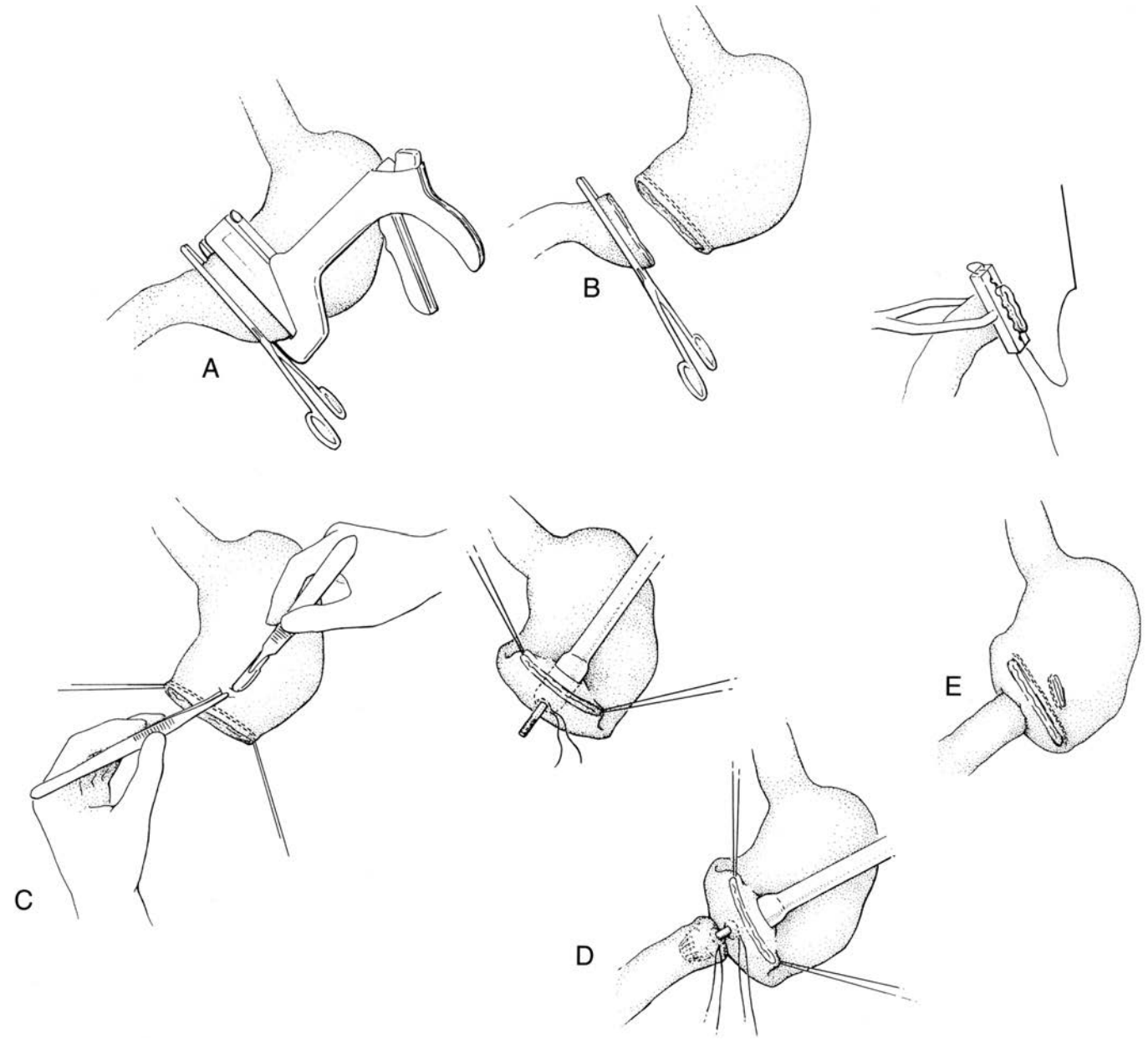


Figure 19-9. A. Technique for side-to-end gastroduodenostomy (Billroth I) using TA and EEA stapling devices to form a circular anastomosis. After ligation and division of omental vessels, the gastric pouch is closed using an appropriate size thoracoabdominal instrument. The instrument is placed proximal (oral) to the mass, leaving appropriate margins of grossly normal tissue and at least 1cm oral to the major duodenal papilla. Tissue forceps are placed adjacent to the mass, and the stomach is transected with a scalpel blade, using the instrument edge as a cutting guide. **B.** The pursestring instrument (Furniss clamp) is placed around the duodenum, distal (aboral) to the mass, leaving appropriate margins of grossly normal tissue. Monofilament 3-0 suture is passed through the superior jaw of the pursestring instrument and returned through the inferior jaw. Tissue forceps are placed adjacent to the mass, and the duodenum is transected using the pursestring instrument edge as a cutting guide. **C.** The pursestring instrument is removed and the appropriately sized end-to-end anastomosis (EEA) cartridge is chosen on the basis of the luminal diameter of the proximal duodenum. A stab incision is made in an avascular portion of the ventral aspect of the stomach, approximately 3 cm away from the edge of the TA staple line. Stay sutures aid in the retraction of the stomach. **D.** The EEA instrument is introduced, without the anvil, through the stab wound on the ventral surface of the stomach. The center rod of the instrument is exited through a small stab incision in the center of a pursestring suture that has been placed on the dorsal surface of the stomach. The pursestring suture is tied on the stomach side, and the anvil is placed on the central rod. The anvil is introduced into the duodenal lumen and the pursestring suture is tied. The EEA instrument is then closed and fired. A circular, double-staggered row of staples joins the organs, and the circular blade in the instrument cuts a stoma. **E.** Completion of the gastroduodenostomy. The EEA instrument has been gently removed from the entry site on the ventral surface of the stomach and the staple line inspected for hemostasis. The gastrotomy incision has been closed with a TA instrument. The completed anastomosis consists of two linear staple closures on the stomach and a circular stapled anastomosis forming the gastroduodenostomy.

Closure

Once abnormal gastric/pyloric tissue is resected, the incisions of the remaining gastric and duodenal segments are anastomosed using hand suturing or stapling devices such as a GIA™ (gastrointestinal anastomosis) (USSC, Tyco Healthcare Group LP, Norwalk, CT), or TA (thoraco-abdominal) 30, 55, or 90™ (USSC, Tyco Healthcare Group LP, Norwalk, CT) depending on the dimensions. When hand suturing, an end-to-end gastroduodenostomy anastomosis is most simple (Figure 19-8). If there is significant disparity between the gastric and duodenal lumen diameters, the antimesenteric border of the duodenum can be incised longitudinally ("fish mouthed") to increase its lumen diameter. The anastomosis should be created to resemble the normal anatomic position of the duodenum in relation to the remaining gastric fundus as much as possible, rather than creating a potential blind sac. Gastric mucosal closure is initiated at the margin of the lesser curvature in either a single-layer simple continuous appositional pattern (incorporating mucosa, submucosa, muscularis and serosa) or a double-layer simple continuous appositional pattern (incorporating mucosa first, then the other 3 layers), both with 2-0 to 4-0 monofilament absorbable material depending on patient size. Once the remaining gastric mucosa is a diameter approximating the normal pylorus, full-thickness simple interrupted or continuous, appositional sutures are used to anastomose the duodenum and stomach. The anastomotic site can be tested for leakage by temporarily occluding the tissue on either side of the site and injecting warm saline solution with a 22G needle and syringe. An omental patch can be anchored over the anastomotic site using a few simple interrupted sutures to anchor omentum to the gastric and duodenal serosa.

Alternatively, stapling devices can be used to create a side-to-end gastroduodenostomy with the dorsal surface of the stomach (Figure 19-9). The pyloric antral margin is closed using a linear stapling device of appropriate size. A purse-string suture is placed in the remaining duodenal margin. A small gastrotomy incision is made (using a scalpel blade or GIA™ stapling device) to allow access of the EEA™ (USSC, Tyco Healthcare Group LP, Norwalk, CT) (end-to-end anastomosis) stapling device. A purse-string suture is placed at the proposed anastomotic site on the dorsal gastric wall and a second gastrotomy incision is performed to allow placement of the EEA™ circular stapling device center rod. The anvil is attached to the center rod and introduced into the duodenal segment. Both purse strings are tied. The EEA is fired, released and removed. The result is a gastroduodenostomy with a staggered row of staples that incorporated the second gastrotomy site. The gastrotomy site used for access of the EEA to the stomach is closed using a TA stapling device of appropriate size.

Postoperative Care

Since the pancreas is in close proximity to the tissues being manipulated, postoperative pancreatitis is possible. Refer to the preceding section on postoperative alimentation and nutrition. Appropriate intravenous fluids and medical management are indicated if vomiting occurs.

Suggested Readings

Buhner S, Ehrlein HJ, Thomas G, Schumpelick V. Effects of nutrients on gastrointestinal motility and gastric emptying after Billroth-I gastrectomy in dogs. Dig Dis Sci 1988 Jul; 33(7):784-94.

Buhner S, Ehrlein HJ, Thomas G, Schumpelick V. Canine motility and gastric emptying after subtotal gastrectomy. Am J Surg.1988 Sep;156(3 Pt 1):194-200.

Eisele J, Kovak McClaren J, Runge J J, et al. Evaluation of risk factors for morbidity and mortality after pylorectomy and gastroduodenostomy. Vet Surg 2010, 39: 261-267.

Hunt G. Bilroth 1 or Bilroth 2: To Do or Not To Do? Proceedings of the American College of Veterinary Surgeons, 2005 p201-4.

Sumner AE, Chin MM, Abraham JL, Berry GT, Gracely EJ, Allen RH, Stabler SP. Elevated Methylmalonic Acid and Total Homocysteine Levels Show High Prevalence of Vitamin B12 Deficiency after Gastric Surgery. Ann Intern Med.1996;124:469-76.

Swan HM, Holt DE. Canine gastric adenocarcinoma and leiomyosarcoma: A retrospective study of 21 cases (1986-1999) and literature review. J Am Anim Hosp Assoc 2002; 38:157-164.

Tobias KM. Surgical stapling devices in veterinary medicine: A review. Vet Surg 36 (2007) 341-349.

Walter MC, Matthiesen DT, Stone EA. Pylorectomy and gastroduodenostomy in the dog: Technique and clinical results in 28 cases. JAVMA Nov 1, 1985:187(9):909-14.

Gastric Dilatation-Volvulus

Jacqueline R. Davidson

Acute gastric dilatation with volvulus (GDV) is a medical and surgical emergency, which can be life-threatening. Acute GDV is usually a disease of large and giant breed dogs,[1] but can occur in any breed of dog or cat. It typically affects middle-aged or older dogs,[1] but there is no sex predilection.

Pathophysiology

Gastric dilatation is generally thought to precede volvulus, although this has not been proven. The composition of entrapped air within the gastric lumen suggests that it is secondary to aerophagia, but may also contain gases produced by fermentation of carbohydrates or diffusion from blood.[2] As the stomach continues to dilate, gastric outflow becomes obstructed by compression of the duodenum and esophagus. The stomach rotates around the long axis of the esophagus, with the pylorus moving cranioventrally from right to left (Figure 19-10). The typical location for the pylorus during GDV is dorsal to the esophagus and fundus, on the left aspect of the abdominal cavity. The degree of gastric rotation may range from 0° to 360°, but most are between 180° and 270°. The spleen is attached to the greater curvature, so it is displaced as the stomach rotates and becomes congested. Gastric dilatation-volvulus can cause severe changes in cardiovascular, respiratory, and gastrointestinal physiology.

Gastric dilatation and increased intraabdominal pressure causes obstruction of the portal vein and caudal vena cava, which causes decreased venous return to the heart and portal hypertension with splanchnic vascular pooling. This results in decreased

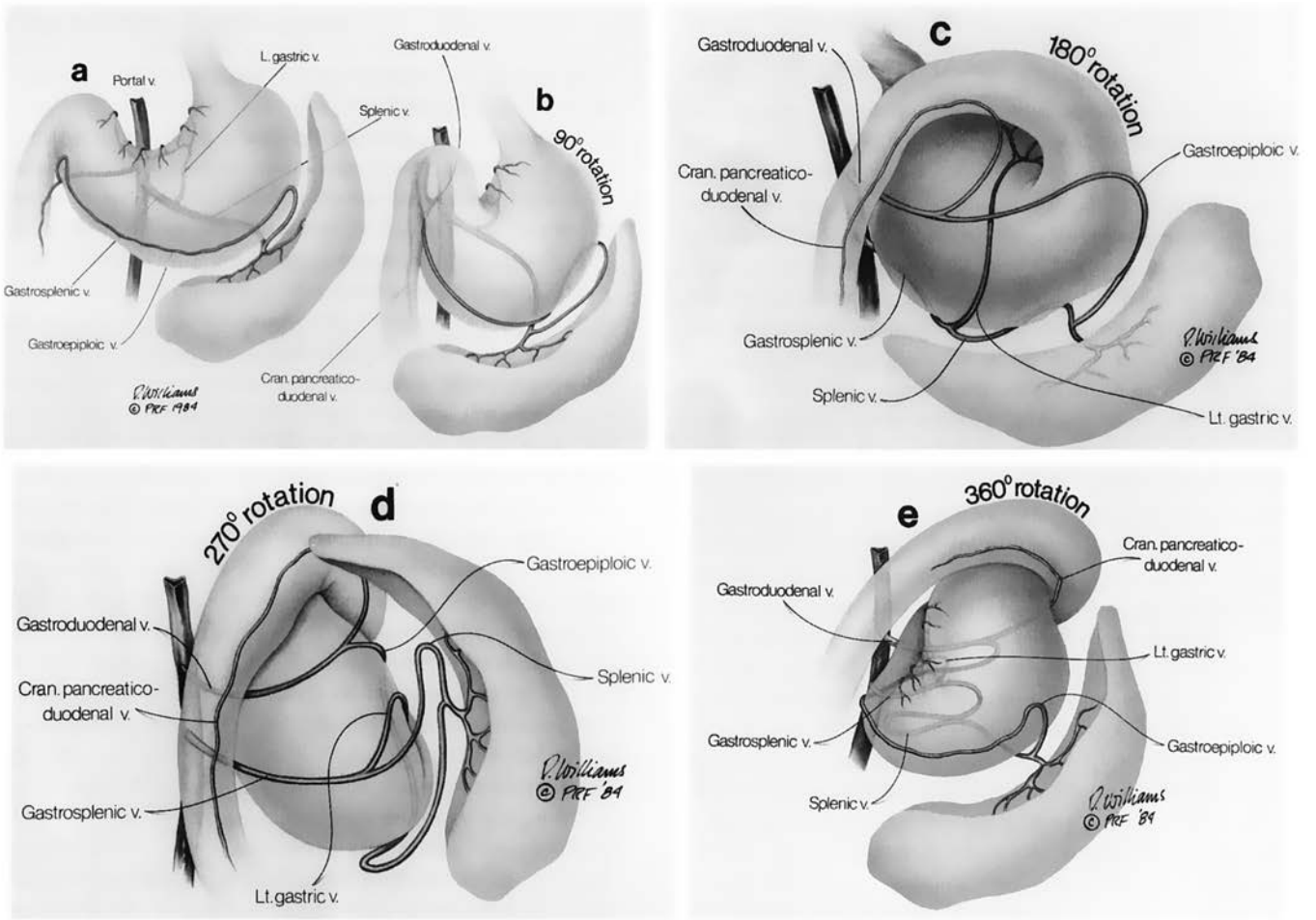


Figure 19-10. *A.* Normal stomach position when viewed in a ventrodorsal position. *B-E.* In gastric dilatation-volvulus, the stomach is rotated about the esophagus in a clockwise direction causing malposition of the pylorus, fundus, and spleen. For illustrative purposes, the gastric dilatation has not been pictured. Vessels are included for orientation.

cardiac output with decreased systemic blood pressure and decreased tissue perfusion to major organs. Portal hypertension also causes interstitial edema, which further compromises the microcirculation of the abdominal viscera and contributes to a reduced vascular volume. When there is lack of blood flow to the tissues, waste products and toxins may accumulate in the hypoxic cells. As blood flow is restored, oxygen free radicals may form and cause tissue damage, known as reperfusion injury.

Although cardiac arrhythmias commonly occur with GDV, the etiology is unclear.[3] Reduced tissue perfusion stimulates the release of catecholamines, which cause peripheral vasoconstriction and increased heart rate, thereby increasing myocardial oxygen demand. Myocardial ischemia has been implicated as a leading cause of the cardiac arrhythmias.[4] Coronary blood flow may be reduced because of the poor venous return and also because of the shortened diastole that occurs with tachycardia. Other factors that could contribute to arrhythmias include substances that are released in association with tissue hypoperfusion or systemic inflammation, electrolyte and acid-base imbalances, and endotoxemia.

Stomach distension prevents normal diaphragmatic excursions, thereby reducing tidal volume. Respiratory rate and effort are increased as a compensatory mechanism, but respiratory acidosis may result. This can exacerbate a metabolic acidosis. Aspiration may occur secondary to vomiting, and this may also impair respiratory function.

Increasing gastric intraluminal pressure impairs perfusion of the gastric wall resulting in hemorrhage, edema, ulceration or necrosis, particularly to the gastric mucosa. More severe pressure will compromise perfusion of the seromuscular layers, and can result in full thickness necrosis with perforation and subsequent peritonitis. Both reduced cardiac output and mechanical kinking or avulsion of vessels can further compromise blood flow to the stomach wall. The short gastric vessels are often affected, but the extensive gastric collateral blood supply makes full-thickness necrosis uncommon.

Local lymphatic tissue that has suffered ischemic damage is unable to prevent translocation of intestinal pathogens from the gastrointestinal mucosa into the circulatory system. Translocation of bacteria to the gut-associated lymphatics is believed to stimulate production of numerous cytokines, which is a factor in promoting the systemic inflammatory response syndrome and multiple organ dysfunction syndrome.[6] In addition, impaired return of lymphatic and venous fluid inhibits delivery of pathogens to the immune centers. When circulation is restored, there is potential for release of pathogens and endotoxins into

the systemic circulation. Systemic effects include decreased systemic vascular resistance and increased cardiac output, increased vascular permeability, hepatocellular dysfunction, renal tubular damage, microvascular occlusion, and disseminated intravascular coagulation.

Diagnosis

A presumptive diagnosis of GDV or gastric dilatation can often be made based on signalment, history and physical examination. Clinical signs include restlessness, hypersalivation, and unproductive vomiting or retching. A distended, tympanic abdomen is usually obvious, but may not be apparent in some cases. The dog may be dyspneic due to pain, aspiration, or abdominal distention. Dogs may present in compensatory shock, with tachycardia, tachypnea, pale mucous membranes, prolonged capillary refill time, normal pulses, and cold extremities with normothermia. Endotoxic shock differs from compensatory shock in that the membranes may be injected or "muddy", and fever may be present. Severely affected dogs may be recumbent or comatose. Signs of noncompensatory shock include bradycardia, weak respiration, white or muddy mucous membranes, no capillary refill, poor pulses, cold extremities and hypothermia.

Initial hematology may indicate hemoconcentration (increased packed cell volume and total protein), and a stress or inflammatory leukogram (increased polymorphonuclear leukocytes, increased monocytes, decreased lymphocytes). In cases of decompensation, polymorphonuclear leukocytes are decreased. Thrombocytopenia may be evident on hematology. Changes in activated clotting time, prothrombin time, and partial thromboplastin time may suggest a hypercoagulable state or disseminated intravascular coagulation. Abnormalities of multiple values in the coagulation profile are associated with an increased likelihood of gastric necrosis.[7]

Initial clinical chemistries may show evidence of liver damage (increased alanine transaminase), biliary stasis (increased total bilirubin), and prerenal or renal azotemia (increased blood urea nitrogen and creatinine). There may also be evidence of blood loss or transudation (lower than expected total protein and albumin) and impaired glucose control. There may be electrolyte abnormalities, particularly hypokalemia. Plasma lactate may be elevated due to anaerobic metabolism or endotoxins.[8] Plasma lactate levels are presumably an indication of the degree of systemic hypoperfusion, and higher levels are seen in dogs that are more severely affected clinically.[8] Increased lactate concentration may also be associated with gastric necrosis.[8] However, change in lactate during the treatment period provides more useful information regarding prognosis than the plasma lactate level at a single point in time.[9]

Abdominal radiographs are usually not needed to diagnose gastric dilatation, but may be used to confirm the clinical diagnosis or to distinguish between simple gastric dilatation and GDV. Emergency medical therapy is initiated to stabilize the dog before obtaining radiographs. The right lateral recumbent view is the best single view to determine whether the stomach is rotated.[10] Radiographs of dogs with gastric dilatation reveal a large, uniform gas-filled gastric shadow and possibly excessive gas in the intestines as well. Gastric dilatation-volvulus is suspected if a tissue density separates the gas-filled gastric shadow into two regions. The gas-filled pylorus may be identified dorsal to the fundus of the stomach. Gas within the gastric wall is suggestive of gastric necrosis, but is not a reliable finding.[11] Free gas is present in the abdominal cavity in cases where the stomach has perforated. However, free gas may also be present in those cases where trocarization for gastric deompression was performed prior to obtaining radiographs. Gas in the esophagus may be due to aerophagia and does not necessarily indicate megaesophagus.

Treatment

The initial therapeutic goals are to relieve the gastric distention and treat the cardiovascular compromise. Treatment should begin immediately, and diagnostic tests may be performed as the dog becomes more stable.

Initial Medical Therapy

Aggressive fluid therapy with isotonic crystalloids should be instituted immediately. Several large-bore catheters may need to be placed in order to achieve an adequate rate of fluid administration. The catheters should be in the cephalic or jugular veins, since venous return from the hind limbs may be compromised. The administration rate of crystalloid fluids is 90 ml/kg. A quarter of the total shock dose is administered quickly, and the dog is reassessed. It is preferable to administer crystalloids (10 to 40 ml/kg) in conjunction with high molecular weight fluids (10 to 20 ml/kg hetastarch or 5 ml/kg of 7% hypertonic saline solution in 6% dextran 70 over 5 minutes).[12] After initial fluid administration, crystalloid fluids are continued at approximately 20 ml/kg/hr, depending on the dog's response to therapy. Dopamine or dobutamine (2 to 5 µug/kg/min) may also be indicated to improve splanchnic blood flow or provide positive inotropic effects. If disseminated intravascular coagulation is suspected, plasma and heparin (100 mg/kg SQ TID) therapy may be instituted.

The acid-base status of dogs with GDV is unpredictable, so specific acid-base therapy should not be administered unless a blood gas analysis has been performed. Acid-base imbalances will generally self-correct as effective circulation is restored. However, if the pH is below 7.2, bicarbonate therapy may be indicated. Oxygen therapy (40 to 100% inspired) administered by face mask, nasal catheter, or oxygen cage may be beneficial to offset the effects of impaired ventilation.

Many dogs develop cardiac arrhythmias in association with GDV.[13] The arrhythmias are most commonly ventricular in origin and may include premature ventricular contractions, ventricular tachycardia, or idioventricular tachyarrhythmias. Treatment should be considered if fluid volume has been adequately replaced and the arrhythmia is life threatening or causing poor perfusion. Pain control, and correction of potassium and acid-base abnormalities are important aspects of management prior to specific antiarrythmia therapy. Treatment may be indicated in the presence of R-on-T phenomenon or ventricular tachycardia. Treatment may also be considered if PVCs occur at a rate of more than 20 to

30 per minute, there are runs of PVCs, or PVCs are multifocal in origin. Pulse quality and mucous membrane color should be evaluated and used to guide therapeutic decisions. The initial treatment of choice for ventricular arrhythmias is 2% lidocaine hydrochloride without epinephrine. A slow bolus (1 to 2 mg/kg IV) may be administered until a normal sinus rhythm appears. This may be repeated twice within a 30-minute period if needed, but the entire dose should not exceed 8 mg/kg. If the arrhythmia persists, a continuous intravenous infusion of lidocaine (50 to 100 µug/kg/min) is administered, adjusting the rate based on the dog's response to therapy. Procainamide (10 to 40 µug/kg/min IV or 6 to 8 mg/kg IM q.i.d.) may be used instead of lidocaine in refractory cases. Antiarrhythmic therapy should continue for three to five days after the arrhythmias resolve.

Treatment with corticosteroids and antibiotics are not necessary in uncomplicated cases of GDV. There is no confirmed clinical benefit from corticosteroids when they are administered after the onset of shock. Risks of corticosteroid use include impaired immune function and possible increased rate of gastrointestinal ulceration. If used, they should be given gradually after adequate volume restoration has been initiated to prevent further hypotension.

If gastric ischemia or necrosis is suspected, broad-spectrum antibiotics such as first- or second- generation cephalosporins or ampicillin are used. Drugs such as deferoxamine and allopurinol have been used experimentally to prevent reperfusion injury, but their use has not been supported by clinical trials.[14]

During treatment, parameters such as heart rate, pulse character, mucous membrane color, capillary refill time, urine output, plasma oncotic pressure, and blood pressure are monitored to assess cardiac function and tissue perfusion. In addition packed cell volume, total solids, and plasma lactate levels may be useful measurements to monitor response to fluid therapy. Serum cardiac troponin I and cardiac troponin T may be useful markers of myocardial injury.[4] Elevated myoglobin can be seen and is not specific to myocardial injury, but may be used as one indicator to help estimate prognosis.[5]

Gastric Decompression

Gastric decompression should be performed immediately after intravenous catheters have been placed and volume support has been started. Decompression improves venous return, ventilation, and gastric wall perfusion. However, it can also result in systemic release of endotoxins and metabolic waste products that have accumulated in the areas of vascular stasis and ischemia. This may cause deterioration in clinical signs that necessitate further monitoring and treatment. The stomach is decompressed by orogastric intubation or trocarization. Temporary gastrotomy may be used in rare cases. Esophagostomy or nasogastric intubation may be used to provide continued decompression.

Before attempting orogastric intubation, the distance from the dog's nose to the 13th rib should be measured to estimate the length of tubing needed. A roll of white tape may be placed in the dog's mouth as a speculum. A well-lubricated stomach tube is passed slowly through the tape roll and into the esophagus and stomach. The tube should be passed gently to avoid esophageal or gastric tears. Rotating the tube as it is advanced may facilitate passage. In some cases, elevation of the forequarters may decrease pressure on the gastroesophageal junction and allow the tube to pass. Failure to pass the tube does not necessarily indicate gastric volvulus, nor does easy passage indicate the presence of a simple dilatation. If the orogastric tube cannot be passed, or if the dog strongly resists the procedure, needle trocarization may be performed first.

To trocarize the stomach, two to four large-bore (14- to 16- gauge) over-the-needle catheters are inserted percutaneously through the abdominal and stomach walls in the region of greatest abdominal distention. The skin should be clipped and aseptically prepared prior to catheter insertion. After some gas has been evacuated from the stomach it may be easier to pass an orogastric tube to remove more gas, fluid and ingesta. Complications, such as peritonitis, are rare with trocarization.

If orogastric intubation is unsuccessful and surgery cannot be performed for an extended period, temporary gastrostomy may be considered to maintain gastric decompression. An inverted "L" line block of 2% lidocaine is performed in the right paracostal region. An incision is made in the anesthetized region. The abdominal musculature is separated between the fibers. The stomach is identified and sutured to the skin edges circumferentially with a continuous suture pattern to provide a good seal. An incision is made in the exposed stomach wall to allow decompression. The temporary gastrostomy has several disadvantages. It does not correct gastric rotation and it increases the risk of peritonitis. In addition it may interfere with the permanent gastropexy and must be repaired prior to performing the definitive abdominal surgery. Therefore, this procedure should only be performed if absolutely necessary.

Client Education

The etiology of GDV is not well understood. It is likely that multiple environmental and hereditary factors play a role.[16] Anatomic differences, diet, gastric motility, and gastrointestinal hormones have been studied. Irish setters with an increased thoracic depth to width ratio are at increased risk. Although overeating, pre- or postprandial exercise, large water consumption, and temperament of the dog have been implicated, there is little evidence to support any of these factors as the cause.[1,17,18] Factors associated with an increased risk of GDV that were identified in a prospective study of large breed dogs include increasing age, having a first-degree relative with GDV, faster eating speed (for large breed dogs, but not giant breeds), and eating from a raised food bowl.[17] Feeding a large volume once daily is associated with an increased risk of GDV compared to feeding a smaller volume twice daily.[18] Feeding dry foods containing fats or oils among the first four label ingredients was associated with a significant increased risk of GDV in one retrospective study.[19] Poor body condition and a history of chronic health problems are also associated with an increased risk of GDV, although a causal relationship has not been established.[18] Therefore, it is recommended that large and giant breed dogs be fed more than once

daily using a food bowl that is not elevated. It can also be recommended to avoid breeding dogs that have a first-degree relative that has had GDV. Prophylactic gastropexy may be considered for breeds that have a high risk of developing GDV.[20,21]

Dogs that have had one episode of GDV are more likely to have another, although gastropexy reduces this likelihood. Clients should be educated regarding the potential for recurrence and the clinical signs that should alert them to seek prompt veterinary care. Survival rates for dogs that are treated surgically for GDV are about 85%.[3,13,22-23]

References

1. Glickman LT, Glickman NW, Schellenberg DB, et al. Incidence of and breed-related risk factors for gastric dilatation-volvulus in dogs. *Journal of the American Veterinary Medical Association* 2000;216:40-45.

2. Caywood DD, Teague HD, Jackson DA, et al. Gastric gas analysis in the canine gastric dilatation-volvulus syndrome. *Journal of the American Animal Hospital Association* 1977;13:459-462.

3. Brourman JD, Schertel ER, Allen DA, et al. Factors associated with perioperative mortality in dogs with surgically managed gastric dilatation-volvulus: 137 cases (1988-1993). *Journal of the American Veterinary Medical Association* 1996;208:1855-1858.

4. Schober KE, Cornand C, Kirbach B, et al. Serum cardiac troponin I and cardiac troponin T concentrations in dogs with gastric dilatation-volvulus. *Journal of the American Veterinary Medical Association* 2002;221:381-388.

5. Adamik KN, Burgener IA, Kovacevic A, et al. Myoglobin as a prognostic indicator for outcome in dogs with gastric dilatation-volvulus. Journal of Veterinary Emergency and Clinical Care 2009; 19:247-253.

6. Winkler KP, Greenfield CL, Schaeffer DJ. Bacteremia and bacterial translocation in the naturally occuring canine gastric dilatation-volvulus patient. *Journal of the American Animal Hospital Association* 2003;39:361-368.

7. Millis DL, Hauptman JG, Fulton RB. Abnormal hemostatic profiles and gastric necrosis in canine gastric dilatation-volvulus. *Veterinary Surgery* 1993;22:93-97.

8. de Papp E, Drobatz KJ, Hughes D. Plasma lactate concentration as a predictor of gastric necrosis and survival among dogs with gastric dilatation-volvulus: 102 cases (1995-1998). *Journal of the American Veterinary Medical Association* 1999;215:49-52.

9. Zacher LA, Berg J, Shaw SP, et al. Association between outcome and changes in plasma lactate concentration during presurgical treatment in dogs with gastric dilatation-volvulus: 64 cases (2002-2008). Journal of American Veterinary Medical Association 2010; 236:892-897.

10. Hathcock JT. Radiographic view of choice for the diagnosis of gastric volvulus: The right lateral recumbent view. *Journal of the American Animal Hospital Association* 1984;20:967-969.

11. Fischetti AJ, Saunders HM, Drobatz KJ. Pneumatosis in canine gastric dilatation-volvulus syndrome. *Veterinary Radiology and Ultrasound* 2004;45:205-209.

12. Allen DA, Schertel ER, Muir WW, et al. Hypertonic saline/dextran resuscitation of dogs with experimentally induced gastric dilatation-volvulus shock. *American Journal of Veterinary Research* 1991;52:92-96.

13. Brockman DJ, Washabau RJ, Drobatz KJ. Canine gastric dilatation/volvulus syndrome in a veterinary critical care unit: 295 cases (1986-1992). *Journal of the American Veterinary Medical Association* 1995;207:460-464.

14. Guilford WG, Komtebedde J, Haskins SC, et al. Influence of allopurinol on the pathophysiology of experimental gastric dilatation-volvulus. *The Journal of Veterinary Emergency and Critical Care* 1995;5:51-60.

15. Lantz GC, Bottoms GD, Carlton WW, et al. The effect of 360 gastric volvulus on the blood supply of the nondistended normal dog stomach. *Veterinary Surgery* 1984;13:189-196.

16. Brockman DJ, Holt DE, Washabau RJ. Pathogenesis of acute canine gastric dilatation-volvulus syndrome: Is there a unifying hypothesis? *Compendium on Continuing Education* 2000;22:1108-1114.

17. Glickman LT, Glickman NW, Schellenberg DB, et al. Non-dietary risk factors for gastric dilatation-volvulus in large and giant breed dogs. *Journal of the American Veterinary Medical Association* 2000;217:1492-1499.

18. Raghavan M, Glickman N, McCabe G, et al. Diet-related risk factors for gastric dilatation-volvulus in dogs of high-risk breeds. *Journal of the American Animal Hospital Association* 2004;40:192-203.

19. Raghavan M, Glickman NW, Glickman LT. The effect of ingredients in dry dog foods on the risk of gastric dilatation-volvulus in dogs. Journal of the American Animal Hospital Association 2006; 42:28-36.

20. Ward MP, Patronek GJ, Glickman LT. Benefits of prophylactic gastropexy for dogs at risk of gastric dilatation-volvulus. *Preventive Veterinary Medicine* 2003;60:319-329.

21. Rawlings CA, Mahaffey MB, Bement S, et al. Prospective evaluation of laparoscopic-assisted gastropexy in dogs susceptible to gastric dilatation. *Journal of the American Veterinary Medical Association* 2002;221:1576-1581.

22. Glickman LT, Lantz GC, Schellenberg DB, et al. A prospective study of survival and recurrance following the acute gastric dilatation-volvulus syndrome in 136 dogs. *Journal of the American Animal Hospital Association* 1998;34:253-259.

23. Mackenzie G, Barnhart M, Kennedy S, et al. A retrospective study of factors influencing survival following surgery for gastric dilatation-volvulus syndrome in 306 dogs. Journal of the American Animal Hospital Association 2010; 46:97-102.

Gastric Dilatation-Volvulus (GDV): Surgical Treatment

Amelia Simpson

The goals of surgery for a dog with a GDV are to de-rotate the stomach and return other organs to their normal anatomic positions, evaluate the viability of stomach and spleen, perform a splenectomy (partial or complete) and/or a partial gastrectomy if indicated, and perform a perform a permanent gastropexy to prevent recurrence of volvulus. Surgery should take place as soon as the patient is stable enough to undergo anesthesia. If signs of shock are minimal, surgery may be performed immediately after gastric decompression and initiation of fluid therapy. Dogs with moderate or severe signs of shock may be stabilized by gastric decompression and fluid therapy for several hours until the vital signs improve. A prolonged period of stabilization, however, is undesirable, since the blood supply to the rotated stomach may remain compromised even after it has been decompressed.[1]

Surgical Technique

A ventral midline celiotomy is performed with the incision extending from the xiphiod process of the sternum to a point midway between the umbilicus and pubis. The use of Balfour

retractors is recommended to maintain adequate exposure of the abdominal cavity. The surgeon should evacuate free blood form the abdomen and any actively bleeding short gastric vessels should be ligated. Most commonly, with the dog in dorsal recumbency, the stomach rotates 180° to 270° clockwise around the long axis of the esophagus. In this position, the ventral leaf of the omentum covers the ventral aspect of the displaced stomach which is readily apparent to the surgeon after the abdomen is opened (See Figure 19-10A-E). A clockwise rotation causes the pylorus and the gastric antrum to become displaced from the right ventral body wall and move ventrally over the gastric fundus and body to become positioned adjacent to the esophagus along the left body wall (See Figure 19-10D and E). The maximum rotation of the stomach in the clockwise rotation is 360°. Counterclockwise rotation, although uncommon, has a maximum rotation of 90°. When counterclockwise rotation occurs, the pylorus and antrum move dorsally along the right body wall to a position adjacent to the esophagus. Counterclockwise rotation direction, causes minimal ventral displacement of the gastric fundus and body and the omentum does not cover the ventral aspect of the displaced stomach.[2] Depending upon the degree of gastric rotation, the spleen can be found in various positions within the cranial abdomen. Occasionally the spleen may undergo torsion around its vascular pedicle.

To de-rotate the stomach for a 180° clockwise rotation, the fundus, which is located near the right abdominal wall, is depressed in a dorsal direction and the pylorus, abnormally located on the dorsal left, abdominal wall is retracted ventrally and from the left to right side of the abdomen. To prevent further trauma to the gastrosplenic vessels, the spleen is placed in its normal position as gastric de-rotation is performed. If significant distension is present, the stomach may be impossible to de-rotate. In this case, gastric decompression is necessary and can be achieved by passage of an orogastric tube, trocharization, or by a combination of these two methods. If an orogastric tube cannot be advanced into the stomach, trocharization of the stomach should be performed. A large bore needle or IV catheter is placed into the gastric lumen through an area of the stomach wall that appears. The needle/catheter can be connected to suction for rapid removal of accumulated gas and fluid and usually, the orogastric tube can then be successfully passed into the stomach. Following successful decompression, the needle/catheter is removed and the stomach is de-rotated as described above. Suturing of the trocharization site is not necessary, unless a tear was created in the gastric wall during needle placement. The surgeon should be certain that the stomach is completely de-rotated and in a normal anatomic location. This can be achieved by visualizing the junction of the intra-abdominal esophagus and cardia of the stomach and noting a lack of tissue folds in the area. After confirming complete de-rotation of the stomach, a complete abdominal exploration is performed.

During the abdominal exploration, particular attention is paid to the viability of the gastric wall and spleen. Initially, the spleen is often enlarged and congested and its viability may appear questionable. Often, after return to its normal anatomic rotation the spleen begins to return to its normal size and color and splenectomy is not required. Thrombosis of the splenic artery and/or vein can be detected by careful palpation and, if identified, requires partial or complete splenectomy. If the spleen has undergone torsion around its vascular pedicle, it should be removed. In order to prevent deleterious toxin release, splenectomy is performed without de-torsing the splenic vasculature. Splenectomy is required in approximately 25% of cases of GDV.

Partial Gastrectomy

Approximately 10% of dogs with GDV have necrosis along the greater curvature of the fundus or body of the stomach.[3] Perforation early in the course of disease due to gastric necrosis is rare. Several methods have been described to evaluate viability of the gastric wall. These include: clinical assessment of serosal

Table 19-2. Partial Gastric Resection

Color of the gastric serosa	Indicative of:	Recommendation
Diffuse petechia/ecchymosis	Vascular damage	Tissue resection usually not necessary.
Diffuse dark red/red-purple hemorrhagic areas	More severe vascular damage	Tissue resection usually not necessary.
Blue-black or black areas	Venous occlusion and intramural-subserosal hemorrhage	These lesions may be reversible. After the stomach is de-rotated small incision is made in the serosa. If arterial blood is not seen, severe hypoxic damage and tissue necrosis are present and the section is resected.
Pale greenish to grayish areas	Ischemia and necrosis	Tissue resection is recommended.

Texture of the stomach wall	Indicative of:	Recommendation
Thickened - often associated with mild to moderate bruising	Congestion with blood and edema	Tissue resection usually not necessary.
Thin/stretched - often associated with a pale greenish to gray color	Devitalized tissue	Tissue resection is recommended.

color and gastric wall texture, the use of intravenous fluroesceine dye, and nuclear scintigraphy. In a study evaluating the use of fluoresceine fluorescence to predict gastric viability, it was found that fluoresceine fluorescence was only 58% accurate.[4] Nuclear scintigraphy, while accurate in assessing stomach wall viability, is impractical in a clinical setting.[5-7] Gastric viability determined by clinical assessment of serosal color and gastric wall texture was accurate in 85% of cases of dogs with GDV in one study.[4] Since clinical assessment of gastric tissue viability is not always accurate, it is possible to remove tissue which may survive as well as to leave tissue behind which may subsequently necrose and lead to gastric perforation hours to days later. General guidelines for partial gastric resection include in Table 19-2.

Ischemic or necrotic gastric tissue can be excised by partial gastrectomy, or it can be invaginated by an inverting or purse-string suture technique and left to be auto-digested within the gastric lumen. I prefer to perform partial gastrectomy and gastric wall closure with staples or suture (Figure 19-11A-C). The stomach is packed off with moistened laparotomy pads to prevent contamination of the abdomen from spillage of gastric contents. Doyen forceps or stay sutures are placed in viable gastric tissue and can be used to help prevent leakage of gastric contents. The necrotic portion of the stomach wall is resected with a scalpel to the point where there is active arterial bleeding at the surgical margin. A monofilament, absorbable or non-absorbable, suture material is used for a two layer closure. A full thickness simple continuous suture pattern followed by an inverting pattern such as a Cushing's oversew is recommended. Alternatively, a thoraco-abdominal stapler can be used followed by a Cushing's oversew using a monofilament, absorbable or non-absorbable suture material. Mortality rates are known to be higher in animals

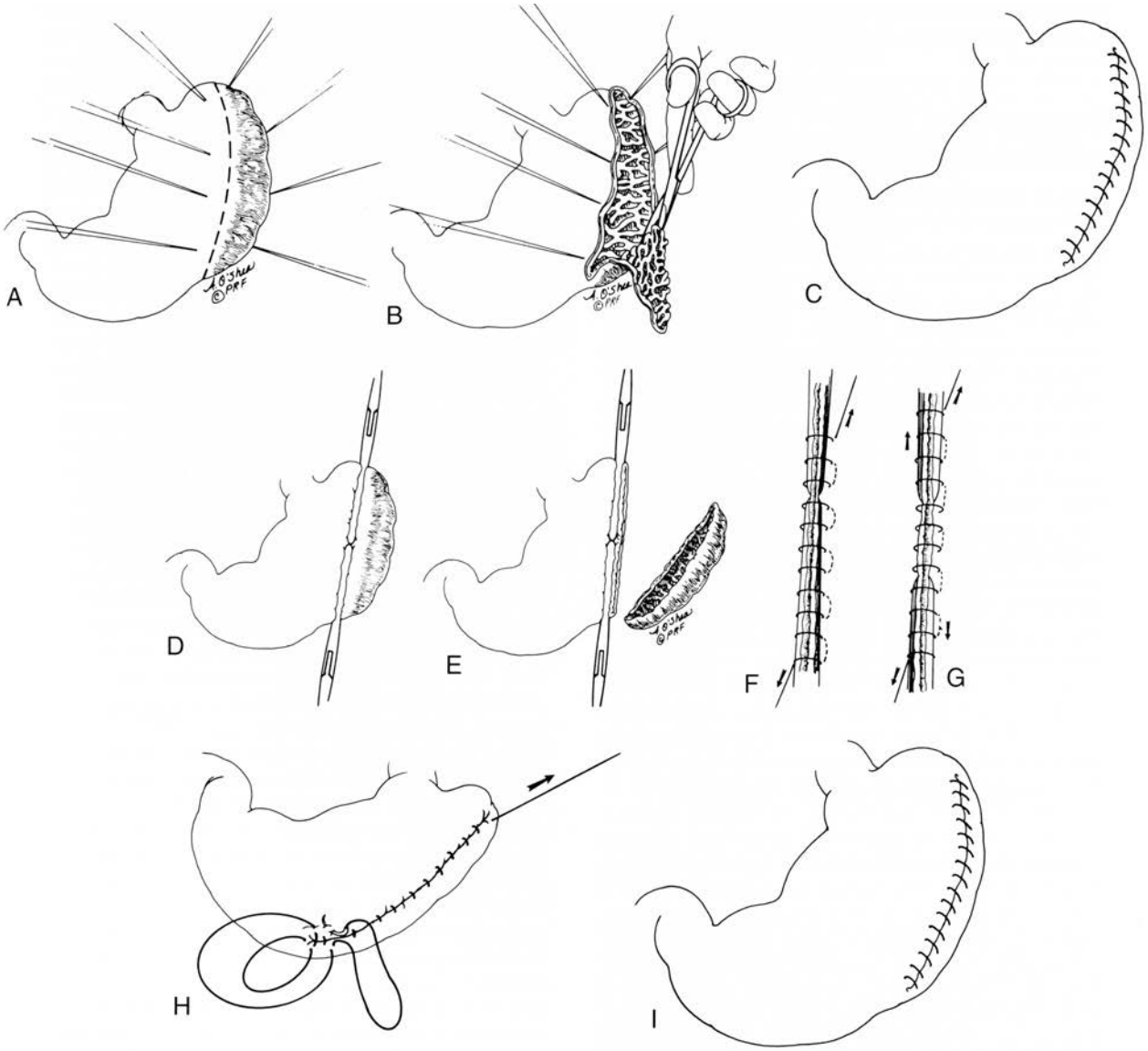


Figure 19-11. Two variations of partial gastrectomy are shown. In **A-C**, stay sutures are placed to elevate the stomach and to minimize leakage. Necrotic tissue is excised with a rim of viable tissue (dotted line). A two-layer inverting closure is used. In **D-I**, atraumatic clamps are placed across viable tissue, and the necrotic tissue is excised. The stomach body is subsequently closed with a Parker-Kerr suture line. The first inverting layer of suture is placed over the clamps. The clamps are subsequently removed as the suture line is pulled tight to invertthe suture line. A second inverting suture line completes the closure. (Redrawn in part from Matthiesen DT. Gastric dilatation-volvulus syndrome. In: Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1995:580-593.)

where gastric wall excision is required. The owners should be given a poor prognosis in cases where there is complete gastric necrosis or necrosis of the cardia and abdominal esophagus.

Gastropexy

Mortality rates for dogs with a GDV have been reported to be as high as 23%.[8] Studies have shown that dogs who receive an effective permanent gastropexy at the time of surgery have less than a 5% chance of recurrence of GDV, whereas dogs who do not receive a gastropexy during surgery have a 54.5-80% rate of recurrence within the first year.[8,9] Based on these results, it is strongly recommended that all dogs with a GDV should have a permanent gastropexy performed during surgery for gastric repositioning. Several effective gastropexy techniques have been described including: tube gastropexy, incisional gastropexy, circumcostal gastropexy, belt-loop gastropexy, fundic gastropexy and laparoscopic gastropexy.[10-14] Gastrocolopexy and gastrojejunostomy have also been described, but are rarely performed in a clinical setting and are no longer recommended.[15,16]

I prefer to perform an incisional gastropuexy for prevention of GDV. It is simple to perform, can be completed quickly, has minimal complications, and creates a strong adhesion between the pyloric antrum and the right abdominal wall. The gastropexy is performed only after confirming that the stomach is fully de-rotated and in normal anatomic rotation. The procedure is easier to perform with the surgeon standing on the left side of the dog. A 5-6 cm partial thickness incision is made in the serosal and muscularis layers of the pyloric antrum, midway between the greater and lesser curvature of the stomach, along the long axis of the stomach (Figure 19-12). A corresponding incision is made in the right lateral body wall just caudal to the last rib. The body wall incision should extend through the peritoneum and transverse abdominal muscle. The gastric incision edges are sutured to the corresponding body wall incision edges using a monofilament absorbable (polydioxanone) or non-absorbable suture in a simple continuous pattern (Figure 19-13). The suture should not enter the gastric lumen as this may lead to fistula formation and/or sepsis. Routine abdominal closure is performed after copious lavage.

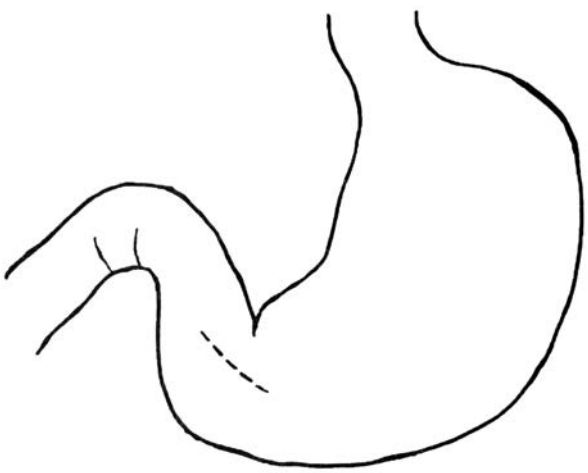


Figure 19-12. The location of the gastropexy site in the area of the pyloric antrum.

Post-Operative Care and Complications

Intensive nursing care should be provided during the postoperative period. Pain control, maintenance of vascular volume, and return to normal alimentation and gastric motility are important. Pain is controlled with injectable hydromorphone (0.05-0.1 mg/kg, SC or IV q4-6hrs) or injectable burenorphine (0.02 mg/kg, SC or IV, q6hrs) for 48-72 hours after surgery. Since these dogs usually have extended hospitaliztion times, they are comfortable by the time of discharge and analgesic medication is not routinely necessary after discharge. If the dog appears painful, Tramadol (1-4 mg/kg, PO, q8hrs) can be prescribed to be administered at home for 3-5 days. Dogs are routinely maintained on intravenous fluids for the first 24-36 hours postoperatively for maintenance and continuing fluid losses, or until they are eating and drinking without vomiting. Food and water are withheld for the first 18-24 hours postoperatively unless the animal is hypoalbuminemic. Ice chips or small quantities of water are offered in small amounts. If there is no vomiting after several hours of starting the patient on water, food is offered in small amounts every 4-6 hours and the patient is gradually returned to normal alimentation over 24-48 hours.

If vomiting occurs, potassium levels should be assessed as hypokalemia is common and may promote ileus. Prokinetic drugs (metoclopramide or cisapride, ranitidine, erythromycin) and gastric acid-inhibitors (cimetidine, ranitidine, famotidine, omeprazole) are beneficial in animals that have vomiting or regurgitation postoperatively.

Antibiotics administered perioperatively are continued in animals that have abdominal contamination during surgery secondary to gastric necrosis and in animals that are suspected of having endotoxic shock initially.

Cardiac Arrhythmias

After surgery, dogs are observed for cardiac arrhythmias with continuous ECG monitoring for 48-72 hours. The most common arrhythmia seen in these patients is ventricular premature contractions (VPCs) although supraventricular arrhythmias such as atrial fibrillation and atrial premature depolarization have also been observed.[17,18] Electrolyte levels should be checked and corrected if abnormal prior to considering therapy for arrythmias. Patients with VPCs occurring at a high rate (200-240+ beats per minute) who appear clinically affected by the arrhythmia (weak pulse quality, poor mucous membrane color, prolonged capillary refill time, and weakness/lethargy) should be treated with antiarrhythmic medication. Most commonly, lidocaine hydrochloride at a dose of 2-4 mg/kg, is administered as an intravenous bolus given slowly to effect. The lidocaine dose can be repeated and, if necessary, it can be continued at a constant rate infusion of 0.05-0.08 mg/kg/min. If the arrhythmia is refractory to lidocaine, procainamide can be used. Procainamide should be administered at a dose of 6mg/kg as an IV bolus over 5 minutes, followed by a 10 to 25 ug/kg/min constant rate infusion. The dog should be placed on oral procainamide at a dose of 10 mg/kg every 8 hours for 15 days. Long-term antiarrhythmic treatment is usually unnecessary as the arrhythmias usually resolve.

Sepsis (Gastric Necrosis/Perforation)

The risk of dehiscence following partial gastrectomy is greatest within the first 72 hours after surgery. Dogs are monitored closely for signs of peritonitis such as lethargy, abdominal pain and/or distension, vomiting, hypotension, hypoglycemia, and hyper- or hypothermia. If dehiscence is suspected, a CBC and abdominocentesis should be performed. The abdominal fluid should be evaluated for the presence of intracellular bacteria. A paired sample of the abdominal fluid and blood should be measured for glucose levels. A glucose level in the abdominal effusion that is more than 20 mg/dl lower than the blood glucose is indicative of septic peritonitis and warrants re-exploration.[19]

Prophylactic Gastropexy

Prophylactic gastropexy is currently recommended for dogs who have had a spontaneous episode of gastric dilatation, in dogs that have a first-degree relative who has had GDV, and in some breeds that are at high risk for the development of GDV such as Great Danes, Irish Setters, and Bloodhounds. Prophylactic gastropexy can be performed at the time of elective neutering in susceptible breeds. Any of the previously mentioned gastropexy techniques can be performed by an open approach. Rawlings and colleagues have performed laparoscopic-assisted prophylactic gastropexy in 23 dogs susceptible to GDV and found that it resulted in a persistent attachment between the stomach and abdominal wall, few complications and no occurrence of GDV within one year of the original surgery.[20] Clinically, laparoscopic assisted gastropexy has proven an easy and effective prophylactic gastropexy technique.[20]

References

1. Lanz GC, Bottoms GD, Carlton WW, et al. The effect of 360 gastric volvulus on the blood supply of the nondistended normal dog stomach. Vet Surg 1984; 13:189-196.

2. Brockman DJ, Holt DE, Washabau RJ. Pathogenesis of acute gastric dilatation-volvulus syndrome: Is there a unifying hypothesis? Compend Cont Educ Pract Vet 2000;22:1108-1114.

3. Matthiesen DT: Partial gastrectomy as treatment of gastric volvulus: Results in 30 dogs. Vet Surg 14: 185-193, 1985.

4. Wheaton LG, Thacker HL, Caldwall S: Intravenous fluroescein as an indicator of gastric viability in gastric dilation-volvulus. J Am Anim Hosp Assoc 22:197-204, 1986.

5. Berardi C, Twardock AR, Wheaton LG, et al. Nuclear imaging of the stomach of healthy dogs. Am J Vet Res 1991;52:1081-8

6. Berardi C, Wheaton L, Twardock AR, et al. Nuclear imaging to evaluate gastric mucosal viability following surgical correction of gastric dilatation/volvulus. J Am Anim Hosp Assoc 1993;29:239-46.

7. Berardi C, Wheaton L, Twardock AR, et al. Use of nuclear imaging technique to detect gastric wall ischemia. Am J Vet Res 1991;52:1089-96.

8. Glickman LT, Glickman NW, Schellenberg DB, et al. Non-dietary risk factors for gastric dilatation-volvulus in large and giant breed dogs. J Amer Vet Med Assoc 2000;217:1492-1499.

9. Wingfield WE, Betts CW, Greene RW. Operative techniques and recurrence rates associated with gastric volvulus in the dog. J Sm Anim Pract 1975;16:427-32.

10. Parks JL, Green RW: Tube gastrostomy for the treatment of gastric volvulus. J Am Anim Hosp Assoc 12:168-172, 1976.

11. MacCoy DM, Sykes GP, Hoffer RE, et al: A gastropexy technique for permanent fixation of the pyloric antrum. J Am Anim Hosp Assoc 18:763-768, 1982.

12. Fallah AM, Lumb WV, Nelson AW, et al: Circumcostal gastropexy in the dog: A preliminary study. Vet Surg 11;9-12, 1982.

13. Whitney WO, Scavelli TD, Mattheisen DT, et al: Belt-loop gastropexy: Technique and surgical results in 20 dogs. J Am Anim Hosp Assoc 25:75-83m 1989.

14. Myer-Lindenberg A, Harder A, Fehr M, et al: Treatment of gastric dilatation-volvulus and a rapid method for prevention of relapse in dogs: 134 cases. J Am Vet Med Assoc 203:1303-1307, 1993.

15. Christie TR, Smith CW: Gastrocolopexy for prevention of recurrent gastric volvulus. J Am Anim Hosp Assoc 12:173-176, 1976.

16. Pritchard D: Prevention of acute gastric dilation by gastrojejunostomy. Canine Pract 4:51-55, 1977.

17. Muir WW, Lipowitz AJ: Cardiac dysrhythmias associated with gastric dilatation-volvulus in the dog. Am J Vet Res 172:683, 1978.

18. Muir WW, Bonagura JD: Treatment of cardiac arrhythmias in dogs with gastric distension-volvulus. J Am Vet Med Assoc 184:1366, 1984.

19. Bonczynski JJ, Ludwig LL, Barton LJ, et al: Comparison of peritoneal fluid and peripheral blood pH, bicarbonate, glucose, and lactate concentration as a diagnostic tool for septic peritonitis in dogs and cats. Vet Surg 32:161-166,2003.

20. Rawlings CA, Mahaffey MB, Bement S, et al: Prospective evaluation of laparoscopic-assisted gastropexy in dogs susceptible to gastric dilation. J Am Vet Med Assoc 221:1576-1581.

Incisional Gastropexy

Douglas M. MacCoy

Gastric volvulus is a serious, often fatal problem that occurs primarily in large, deep-chested dogs. Gastropexy,[1,2] gastroplasty,[3] tube gastrostomy,[4] and gastrocolopexy[5] have all been used in an attempt to fix the stomach to the body wall permanently and to prevent recurrent volvulus. The incisional gastropexy[1] offers a method of producing a permanent gastropexy without the potential complications and aftercare associated with tube gastrostomy. It may be used as an alternative to a tube gastrostomy when postoperative decompression will be provided by pharyngostomy tube or is not thought necessary, but a permanent gastropexy is still desired.[6] The same low potential for complications also makes it suitable as a prophylactic procedure in high-risk patients.

Surgical Technique

The cranial abdomen is approached by a ventral midline laparotomy. The pyloric antrum is identified and is held in the surgical field by thumb forceps, Babcock forceps, or stay sutures. Using a scalpel, the surgeon makes an incision equal in length to the diameter of the duodenum through the gastric serosa and into but not through the muscularis over the parietal surface of the pyloric antrum equidistant from the attachments of the greater and lesser omenta (See Figure 19-13A). The incision should be at least one duodenal diameter away from the pylorus, to avoid distortion of the pylorus. A second incision of the same length is made through the peritoneum and internal fascia of the rectus abdominis muscle or transversus abdominis muscle of the ventrolateral abdominal wall adjacent to the incision on the pyloric antrum (See Figure 19-13B).

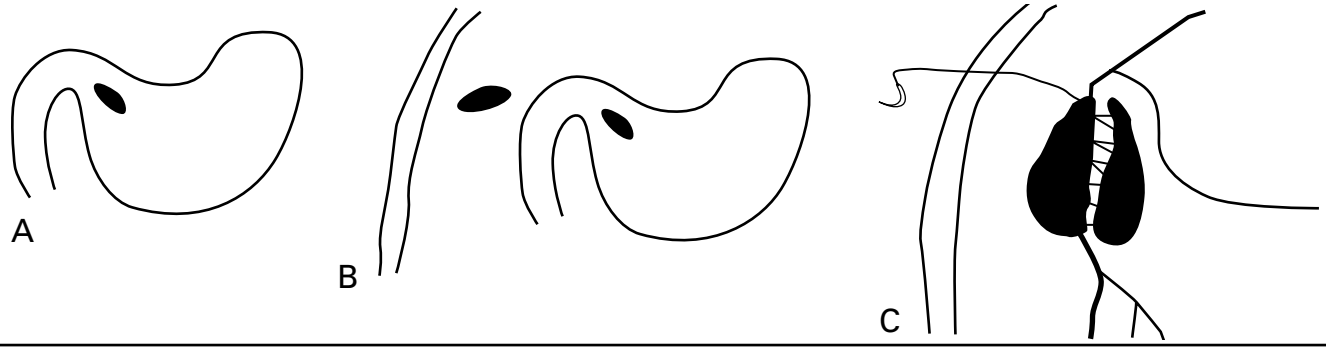


Figure 19-13. A. Initial pyloric antrum incision. **B.** Matching incision on body wall. **C.** Suturing of body wall and pyloric antrum.

The edges of the abdominal wall incision are sutured to the edges of the antral incision using 2-0 or 1-0 monofilament nylon or polypropylene in a simple continuous pattern, creating an imperforate, circular stoma (See Figure 19-13C). The abdominal incision is closed in a routine fashion.

Postoperative Care

Exercise is restricted for a minimum of 3 weeks to allow healing of the abdominal incision. No dietary restrictions are needed.

Editor's Note: Techniques such as gastrocolopexy do not prevent gastric volvulus. I pefer the incisional gastropexy technique described however I make the antral incision 5-6 cm in length. Many surgeons prefer a long-acting absorbable suture such as polydioxanone for gastropexy.

References

1. MacCoy DM, Sykes GP, Hoffer RE, et al. A gastropexy technique for permanent fixation of the pyloric antrum. J Am Anim Hosp Assoc 1982;18:763-768.

2. Woolfson JM, Kostolich M. Circumcostal gastropexy: clinical use of the technique in 34 dogs with gastric dilation-volvulus. J Am Anim Hosp Assoc 1986;22:825-830.

3. Matthiesen DT. Partial gastrectomy as treatment of gastric volvulus; results in 30 dogs. Vet Surg 1985;14:185-193.

4. Parks JL, Greene RW. Tube gastrostomy for the treatment of gastric volvulus. J Am Anim Hosp Assoc 1976;12:168-172.

5. Christie TR, Smith CW. Gastrocolopexy for prevention of recurrent gastric volvulus. J Am Anim Hosp Assoc 1976;12:173-176.

6. Lindgren WG, Mullen HS, Marino DJ, et al. Long-term follow-up and clinical results of incisional gastropexy for repair of gastric dilation-volvulus syndrome. In: Proceedings of the Fifth American College of Veterinary Surgeons Veterinary Symposium. American College of Veterinary Surgeons. Chicago, IL. 1995:11.

Circumcostal Gastropexy

Gary W. Ellison

The circumcostal gastropexy technique[1] has become popular with many small animal surgeons because it forms a stronger adhesion than the tube gastrostomy or incisional gastropexy technique.[2] Other potential advantages of this technique include a viable muscle flap adhesion and a more proper anatomic placement of the stomach.[1] Potential disadvantages of the circumcostal gastropexy technique include possible rib fracture or creation of pneumothorax when the operation is performed by surgeons who are inexperienced with the technique.[3] This procedure is also reported to be more technically demanding and time-consuming to perform than other gastropexy techniques, but I disagree with this statement.

Surgical Technique

To perform the circumcostal gastropexy, two 1x4 cm partial-thickness gastric flaps are created and are wrapped around either the eleventh or twelfth costal cartilage. Initially, 2-0 polypropylene stay sutures are placed 2 and 8 cm proximal to the pylorus, respectively. A transverse nick incision is then made 3 cm distal to the pylorus with Metzenbaum scissors. A second transverse nick incision is made at the other end 4 cm proximal to the first. To avoid penetrating the gastric lumen when making these incisions, the serosa and muscularis are first grasped between the surgeon's thumb and forefinger. This maneuver separates these layers from the underlying submucosa. The two transverse incisions are then connected with a scalpel or scissors. The seromuscular layer is then separated from the submucosa with scissors on both sides, thereby creating two 1.0x4 cm seromuscular pedicle flaps (Figure 19-14). The chondral portion of the right eleventh or twelfth rib is encircled with towel clamps from the abdominal surface, and the peritoneum and transverse abdominal muscle are incised with a No. 10 blade (Figure 19-15). A tunnel is then made around the medial aspect of the rib using Metzenbaum scissors. If the eleventh or twelfth rib is used, the incision is caudal to all diaphragmatic attachments, and the thoracic cavity is not entered. The caudal arm of each stay suture is then passed through the rib tunnel, and the stomach is pulled up against the right abdominal wall. The caudal muscular flap is passed around the lateral aspect of the rib with a stay suture or grasping forces, and the two stay sutures are tied around the rib (Figure 19-16). The caudal muscular flap is then apposed to the cranial muscular flap with simple interrupted sutures of 2-0 polypropylene (Figure 19-17). A second layer of simple interrupted sutures of 3-0 po lypropylene is used to appose gastric serosa to the incised transversus muscle (Figure 19-18). The ventral midline is then closed routinely. Postoperative care is similar to that for other gastropexy techniques.

Results

In one study, 30 patients with GDV were followed-up for an average of 12.7 months after circumcostal gastropexy with contrast studies or necropsy.[4] Of the animals that survived, just 1 dog (3.3%) suffered

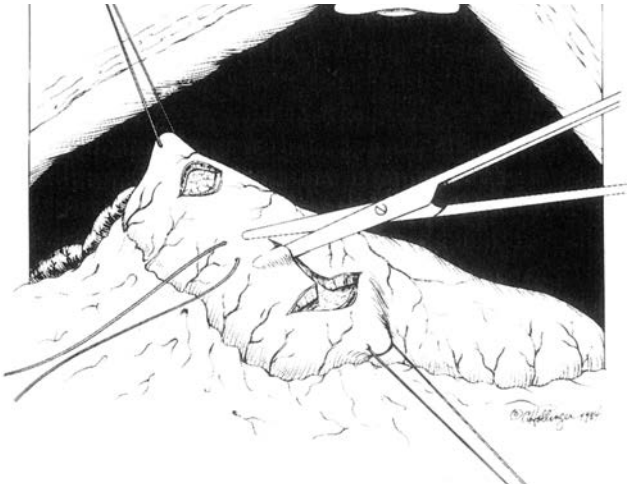


Figure 19-14. After placing stay sutures, two small incisions are made through the seromuscular layer of the pyloric antrum and are connected with scissors. The flaps are undermined for a distance of I cm. (From Ellison GW. Gastric dilatation volvulus: surgical prevention. Vet Clin North Am Small Anim Pract 1993:23:524.)

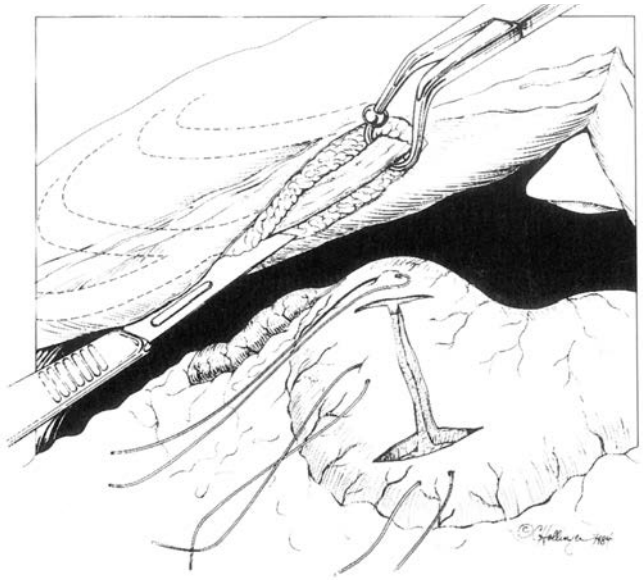


Figure 19-15. The eleventh or twelfth rib is then grasped with towel clamps from the abdominal surface, and the peritoneum and transverse abdominal muscle are incised with a No. 10 blade. (From Ellison GW. Gastric dilatation volvulus: surgical prevention. Vet Clin North Am Small Anim Pract 1993:23:524.)

a clinical recurrence of gastric dilatation. In another study, 34 dogs were followed-up after circumcostal gastropexy, with a mean follow-up of 11.3 months. One patient developed peritonitis as a result of inadvertent penetration of the gastric wall during flap formation. The overall mortality was 8.8%, and suspected recurrence occurred in 2 patients (6.9%) because of a second episode of gastric distension.[5] Neither of these recurrences was documented with radiographs or necropsy as due to gastropexy failure.

References

1. Fallah AM, Lumb WV, Nelson AW, et al. Circumcostal gastropexy in the dog: a preliminary study. Vet Surg 1982;11:19-22.

2. Fox SM, Ellison GW, Miller GJ. Observations on the mechanical failure

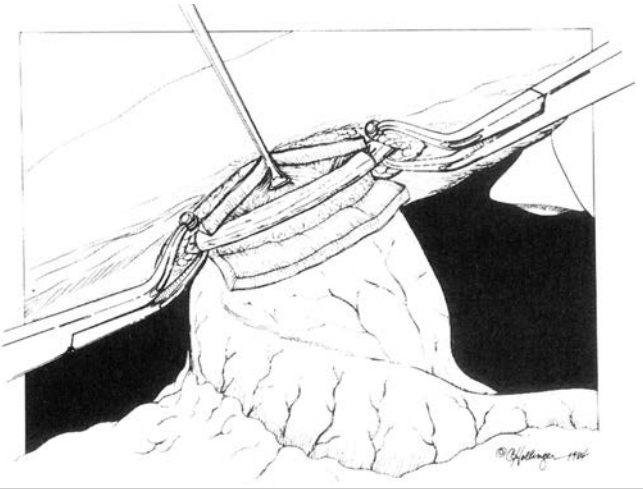


Figure 19-16. After dissecting lateral to the rib, the caudal flap is brought around, and the two stay sutures are tied. (From Ellison GW. Gastric dilatation volvulus: surgical prevention. Vet Clin North Am Small Anim Pract 1993:23:524.)

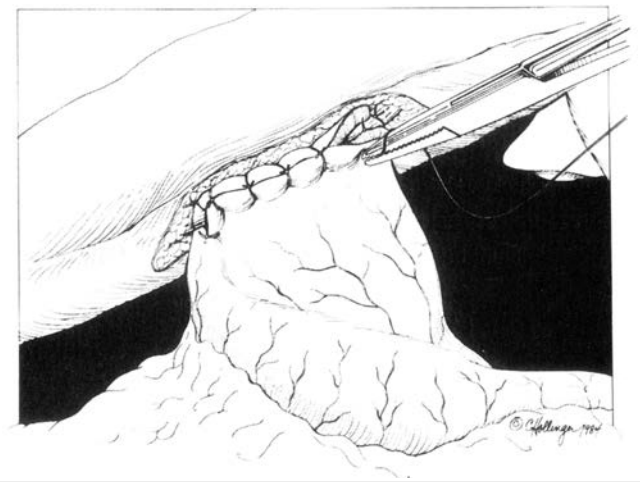


Figure 19-17. The two flaps are then apposed with simple interrupted sutures. (From Ellison GW. Gastric dilatation volvulus: surgical prevention. Vet Clin North Am Small Anim Pract 1993:23:524.)



Figure 19-18. A second layer of simple interrupted sutures apposes the stomach wall with the incised transverse abdominal muscle and completes the procedure. (From Ellison GW. Gastric dilatation volvulus: surgical prevention. Vet Clin North Am Small Anim Pract 1993:23:524.

of three gastropexy techniques. J Am Anim Hosp Assoc 1985;21:739-734.

3. Leib MS, Blass CE. Gastric dilatation-volvulus in dogs: an update. Compend Contin Educ Pract Vet 1984;6:961-967.

4. Leib MS, Konde LJ, Wingfield WE, et al. Circumcostal gastropexy for preventing recurrence of gastric dilatation-volvulus in the dog: an evaluation of 30 cases. J Am Vet Med Assoc 1985; 187:245-248.

5. Woolfson JM, Kostolich M. Circumcostal gastropexy: clinical use of the tech nique in 34 dogs with gastric dilatation-volvulus. J Am Anim Hosp Assoc 1986;22:825-830.

Laparoscopic Assisted Gastropexy

Don R. Waldron

Introduction

Creation of a permanent gastropexy is the single most important factor in preventing gastric-dilatation volvulus (GDV) in susceptible dogs. Gastropexy is performed most commonly as part of therapeutic surgery following gastric repositioning for animals with gastric volvulus. Performance of an effective gastropexy includes fixation of the gastric antrum to the right abdominal wall or rib area. Many methods of gastropexy have been described and are effective if performed well technically. Incisional gastropexy is a simple and effective technique that has been widely used and is simple to perform.

Increased knowledge of GDV among veterinarians and owners and identification of known risk factors for dogs susceptible to the condition has resulted in increased numbers of dogs having prophylactic gastropexy to prevent gastric volvulus. Risk factors for development of the disease include first-degree relatives who have been affected (genetic), stress, breed/confirmation (Great Danes, St, Bernards, Weimeraners, Irish Setters, Gordon Setters, Standard Poodles) and diet.[1] It is widely accepted that animals with deep thorax-to-width ratios are especially at risk for the disease. Because of high mortality rates associated with GDV, prophylactic gastropexy should be considered in dogs identified as being at high risk.

Prophylactic gastropexy can be performed by open laparotomy concurrently with elective ovariohysterectomy in the female however the incision required is a substantial one extending from xiphoid caudal to the umbilicus. Laparoscopic gastropexies have been described however a high degree of laparoscopic surgical skill and experience are required.[2] The laparoscopic-assisted gastropexy technique described here was developed and described by Rawlings et al in 2001 and 2002.[3,4] The technique was investigated in the laboratory and has been widely used on client owned dogs with minimal morbidity and a high degree of success in preventing GDV. Two portals are used and the laparoscope is used to identify and grasp the antrum, however, once the antrum is exteriorized the gastropexy is performed as an open technique. Minimal laparoscopic skills are required making the technique relatively easy to perform.

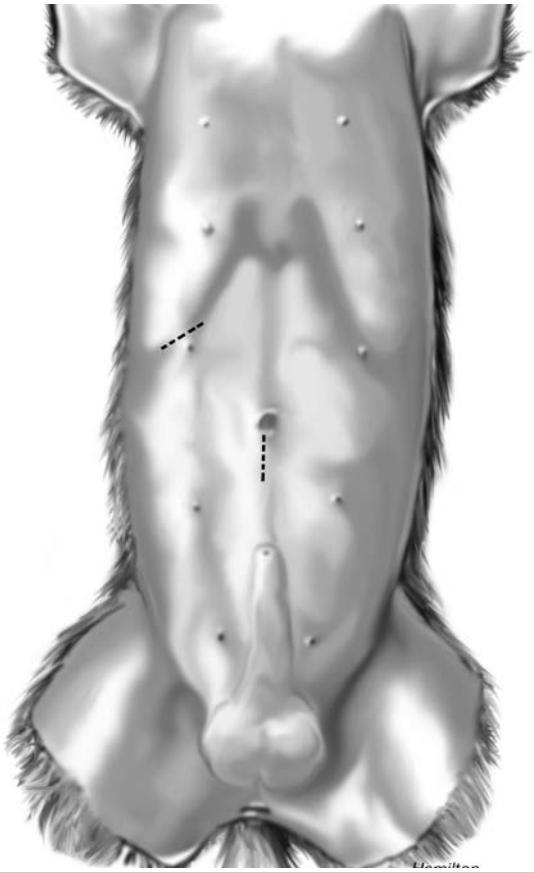


Figure 19-19. The dog is placed in dorsal recumbency and two abdominal incisions are made, midline for the laparoscope and right side caudal to the last rib for the gastropexy.

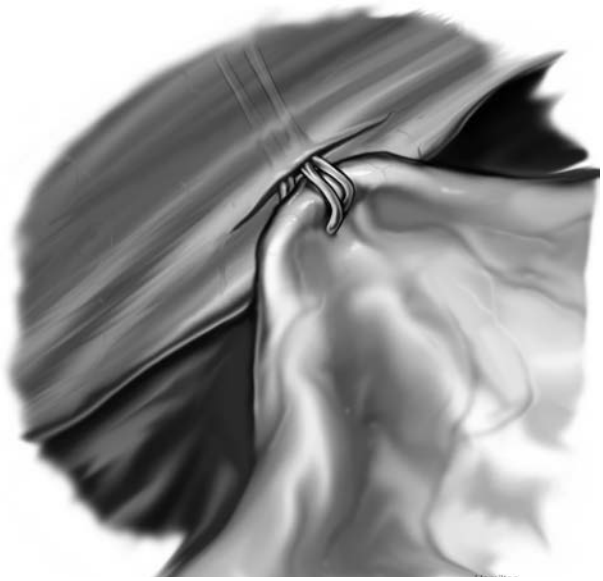


Figure 19-20. The antrum is grasped with tissue forceps midway between the greater and lesser curvatures about 5 to 7 cm orally from the pylorus. The forceps, the right-sided trocar cannula and the antrum are exteriorized through the lengthened cannula incision.

Technique

General anesthesia is induced and positive-pressure ventilation used during laparoscopic surgery. The dog is placed in dorsal recumbency and the complete abdomen prepared for surgery. A trocar cannula is placed 2cm caudal to the umbilicus which accommodates the laparoscope (Figure 19-19). The peritoneal cavity is distended with carbon dioxide and a 0°, 5°, or 10° laparoscope connected to a light source and video camera is inserted through the cannula. A second trocar cannula is placed 3 cm caudal to the last rib and lateral to the rectus abdominis muscle (See Figure 19-18). A 10mm Babcock forcep is placed into the abdomen to grasp the gastric antrum midway between the greater and lesser curvatures approximately 5 to 7 cm proximal to the pylorus. Allis tissue forceps are more traumatic but are useful in grasping the antrum if the stomach slips from the Babcock forceps.

The tissue forceps and antrum are exteriorized by removing the right side cannula and extending the cannula incision to 4cm in length in a direction parallel to the last rib. Care is taken to assure the antrum is not twisted as it is withdrawn from the abdomen (Figure 19-20). Size 0 "stay" sutures are placed 4 to 5 cm apart through the gastric serosa/muscularis to control the gastric wall during gastropexy. A seromuscular longitudinal incision is made in the gastric wall between the stay sutures. The sides of the gastric wall incision are dissected free from the mucosa so that adequate gastric tissue is available for the gastropexy and so that sutures are not placed through the gastric mucosa. A simple continuous pattern of size 0 or 2-0 synthetic monofilament absorbable suture (polydioxanone) is used to appose the seromuscular layer of the stomach to the transversus abdominus muscle (Figure 19-21). A separate suture line is placed on the cranial and caudal aspects of the gastropexy site. The abdominal oblique muscles are closed with interrupted absorbable sutures and the remainder of the incision by surgeon's choice. The completed gastropexy site is viewed intraabdominally (Figure 19-22) to assure that the gastric antrum is not twisted, the midline cannula is removed and the incision is closed.

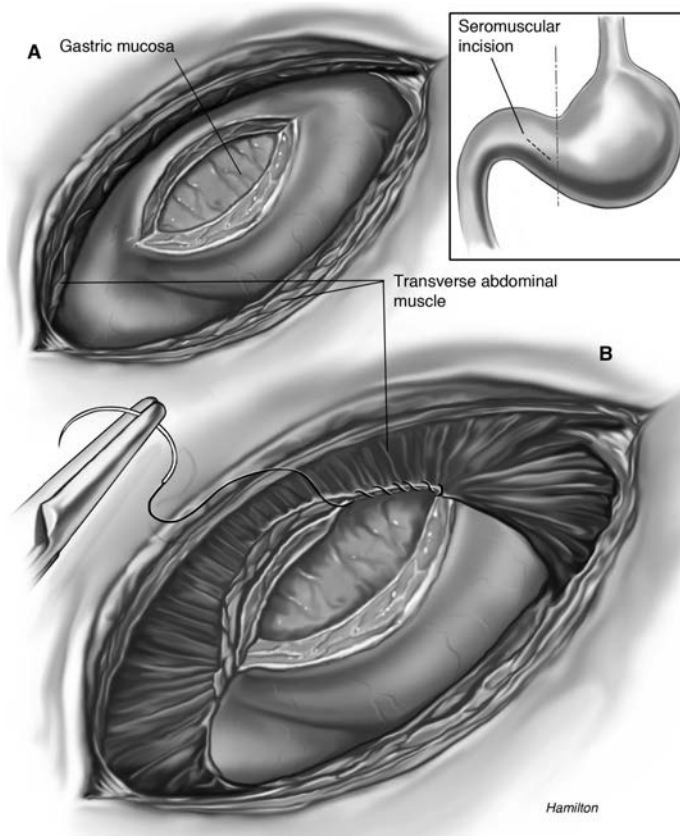


Figure 19-21. A seromuscular incision is made in the gastric wall down to the gastric mucosa and the sides of the incision dissected in both directions from the primary incision. The seromuscular layer is sutured to the transversus abdominis muscle with a continuous pattern of monofilament absorbable suture. SM=seromuscular layer of the stomach; GM=gastric mucosa; TA= transversus abdominis muscle.



Figure 19-22. Laparoscopic view of the completed gastropexy with no evidence of antral twisting.

References

1. Glickman LT, Glickman NW, Perez CM, et al. Analysis of risk factors for gastric dilatation-volvulus in dogs. J Amer Vet Med Assoc 1994; 204: 1465-1471.
2. Hardie RJ, Flanders JA, Schmidt P, et al. Biomechanical and histological evaluation of a laparoscopic stapled gastropexy technique in dogs. Vet Surg 1996;25: 127-133.
3. Rawlings CA, Foutz TL, Mahaffey MB, et al. A rapid and strong laparoscopic-assisted gastropexy in dogs. Am J Vet Res 2001; 62: 871-875.
4. Rawlings CA. Laparoscopic-assisted gastropexy. J Am Anim Hosp Assoc 2002; 38: 15-19.

Chapter 20

Intestines

Enterotomy

Gary W. Ellison

Indications

The most common indication for enterotomy in small animals is to remove intraluminal intestinal foreign bodies that cause obstruction. Foreign bodies can be present in animals of any age, but they are most common in puppies or kittens because of indiscriminate eating habits. Common intestinal foreign bodies in dogs include bones, balls, corncobs, and cellophane wrappers. Cats commonly ingest sharp foreign bodies (e.g., straight pins and needles) and linear foreign bodies (e.g., yarn, tinsel, fishing line, and string meat wrappings). Enterotomy also is performed as a biopsy technique and to examine the intestinal lumen for evidence of mucosal ulceration, strictures, or neoplasia. Superficial ulcerations or intestinal polyps sometimes can be resected via enterotomy, but most intramural lesions require intestinal resection and anastomosis.

Pathophysiology and Preoperative treatment of Intestinal Obstruction

Animals with incomplete intestinal obstruction caused by intraluminal foreign bodies or neoplasia usually vomit sporadically or are anorectic. Surprisingly, sharp foreign bodies such as nails, straight pins, and bones often pass spontaneously through the entire gastrointestinal tract without causing a perforation. Conversely, complete intraluminal obstructions usually cause acute bowel distension and unrelenting clinical signs. With proximal (duodenal) obstructions, vomiting may be projectile. With distal jejunal or ileal obstructions, vomiting may be seen early in the course of the disease, but anorexia and bowel distension follow. After obstruction of the midjejunum in dogs, vomiting often decreases to once a day after 24 to 36 hours, and many dogs can live for several weeks if hydration is maintained.

Most intestinal obstructions are distal to the bile and pancreatic ducts, resulting in loss of highly alkaline duodenal, pancreatic, and biliary secretions. Metabolic acidosis usually occurs from loss of these bicarbonate-rich duodenal contents. Dehydration should be corrected and maintenance fluid needs are usually met with a balanced electrolyte solution such as lactated Ringer's solution. Potassium chloride supplementation of fluids may be indicated, depending on the patient's acid-base status and serum potassium level. With obstructions at the pylorus or proximal duodenum, gastric fluids rich in potassium, sodium, hydrogen ion, and chloride are vomited, and metabolic alkalosis with hypochloremia, hyponatremia, and hypokalemia may result. In those cases, dehydration is corrected with intravenous 0.9% sodium chloride solution supplemented with potassium chloride depending on the patient's preoperative serum potassium level.

Surgical Technique

A ventral midline laparotomy incision is made from the xiphoid to the pubis. The entire intestinal tract should be evaluated to determine the number of foreign bodies and assess the viability of the bowel wall. The affected bowel segment is isolated from the remainder of the viscera with saline-soaked laparotomy sponges. In patients with a complete obstruction, intestinal distension proximal to the obstruction is often profound, and the distended loops of bowel usually take on a congested or cyanotic appearance (Figure 20-1A).

Intestinal viability is best evaluated after decompression of fluid and gas from dilated loops of intestine. Decompression is performed with a 20-gauge needle and suction apparatus or a 60-mL syringe with a three-way stopcock. If intestinal wall ischemia and necrosis are present, resection and anastomosis must be performed (following article). In most cases of simple mechanical obstruction, however, bowel viability is maintained, and the gross appearance of dark, distended loops of bowel improves rapidly after decompression and removal of the obstruction.

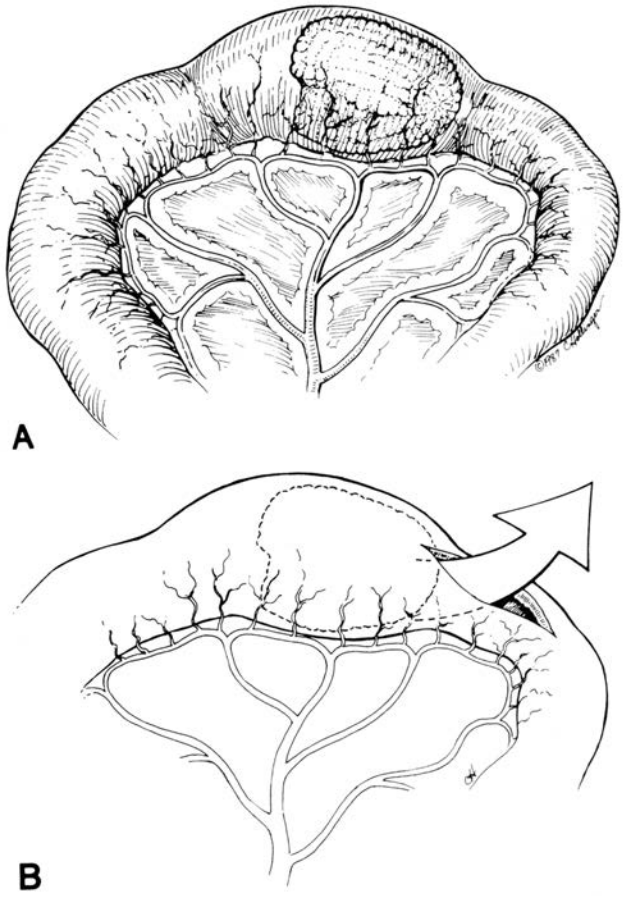


Figure 20-1. A. Complete intestinal obstruction caused by a luminal foreign body such as a corncob causes fluid and gaseous distension. Congestion or cyanotic appearance of the bowel wall occurs proximal to the obstruction. **B.** An enterotomy is made in the antimesenteric surface of viable bowel just distal to the foreign body. The length of the incision approximates the diameter of the foreign body. The foreign body is delivered through the incision with gentle manual pressure.

Intestinal contents are milked 10 cm to either side of the foreign body and the bowel is held between an assistant's fingers or with Doyen intestinal forceps. A No. 15 scalpel blade is used to make a full-thickness longitudinal incision in the antimesenteric border of the intestine in the viable tissue immediately proximal or distal to the foreign body. The length of the enterotomy approximates the diameter of the foreign body. Continuous suction is used to reduce spillage, and the surgeon pushes the foreign body gently through the enterotomy, taking care not to tear the incision margins (Figure 20-1B). The bowel lumen is examined for evidence of perforations or strictures before closure.

Linear foreign bodies such as string, fishing line, meat wrappers, and sewing yarn present a difficult surgical problem. The trailing end of a linear foreign body usually catches over the base of the tongue or in the pyloric antrum and acts as an anchor. Intestinal peristalsis attempts to move the foreign body distally, but because it remains fixed proximally, the bowel plicates itself along the length of the foreign body, which often cuts through the intestinal wall on the mesenteric surface, resulting in local peritonitis.

Linear foreign bodies should be managed by identifying the glossal anchor point initially and releasing it before laparotomy. Commonly, a gastrotomy is also necessary to free wadded string or fishing line from a gastropyloric anchor. The traditional way for linear foreign body removal requires multiple enterotomies to complete removal of the linear body (Figure 20-2). If too few enterotomies are made with too much traction placed on the linear body, the mesenteric border may be perforated in an area that is difficult to explore and suture. Occasionally, the intestinal foreign body perforates at several locations before surgery, and local peritonitis is evident. Sometimes, enough fibrosis has occurred around the foreign body so, even after its removal, the bowel retains its plicated conformation. In these patients, intestinal resection and anastomosis may be necessary.

Linear foreign body removal may often be facilitated using a urinary catheter technique. With this technique only one or two enterotomies are necessary. Once the foreign body is released from its proximal anchor point it is tied or sutured to the tip of an eight to 12 French vinyl urinary catheter (Figure 20-3A). The catheter tip is then pushed distally along the pleated length of bowel. As the catheter is pushed distally, the imbedded linear foreign body disengages from the intestinal wall (Figure 20-3B inset) and the bowel unpleats itself (Figure 20-3B). Once the foreign body is completely disengaged from the bowel wall a second short enterotomy is made distally over the distal tip of the catheter and the remainder of the foreign body is retrieved (Figure 20-3C). Alternatively a longer catheter can be used and pushed down through the colon. The foreign body can then be retrieved from the anus (not shown). The author has found catheter facilitated removal to be a very useful method for linear foreign body retrieval.

Closure of the enterotomy incision usually is performed with a simple interrupted suture pattern in side-to-side longitudinal fashion (Figure 20-4). Single-layer closures are recommended because double-layer closures may cause excessive narrowing of the lumen diameter. Various suture patterns are acceptable, but with all techniques, the vascular and collagen-rich submucosa must be incorporated in the sutures. Single-layer appositional techniques such as the simple interrupted appositional suture pattern is most commonly used. A simple interrupted approximating suture can be used (See Figure 20-10A). Sutures are placed 3 to 4 mm apart and 2 to 3 mm from the cut edge, taking care to incorporate all layers of the intestinal wall. Crushing sutures are tied tightly and cut through the muscularis and engage the submucosa. The author feels they should be avoided since they cause excessive hemorrhage and tissue ischemia (See Figure 20-10B). I prefer a modified Gambee suture, which incorporates the serosa, muscularis and submucosa but excludes the mucosa and is helpful in reducing mucosal eversion (See Figure 20-11).

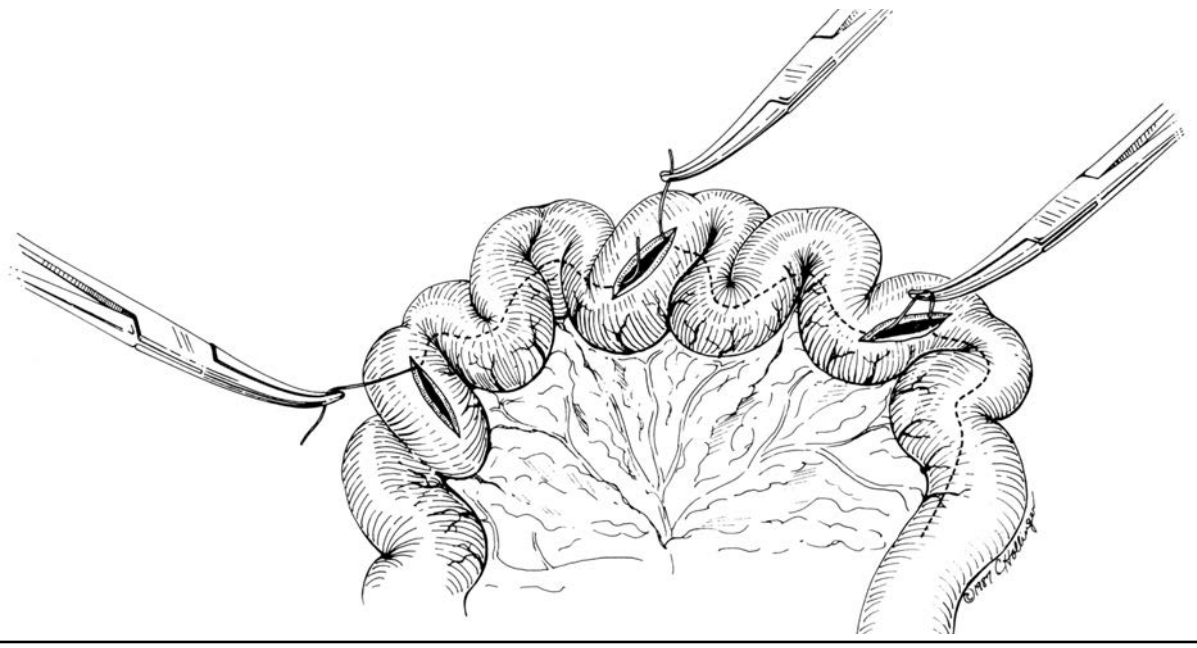


Figure 20-2. With a linear foreign body (e.g., a piece of string), multiple enterotomies usually are required. Mosquito hemostats are used to grasp a loop of the string at each enterotomy site. The string is then sequentially cut and withdrawn through the nearest enterotomy site. See text for details.

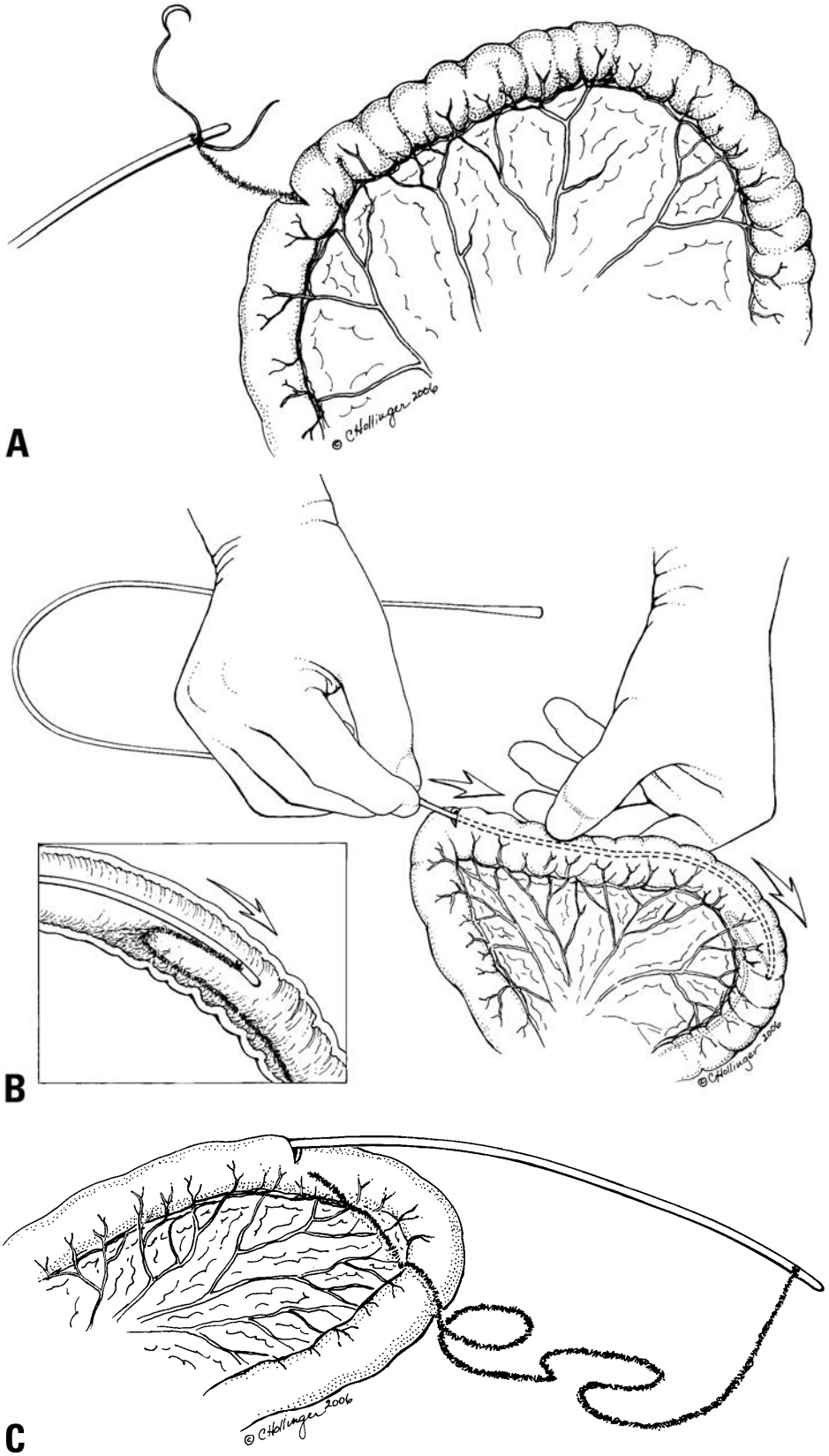


Figure 20-3. Fewer enterotomies are needed if **A.** The linear foreign body is tied or sutured to the tip of a urinary catheter. **B.** The catheter is pushed distally and disengages the foreign body from the intestinal mucosa (inset) as the intestine unpleats itself. **C.** A small enterotomy is made over the tip of the catheter and the foreign body is retrieved. If the catheter is long enough it can be pushed through the colon and out the anus (not shown).

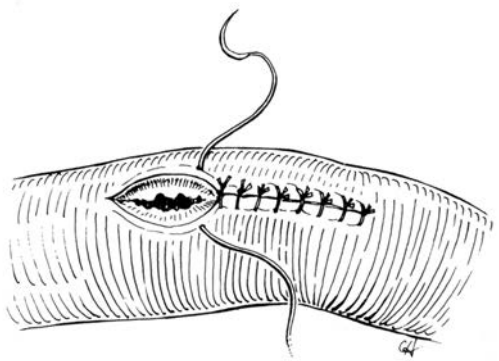


Figure 20-4. An enterotomy usually is closed in side-to-side fashion interrupted suture pattern. Appositional, crushing, or modified Gambee sutures can be used.

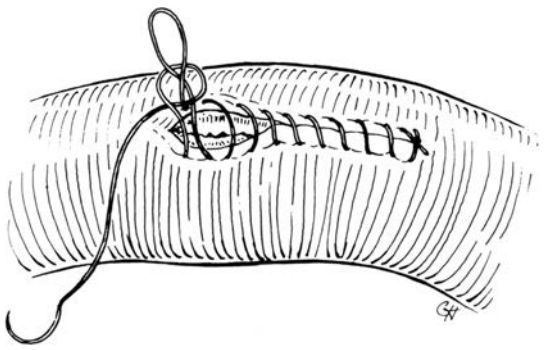


Figure 20-5. An enterotomy also can be closed with a simple continuous appositional pattern.

The enterotomy also can be closed using a simple continuous approximating pattern (Figure 20-5). Suture bites are taken perpendicular to the bowe1 wall 2 to 3 mm from the cut edge and 3 mm apart. The suture line is advanced outside the bowel lumen. Sutures are pulled snugly enough to appose the wound edges gently. Pulling the suture line too tightly may cause strangulation of the wound edge and may lead to dehiscence. Some surgeons tend to close the enterotomy with a Cushing pattern. A continuous inverting Cushing pattern gives good serosa-to-serosa apposition and luminal bursting strengths that exceed those of the interrupted approximating patterns for the first day post operatively. However, lumen diameter is reduced. Suture bites are placed 2 to 3 mm from the wound edge to minimize the amount of inversion (Figure 20-6). The tough submucosal layer is secured with each pass of the needle.

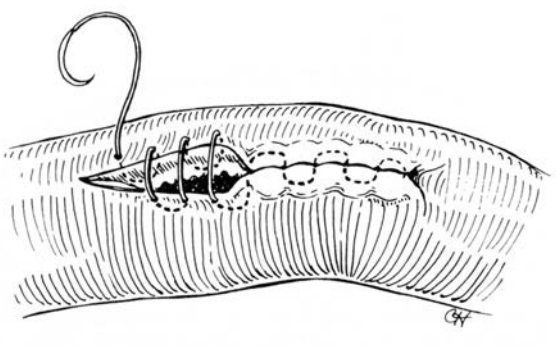


Figure 20-6. A continuous inverting Cushing suture pattern may be chosen for animals lumen who have a higher than normal risk of enterotomy leakage.

A rapid method of closing multiple enterotomies involves the use of a regular dimension skin stapler (AutoSuture multifire premium, United States Surgical, Norwalk, CT). Full thickness traction sutures are placed on both ends of the enterotomy and skin staples are placed every 2-3 mm (Figure 20-7). If the enterotomy is made in a small-diameter loop of bowel, longitudinal closure may cause luminal constriction. To prevent this constriction, the ends of the enterotomy can be closed in transverse fashion. A simple interrupted suture is used to approximate the proximal and distal ends of the longitudinal incision. Additional sutures are then placed 3 to 4 mm apart to appose the remaining bowel wall, resulting in a widened lumen diameter (Figure 20-8). For intestinal biopsies and for enterotomies in small animals I prefer to make a short transverse incision which goes not more than 30 to 40% around the diameter of the enterotomy and then close this wound transversely. I find that making the wound in this direction preserves lumen diameter better than either a longitudinal incision with side to side or transverse closure (Figure 20-9).

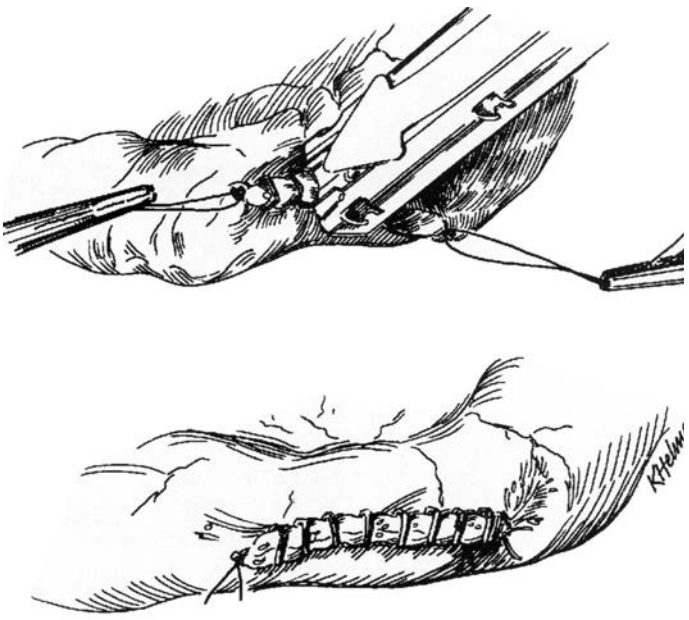


Figure 20-7. Multiple enterotomies can be closed in rapid fashion using a multifire skin stapler. Full thickness stay sutures are placed on the end of the wound and traction applied while staples are applied every 2-3 mm. (From Coolman BR, Ehrhart N, Marretta SM. Use of skin staples for rapid closure of gastrointestinal incisions in the treatment of canine linear foreign bodies. J Am Anim Hosp Assoc 36:542, 2000, with permission).

I prefer to close enterotomies with 3-0 to 4-0 synthetic monofilament suture material. Acceptable materials include polydioxanone (PDS, Ethicon, Inc.), poliglecaprone 25 (Monocryl, Ethicon, Inc.), polyglycomer 631 (Biosyn, United States Surgical) or polyglyconate (Maxon, United Status Surgical) on a narrow-taper, taper-cut, or small reverse-cutting need1e. Due to their rapid absorption time poliglecaprone 25 (Monocryl, Ethicon, Inc.) and polyglycomer 631 (Biosyn, United States Surgical) should be

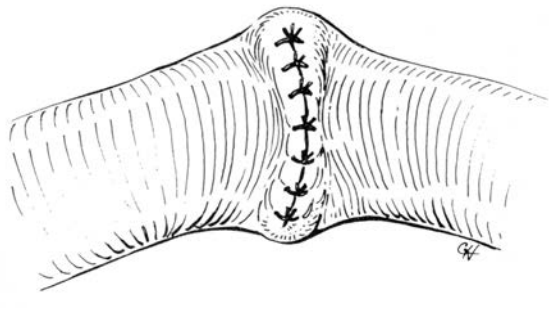


Figure 20-8. In a small-diameter loop of bowel, the longitudinal incision can be closed transversely to prevent luminal stenosis, a simple interrupted pattern is used.

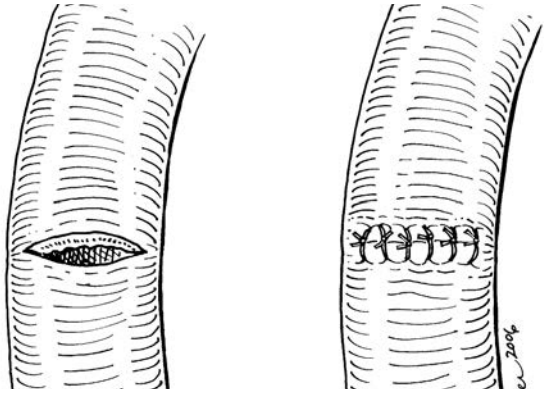


Figure 20-9. For intestinal biopsy make a transverse incision in the bowel wall and close the wound transversely with simple interrupted sutures to preserve lumen diameter.

avoided in colonic surgery (See Chapter 1). Chromic surgical gut has been used with clinical success, but it is not recommended for intestinal closure because it loses tensile strength rapidly in the presence of collagenase and is quickly phagocytized in an infected environment. Nonabsorbable monofilament materials such as nylon (Ethicon, Ethicon, Inc.) or polypropylene (Prolene, Ethicon, Inc.) also may be used but foreign bodies have reportedly become attached to their exposed intraluminal segments. Stainless steel skin staples are reported to migrate into the lumen of the bowel and may be extruded in the feces. After the enterotomy closure is complete, it is rinsed with saline and covered with omentum (See Figure 20-19).

Postoperative Care

The bacterial population of the small intestine is lowest in the proximal duodenum and highest in the distal ileum. Uncomplicated enterotomies of the proximal small bowel may not require postoperative antibiotic therapy. However, when spillage occurs or when an enterotomy is performed on the distal small bowel, parenteral antibiotics are administered prior to or during surgery and are continued for 24 to 48 hours postoperatively. Broad-spectrum bactericidal agents such as intravenous cephazolin, at 10 mg/kg four times daily, in combination with enrofloxacin, 7.5 mg/kg IV twice daily, provide good prophylaxis against most gram positive cocci and gram-negative enteric organisms. Intravenous metronidazole, at 15 mg/kg PO four times daily, is also effective against anaerobic organisms

Replacement intravenous fluids and electrolyte therapy are continued in the postoperative period until dehydration and acid-base and electrolyte abnormalities are resolved. Early introduction of food stimulates bowel contraction, reduces the likelihood of postoperative ileus or adhesion formation, and also serves as a valuable source of fluid and electrolytes. We begin feeding the day after surgery with small amounts of I/D gruel (Hills Pet Nutrition Inc., Topeka, KS). Persistent vomiting, fever, and leukocytosis in the presence of abdominal tenderness may indicate peritonitis resulting from leakage from the enterotomy. Abdominal paracentesis or diagnostic lavage should be performed. If a septic exudate is present, early exploration of the abdomen is indicated, and resection and anastomosis or one of the serosal patching techniques may be performed.

Suggested Readings

Anderson S, Lippincott CL, Gill PJ: Single enterotomy removal of gastrointestinal linear foreign bodies. *J Am Anim Hospt Assoc* 28:487, 1992.

Bebchuck TN: Feline gastrointestinal foreign bodies. *Vet Clin N Am Sm Anim Pract* 32(4):861, 2002.

Capak D, Simpraga M, Maticic D, et al: Incidence of foreign-body-induced ileus in dogs. *Berliner un Munchener tierarztliche Wochenschrift* 114(7-8):290, 2001.

Coolman BR, Ehrhart N, Marretta SM. Use of skin staples for rapid closure of gastrointestinal incisions in the treatment of canine linear foreign bodies. *J Am Anim Hosp Assoc* 36:542, 2000.

Ellison GW. Wound healing in the gastrointestinal tract. *Semin Vet Med Surg* 4:287, 1989.

Enquist IF, Bauman FG, Rehdcr E: Changes in body fluid spaces in dogs with intestinal obstruction. *Surg Gynecol Obstet* 127:17, 1968.

Fossum TW, Hedlund CS: Gastric and intestinal surgery. *Vet Clin North Am Small Anim Pract* 33(5):1117, 2003.

Kirpensteijn J, Maarschalkerweerd RJ, van der Gaag I, et al: Comparison of three closure methods and two absorbable suture materials for closure of jejunal enterotomy incisions in healthy dogs. *Vet Q* 23(2):67, 2001.

Mishra NK, Appert HE, Howard JM: The effects of distention and obstruction on the accumulation of fluid in the lumen of small bowel of dogs. *Ann Surg* 180:791, 1974.

Intestinal Resection and Anastomosis

Gary W. Ellison

Indications

Intestinal resection and anastomosis is performed for various common lesions of the small intestine. Mechanical obstructions, whether luminal, intramural, or extramural commonly require intestinal resection and anastomosis. Lodged intraluminal foreign bodies often cause local bowel wall necrosis or perforation, which may necessitate intestinal resection. Intramural lesions caused by strictures, neoplasms, or fungal granulomas caused by pythiosis must be removed by resection of the affected section of bowel. Occasionally, extramural lesions caused by adhesions secondary to previous surgery, regiona1 peritonitis, or abdominal abscesses require resection of the obstructed segment of intestine.

Strangulated loops of bowel associated with diaphragmatic, ventral, inguinal, perineal, or femoral triangle hernias often require emergency resection and anastomosis. Animals with intestinal or mesenteric volvulus have peracute mesenteric vascular pedicle obstruction and secondary bowel wall ischemia and may require massive resection and anastomosis. With intussusception, the invaginated segment of bowel undergoes early venous congestion and becomes edematous. Intussusceptions then become rapidly irreducible due to outpouring of fibrinous exudate from the invaginated serosal surface. If arterial thrombosis occurs, the invaginated bowel will become ischemic and necrotic. Resection and anastomosis of the affected section of bowel is then necessary.

Determining Intestinal Viability

Non-viable intestine is usually distended, blue, black or grey in appearance and easily discernable from normal bowel. In some cases, determining viability in cyanotic appearing bowel is difficult. The intestine should be decompressed with a needle and suction apparatus to relieve venous congestion. Standard clinical criteria for establishing intestinal viability are color, arterial pulsations, and the presence of peristalsis. Of these three parameters, peristalsis is the most dependable criteria of viability. The "pinch test" should be performed on questionable areas of bowel to determine whether smooth muscle contraction and peristalsis is present. If clinical criteria are inadequate to determine viability, intravenous fluorescein dye or surface oximetry can be used. A 10% fluorescein solution (Fundescein-10, Cooper Laboratories, San Germain, PR) is given at a dosage of 1 mL/5 kg intravenously through any peripheral vein. After 2 minutes, the tissues are examined using long-wave ultraviolet light (Wood's lamp). Areas of bowel are considered viable if they have a bright green glow. Areas of bowel are not viable if they have a patchy density with areas of nonfluorescence exceeding 3 mm, have only perivascular fluorescence, or are completely nonfluorescent. Oxygen saturation may also be a reliable method of determining intestinal wall viability. A sterile probe is placed on the surface of the bowel and an oxygen saturation level reading will occur. According to published reports in rabbits, saturation levels of 81% or above typically mean that the bowel is viable. Values below 76% were consistent with mucosal necrosis and those below 64% indicated transmural intestinal necrosis.

Anastomotic Pattern and Suture Material

Although numerous suture techniques have been used for end-to-end intestinal anastomosis in small animals, approximating patterns are recommended at present. Properly performed approximating techniques create a lumen diameter comparable to normal, result in rapid and precise primary intestinal healing, and minimize the potential for postoperative adhesion formation. Everting techniques (e.g., horizontal mattress pattern) initially create a larger lumen diameter, but ultimately they cause narrowing and stenosis of the lumen. Everting anastomoses are not recommended because they have a greater tendency to leak and because of delayed mucosal healing, prolonged inflammatory response, and increased adhesion formation compared with approximating anastomoses. Inverting anastomoses using Cushing or Connell patterns provide a temporary leak-resistant serosa-to-serosa approximation but they create an internal cuff of tissue, which may cause luminal stenosis. Inflammation is more severe and healing time is slower than with approximating techniques. Despite these dangers, inverting techniques should be considered in patients with a high risk of leakage or for use in colonic resection and anastomosis; in the latter situation, the high bacterial content of feces makes leakage of the anastomosis extremely dangerous.

Approximating end-to-end intestinal anastomoses can be created with various simple interrupted suture patterns or with a simple continuous suture pattern. Interrupted patterns generally are easier to perform, but the simple continuous pattern minimizes mucosal eversion and therefore provides better serosal apposition and primary intestinal healing. Regardless of the suture technique used, proper incorporation of the tough submucosa and reduction of mucosal eversion are vital in performing consistently successful intestinal anastomosis.

A simple interrupted appositional suture incorporates all tissue layers and gently apposes the wound edges (Figure 20-10A). A crushing suture is pulled tightly and cuts through the serosa, muscularis, and mucosa, and engages only the tough submucosal layer of the bowel wall (Figure 20-10B). Crushing sutures create more microhemorrhage and tissue necrosis directly at the anastomosis and the author feels they should be avoided. With both the appositional and crushing techniques, mucosal eversion tends to occur between sutures. I prefer a modified Gambee suture pattern because it reduces mucosal eversion. In this technique, the need1e is passed through the serosa, muscularis, and submucosa, but the mucosal layer is not incorporated in the suture (Figure 20-11). The suture is tied snugly enough to approximate all layers of the intestinal wall gently. The mucosa tends to be pushed into the intestinal lumen and does not evert between sutures.

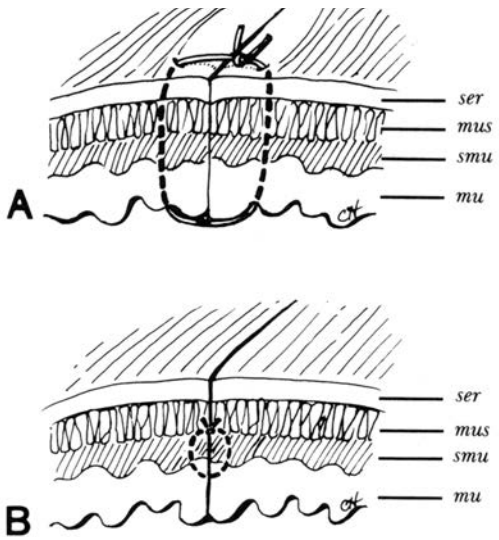


Figure 20-10. A. Simple interrupted appositional suture, the wound edges are gently apposed. mu, mucosa; smu, submucosa; mus, muscularis; ser, serosa. **B.** Crushing suture. The knot is tied tightly cutting through all tissue layers and engaging the submucosa. This suture causes microvascular ischemia and tissue necrosis.

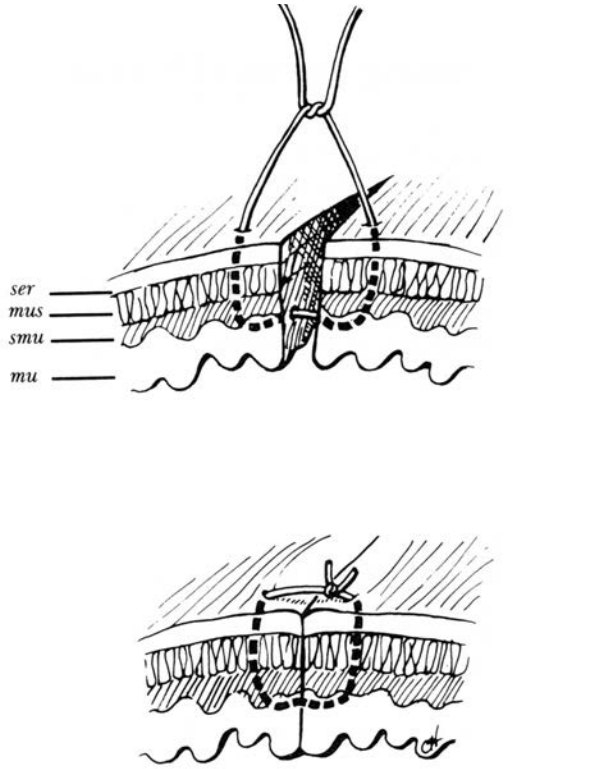


Figure 20-11. Modified Gambee suture. When tied, this suture gently approximates all tissue layers and slightly inverts the mucosa, thereby minimizing mucosal eversion between sutures (bottom). mu, mucosa; smu, submucosa; mus, muscularis; ser, serosa.

A taper-cut, narrow-taper, or small reverse-cutting need1e with 3-0 or 4-0 swaged-on suture material is suitable for most anastomoses. Braided, nonabsorbable materials such as silk or braided polyesters should be avoided. Chromic surgical gut rapidly loses tensile strength due to collagenase and phagocytosis at the wound edge and is not recommended. Synthetic, braided, absorbable suture materials such as polyglactin 910 (Vicryl, Ethicon, Inc., Somerville, NJ) are acceptable, but they have significant tissue drag. I prefer poliglecaprone 25 (Monocryl, Ethicon Inc., Somerville, NJ), glycomer 631 (Biosyn, United States Surgical Corp, Norwalk, CT), polydioxanone (PDS, Ethicon, Inc., Somerville, NJ), and polyglyconate (Maxon, United States Surgical Corp., Norwalk, CT), which are monofilament absorbable sutures with little tissue drag and have all been used successfully for intestinal anastomoses. Nonabsorbable monofilament sutures such as nylon (Ethicon, Ethicon, Inc., Somerville, NJ) or polypropylene (Prolene, Ethicon, Inc., Somerville, NJ) also are acceptable for simple interrupted anastomoses, but they should not be used for simple continuous anastomoses because they do not allow luminal distension. Newer versions of triclosan impregnated polygalactin 910 (Vicryl plus, Ethicon Inc., Somerville, NJ) and poliglecaprone 25 (Monocryl plus, Ethicon Inc., Somerville, NJ) are undergoing investigation in hopes that this bacteriostatic compound will reduce wound infection.

Surgical Technique

A standard midline laparotomy is performed, as well as a thorough examination of the intestinal tract. The area to be resected is packed away from the abdomen with moistened laparotomy sponges. Intestinal contents are milked proximally and distally, and the bowel is held between an assistant's index fingers or with Doyen intestinal forceps 4 to 5 cm from the proposed resection site. A 1- to 2-cm margin of normal viable intestine is included in the proximal and distal boundaries of the area to be resected, which is clamped with Carmalt or Doyen forceps. If luminal disparity is present, the forceps are placed at a 75° to 90° angle on the dilated proximal segment (Figure 20-12A) and at a 45° to 60° angle on the contracted distal segment of bowel (Figure 20-12B). Branches of the mesenteric artery and veins supplying the devitalized bowel are isolated with curved mosquito forceps and are double-ligated. The arcadial vessels located within the mesenteric fat are double-ligated at the area of the proposed resection. A scalpel blade is used to excise the bowel along the outside of the intestinal forceps (See Figure 20-12, dashed lines). With dissecting scissors, the vessels are divided, the mesentery is transected (See Figure 20-10, dotted lines), and the excised bowel is removed from the surgical field. After resection, the small intestinal mucosa has a tendency to evert and can be trimmed back with Metzenbaum scissors (Figure 20-13).

If angling the intestinal incision does not adequately correct for luminal disparity, the smaller stoma can be enlarged by incising the bowel section for a distance of 1 to 2 cm along the antimesenteric surface and then trimming off two triangular flaps (Figure 20-14). This procedure creates an ovoid larger stoma, which can be anastomosed to the larger-diameter section of the bowel.

When the anastomosis is closed with a simple interrupted suture technique, the first suture is placed at the mesenteric border because the presence of fat in this area makes suture placement most difficult, and this is where leakage is most likely to occur. The second suture is placed on the antimesenteric border, and the third and fourth sutures are placed laterally at the 90° quadrants (Figure 20-15A). Depending on bowel diameter, two to four more sutures are placed between each of the quadrant sutures (Figure 20-15B). All sutures are placed 3 to 4 mm apart and 2 to 3 mm from the wound edge. Suture bites on the dilated side of the anastomosis are placed farther apart than on the contracted side of the anastomosis to correct for luminal disparity. Once one side of the anastomosis is sutured, the bowel is flipped over, and the opposite side is completed. From 12 to 20 sutures are used to complete the anastomosis. After the anastomosis has been completed, it is checked for leakage by infusing saline under low pressure into the bowel lumen and massaging the fluid past the anastomosis. The anastomosis can also be checked by gently probing the spaces between sutures with mosquito hemostats for openings. The surgeon then closes the mesenteric defect with a simple continuous pattern, taking care not to include any mesenteric vessels within the suture line (Figure 20-15C).

Occasionally, the small-diameter loop of bowel cannot be enlarged enough to be anastomosed to the larger one. In this case, the large-diameter stoma is reduced by initially angling the cut at 45°. The anti-mesenteric portion of the incision is then apposed with simple interrupted sutures in side-to-side fashion until the remaining opening is an appropriate width to anastomose to the smaller-diameter loop of bowel (Figure 20-16).

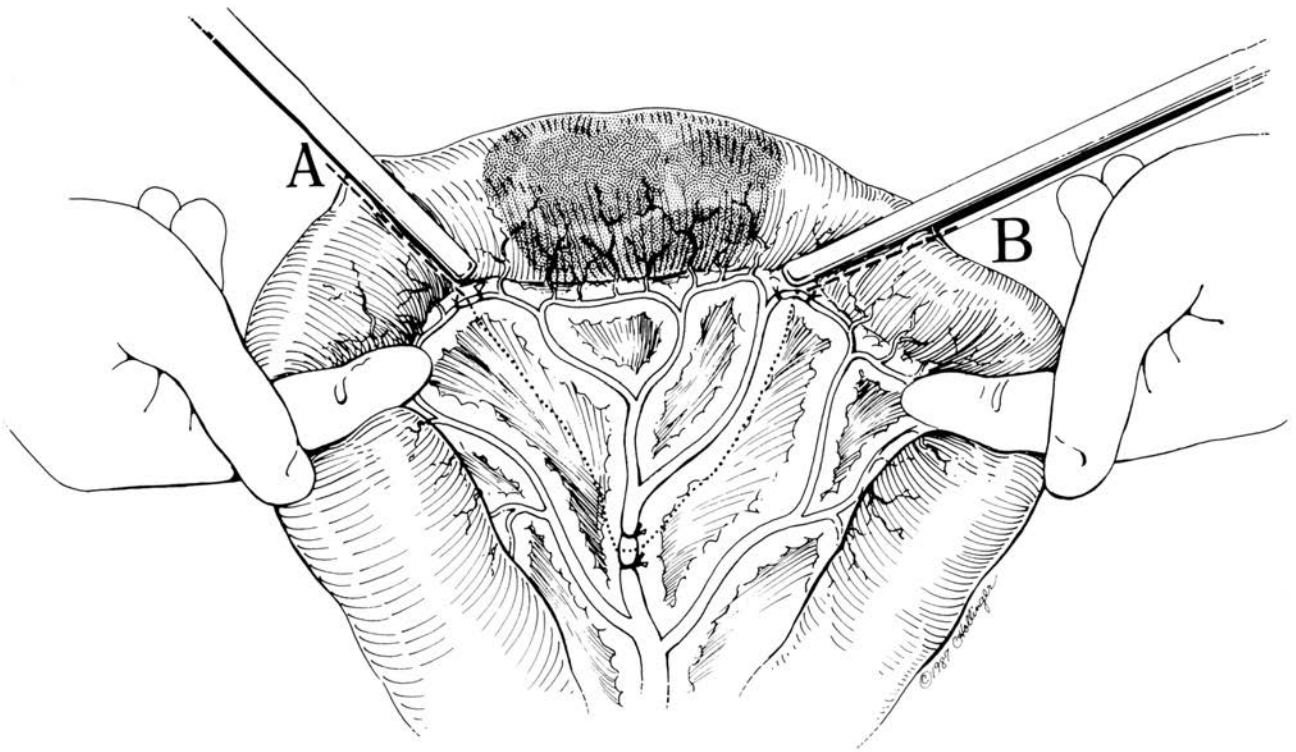


Figure 20-12. Proximal *A.* and distal *B.* forceps are placed at the area to be resected. Mesenteric and arcadial vessels are double-ligated as shown. The bowel is transected with a scalpel blade outside of the clamps (dashed lines), and the mesentery is incised with dissecting scissors (dotted lines). See text for details.

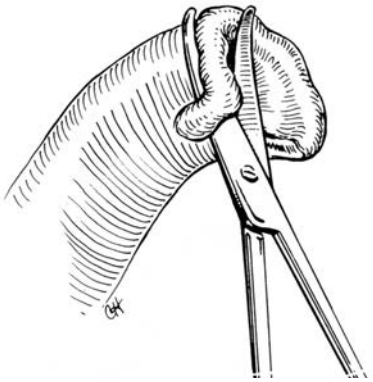


Figure 20-13. Everted mucosa can be trimmed back before the anastomosis is performed.

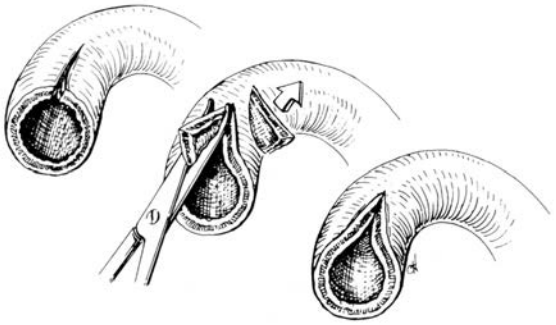


Figure 20-14. Enlargement of bowel section with a smaller diameter may be necessary prior to anastomosis. See text for details.

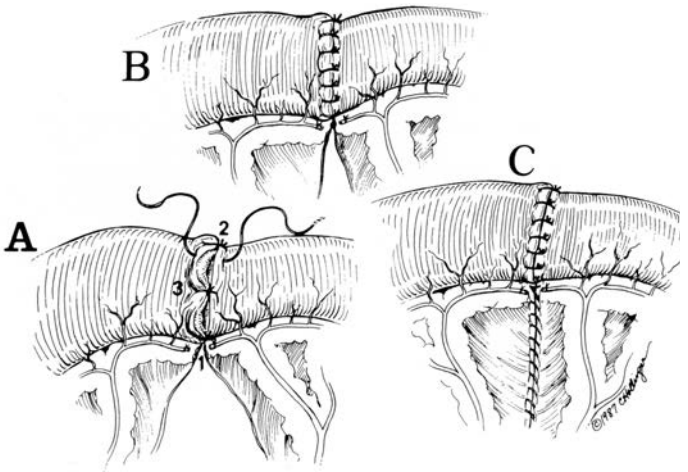


Figure 20-15. Closing anastomosis with simple interrupted suture pattern. **A.** Placement of first (1), second (2), and third (3) sutures; the fourth suture is placed on the lateral bowel wall opposite to the third suture. **B.** Additional sutures are placed between each of the original four. **C.** Final step is closure of the mesenteric defect with simple continuous sutures. See text for details.

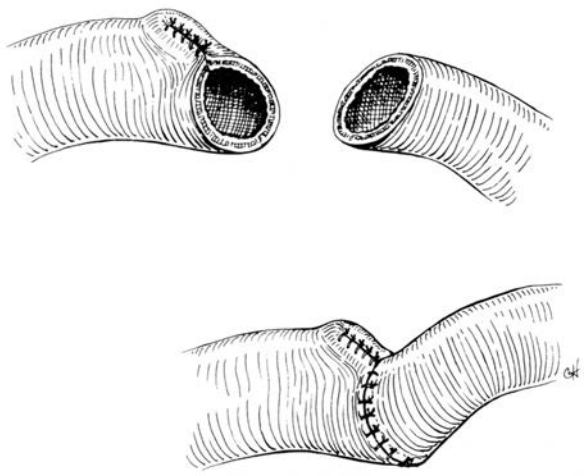


Figure 20-16. Lumen diameter of larger stoma can be reduced to equal that of smaller diameter (top), so anastomosis can be completed (bottom). See text for details.

Alternatively, a simple continuous approximating technique can be used to create the anastomosis. This is performed with two lengths of suture. The first knot is tied at the mesenteric border and the second at the antimesenteric border (Figure 20-17A). The sutures are then advanced around the perimeter approximately 3 mm from the cut edge, with the wound edges gently approximated. The needles are advanced in opposite directions, so one knot is tied to the tag at the antimesenteric border. The final knot is tied to the tag on the mesenteric border (Figure 20-17B and C). If the knot is tied too tightly, a pursestring effect will be produced, and stenosis of the anastomosis may occur. The completed anastomosis is tested for leakage, and the mesenteric defect is closed.

A rapid alterative to sutured anastomosis is the use of stainless steel skin staples. Three stay sutures are used to triangulate the bowel ends and an end-to-end anastomosis is performed with an AutoSuture 35 skin stapler with stainless skin staples (United States Surgical Corp., Norwalk, CT). After triangulating the intestine with three stay sutures, the skin stapler is used to place staples every 2-3 mm around the perimeter of the wound (Figure 20-18). These closures are more rapidly done than handsewn anastomosis and have similar bursting strengths, but some mucosal eversion is created.

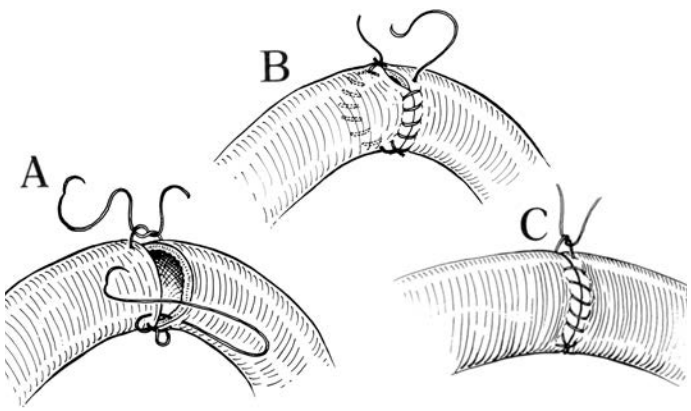


Figure 20-17. Intestinal anastomosis using the simple continuous approximating suture pattern. Two lengths of suture are used. **A.** The first knot is tied at the mesenteric border and the second at the antimesenteric border. **B.** The sutures are advanced in opposite directions around the perimeter of the bowel. **C.** Knots are tied to tags at the mesentery and antimesentery. See text for details.

Leakage of any intestinal anastomosis is most common in animals with pre-existing peritonitis, low serum albumin and in those animals where intestinal foreign bodies have created intestinal ischemia. To help prevent anastomotic leakage, a pedicle of greater omentum is wrapped around the suture line. The omentum is critical to the successful healing of intestinal wounds because it can seal small anastomotic leaks and can prevent peritonitis. Dogs with the greater omentum removed have significant morbidity and mortality associated with intestinal anastomosis, whereas most dogs survive and do well when the omentum is retained. The omentum is tacked to the serosa with two simple interrupted sutures of 3-0 suture material placed on each side of the bowel wall (Figure 20-19).

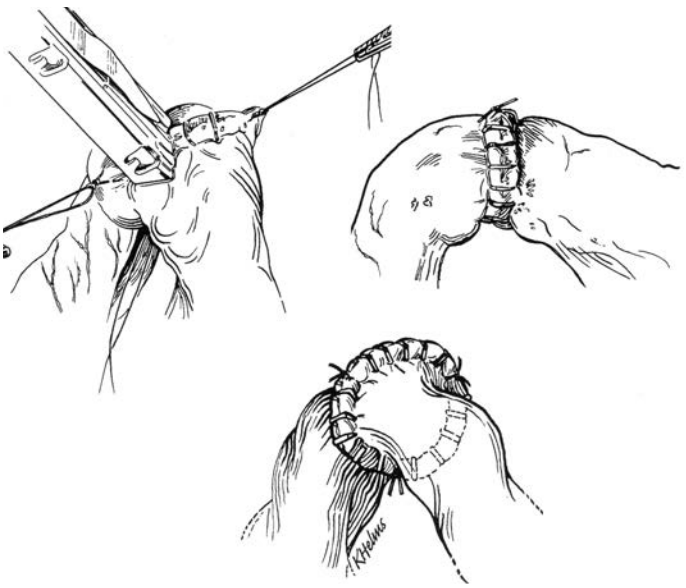


Figure 20-18. Anastomosis can be fashioned using skin staplers by first triangulating the wound ends and then applying staples every 3 mm around the perimeter of the anastomosis. (From Coolman BR, Ehrhart N, Pijanowski G, et al. Comparison of skin staples with sutures for anastomosis of the small intestine of dogs. Vet Surg 29:293, 2000, with permission).

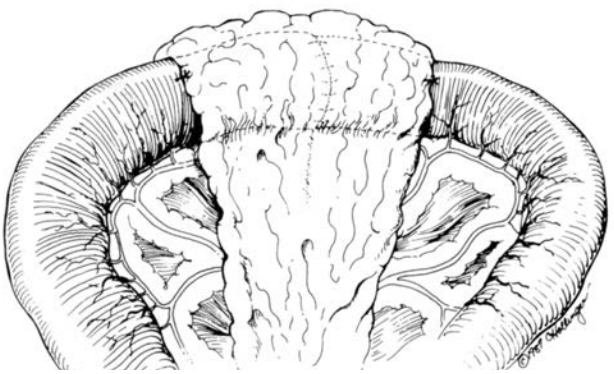


Figure 20-19. To help prevent leakage a pedicle of greater omentum is wrapped around all enterotomies and anastomoses and is tacked to the serosa on both sides with simple interrupted sutures.

Postoperative Care

Fluid and electrolyte deficits are corrected and antibiotic therapy is continued in the postoperative period. The author uses metoclopramide 2.2 mg/kg IV every eight hours to reduce ileus and promote intestinal motility. Feeding a bland diet such as canned I/D gruel (Hills Pet Nutrition Inc., Topeka, KS) is initiated the day following surgery. In uncomplicated cases, reasonable appetite usually resumes within 48 hours. Anorexia or vomiting in the presence of fever, abdominal tenderness, and leukocytosis suggests that anastomotic leakage and peritonitis may have occurred. If degenerate neutrophils with engulfed bacteria or free peritoneal bacteria are present on abdominocentesis, early reexploration of the abdomen is warranted. Further resection and reanastomosis or use of one of the serosal patching techniques described later in this section may be required. Aggressive treatment of generalized peritonitis may be needed to salvage the patient.

Managing Animals with Massive Resection

The propensity for short-bowel syndrome after massive intestinal resection depends on the amount of tissue excised, the location of the resection, and the time allowed for adaptation. Resection of up to 80% of the small intestine in puppies may allow for normal weight gain, whereas resection of 90% produces morbidity and mortality. After resection of large portions of small intestine, maldigestion, malabsorption, diarrhea induced by fatty acids or bile salts, bacterial overgrowth, and gastric hypersecretion may occur. Location of the resection is important. High resection of the duodenum and upper jejunum may decrease pancreatic enzyme secretion because pancreatic-stimulating hormones such as secretin and cholecystokinin are produced in the mucosa of these sections. These reductions in release of pancreatic enzymes contribute to maldigestion. Maldigestion of protein, carbohydrate, and fat leads lo catabolism, negative nitrogen balance, and steatorrhea. Unabsorbed sugars also may cause osmotic diarrhea. If the ileocecal valve is resected, bacteria may ascend, overgrow in the small bowel, and contribute to diarrhea.

After massive resection, the remaining small intestine adapts by increasing lumen diameter, enlarging microvilli size, and increasing mucosal cell number. These compensatory changes may take several weeks; during this period, parenteral fluids, electrolytes, and hyperalimentation may be necessary for the survival of the animal. During this time, the animal ideally will be able to maintain weight even with diarrhea. Medical treatments for unresponsive diarrhea after massive resection include frequent small meals, low-fat diets such as intestinal diet (I/D Hills, Topeka, KS) elemental diet supplements, medium-chain triglyceride oils, pancreatic enzyme supplements, B vitamins, kaolin antidiarrheals, and poorly absorbed oral antibiotics such as neomycin.

Suggested Readings

Agrodnia M, Hauptman J, Walshaw R. Use of atropine to reduce mucosal eversion during intestinal resection and anastomosis in the dog. Vet Surg 32(4):365, 2003.

Bone DL, Duckett KE, Patton CS, et al: Evaluation of anastomosis of small intestine in dogs: crushing versus noncrushing suturing techniques. Am J Vet Res 44:2043, 1983.

Chatworthy HW, Saleby R, Lovingood C: Extensive small bowel resection in young dogs: its effect on growth and development. Surg 32:341, 1952.

Coolman BR, Ehrhart N, Pijanowski G, et al: Comparison of skin staples with sutures for anastomosis of the small intestine of dogs. Vet Surg 29:392, 2000.

Crowe DT: Diagnostic abdominal paracentesis techniques: clinical evaluation in 129 dogs and cats. J Am Anim Hosp Assoc 20:223, 1984.

Ellison GW: End to end intestinal anastomosis in the dog: a comparison of techniques. Comp Cont Educ Sm Anim Pract 3:486, 1981.

Ellison GW, Jokinen MC, Park RD: End to end intestinal anastomosis in the dog: a comparative fluorescein dye, angiographic and histopathologic evaluation. J Am Anim Hosp Assoc 18:729, 1982.

Erikoglu M, Kaynak A, Beyatli EA, et al: Intraoperative determination of intestinal viability: a comparison with transserosal pulse oximetry and histopathological examination. J Surg Res 128(1):66, 2005.

Krahwinkel DJ, Richardson DC: Intestines. In: Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.

McLackin AD: Omental protection of intestinal anastomosis. Am J Surg 125:134, 1973.

Ralphs SC, Jessen CR, Lipowitz AJ. Risk factors for leakage following intestinal anastomosis in dogs and cats: 115 cases (1991-2000). J Am Vet Med Assoc 223(1):73, 2003.

Weisman DL, Smeak DD, Birchard SJ, et al: Comparison of a continuous suture pattern with a simple interrupted pattern for enteric closure in dogs and cats: 83 cases (1991-1997). J Am Vet Med Assoc 214(10):1507, 1999.

Wheaton LB, Strandberg JD, Hamilton SR, et al: A comparison of three techniques for intraoperative prediction of small intestinal injury. J Am Anim Hosp Assoc 19:897, 1983.

Subtotal Colectomy in the Cat and Dog

Ronald M. Bright

Introduction

Megacolon is defined as distension of the large intestine that is usually associated with various degrees of colonic hypomotility. In the cat and dog, this is usually an acquired disorder related to mechanical obstruction of the rectum or colon due to a foreign body, dietary indiscretion, neoplasia (intraluminal/extraluminal), and malformation and stenosis of the pelvis secondary to a healed pelvic fracture. Neurological deficits associated with lumbosacral disease or dysautonomia, a progressive polyneuropathy of the autonomic nervous system of older cats, can also lead to megacolon. Manx cats with partial or complete absence of the sacral and caudal spinal cord may have megacolon with concurrent urinary or fecal incontinence. In cats, megacolon is considered an idiopathic disorder in the majority of cases. Megacolon usually results in impaction of feces resulting in constipation or obstipation.

Dogs and cats can have constipation for several days without clinical signs. If obstruction of the movement of feces is delayed, the stool becomes harder and can form concretions. This

retention of feces, if chronic or prolonged, can result in severe distention of the colon and motility disorders. It can also result in various degrees of mucosal injury that may result in absorption of bacterial toxins contributing to more severe clinical signs. The duration of obstruction that leads to more severe mucosal changes is unknown. One study in cats suggests that if colonic distension is present for 6 months or longer as may be seen with pelvic stenosis secondary to pelvic fractures, degenerative intramural myoneural changes in the colon may not allow return to normal function even if the cause of obstruction is relieved.

When constipation progresses to obstipation, excessively hard feces will prevent defecation. Digital removal of the impaction is usually necessary in these cases. When the condition progresses to obstipation, medical therapy becomes ineffective.

History and Clinical Signs

Regardless of the cause of the constipation, tenesmus with little or no production of feces is the most common complaint. It is not uncommon to have passage of mucus and/or blood associated with obstipation as a result of inflammation of the colonic mucosa. Historically, the owner may describe a possible etiology such as pelvic or lumbosacral trauma or dietary indiscretion.

Systemic signs depend on the duration of the obstipation and degree of injury to the colonic mucosa. These signs can include anorexia, weight loss, lethargy, dehydration, vomiting, and liquid bloody feces. Some cats will eventually become unthrifty and have perineal soiling. Hard concretions within an enlarged colon will often be palpated and some discomfort may be noted. Rectal palpation is done to evaluate for any pelvic canal stenosis, the presence of a perineal hernia, and any intraluminal or extraluminal masses that can result in a mechanical obstruction. In the dog, prostatomegaly or severe lymphadenomegaly of the iliac/sublumbar lymph nodes associated with neoplasia should be considered and carefully evaluated.

Diagnosis

Tenesmus and decreased fecal production should prompt the clinician to consider constipation/obstipation secondary to megacolon. Abdominal and pelvic radiographs will help confirm megacolon and may identify pelvic abnormalities or lumbosacral disease, or other abdominal masses that may be causing colonic or rectal obstruction.

Careful palpation of the abdomen should be performed after feces has been evacuated. Ultrasound examination or colonoscopy can be used to rule out other disease processes such as neoplasia or stricture, especially if there are palpable abnormalites.

Barium enema contrast studies of the rectum and colon may be valuable and can be performed especially in dogs after evacuation of the feces.

Conservative Treatment

Medical management is indicated prior to any surgical intervention. Warm water enemas followed by laxatives and dietary supplements (canned pumpkin) may be helpful. Cisapride, has been used successfully to stimulate colonic motility (0.25 mg/kg or 2.5 mg every 8-12 hours for smaller cats and 5 to 10 mg every 8 to 12 hours in larger cats and dogs). This dose can be safely doubled if lower doses are not effective. Cisapride is no longer commercially available but some pharmacies are able to compound this drug on request. I prefer to use cisapride and lactulose (Lactulose generic, Apotex) concurrently to optimize the effect of keeping the colon evacuated. Some cats aggressively treated in this manner may never require surgical intervention. Other cats, however become less responsive to medical management over time and require surgery.

Surgical Treatment

A subtotal colectomy was once considered a "salvage" procedure. However, a long-term history of success with this technique makes it a very good alternative to medical therapy. Surgery is most often performed in those patients who fail to respond to aggressive medical therapy. However, I have had several owners that opt for surgery on their cat because of their unwillingness or inability to be involved in medical management, which becomes cumbersome or causes behavior problems with the cat. Another group of owners eventually select a surgical option because of the emotional cost that is associated with restraining their cat and giving the appropriate medications.

In cats, a bilateral perineal hernia may be seen concurrently with megacolon. In these cases, performing a subtotal colectomy is usually sufficient to relieve the signs. If not, a bilateral herniorrhaphy may be necessary at a later time.

The standard of surgical treatment for megacolon in the cat is a subtotal colectomy that involves removal of approximately 95% of the colon. I prefer preservation of the ileocolic valve (ICV) in most cats and in all dogs, although numerous reports cite good results when the ICV is removed in cats. I do not remove the ICV except in those cats where a colocolostomy will result in too much tension across the anastomosis.

Before an animal has colectomy performed, it should be carefully evaluated for concurrent problems that may detract from a successful outcome. Loss of anal sphincter tone that is not diagnosed prior to a subtotal colectomy will usually result in an unsatisfactory outcome. Rectal stricture or neoplasia should be ruled out by performing a digital rectal examination prior to surgery.

If the megacolon is the result of an acquired pelvic stenosis that is the result of pelvic fracture malunion and it is less than 6 months from the time of injury, a hemipelvectomy or corrective osteotomy can be tried. The technical demands of the orthopedic procedures make the subtotal colectomy a more viable option.

Enemas should not be administered within 48 hours of surgery to decrease the risk of contamination from liquid intestinal contents at the time of surgery. Applying aseptic surgical principles to colonic surgery, carefully isolating segments of bowel with saline-soaked laparotomy sponges or towels, and employing meticulous and gentle handling of tissues will help ensure success. Perioperative use of an appropriate antimi-

crobial drug is indicated because the surgery results in a "clean contaminated" or "contaminated" wound. A broad-spectrum antibiotic such as a second-generation cephalosporin such as cefoxitin (Mefoxin, Merck and Co.) is preferred because of its effectiveness against most anaerobes as well as the usual gram-negative aerobes. It is preferable to give the drug preoperatively intravenously. Administering the drug 20 to 30 minutes prior to surgery at a dose of 20 mg/kg will result in optimum blood levels of the drug at the operative site. This is repeated 2 to 3 hours later.

Subtotal colectomy is performed through a ventral midline abdominal incision extending from the umbilicus to the pubis. The appropriate colic and caudal mesenteric vessels are ligated and divided. (Figure 20-20) If the ICV is resected, then additional ligatures are necessary for the ileocecocolic artery and vein. I do not find it necessary to ligate the cranial rectal vessels.

In order to optimize exposure of the colon and the planned site of anastomosis, it is helpful to exteriorize the small bowel from the abdomen to the right of the abdominal incision. Moistened laparotomy pads are placed to protect and moisten the small intesine. The urinary bladder is emptied manually or by cystocentesis to ease isolation from the surgical site. Fecal material is massaged toward the middle of the segment of the colon to be removed away from the site of intestinal transection. The colon or ileum is transected proximally and again distally 1-2 cm rostral to the pubis. Straight intestinal clamps (Doyen) are used to hold the segments of the bowel together during the anastomosis. I prefer to perform a single layer anastomosis using simple interrupted appositional sutures of 4/0 polydioxanone or polypropylene (Prolene and PDS, Ethicon, Inc., Somerville, NJ). Some cats have concurrent inflammatory bowel disease and a biopsy of the small bowel may be indicated.

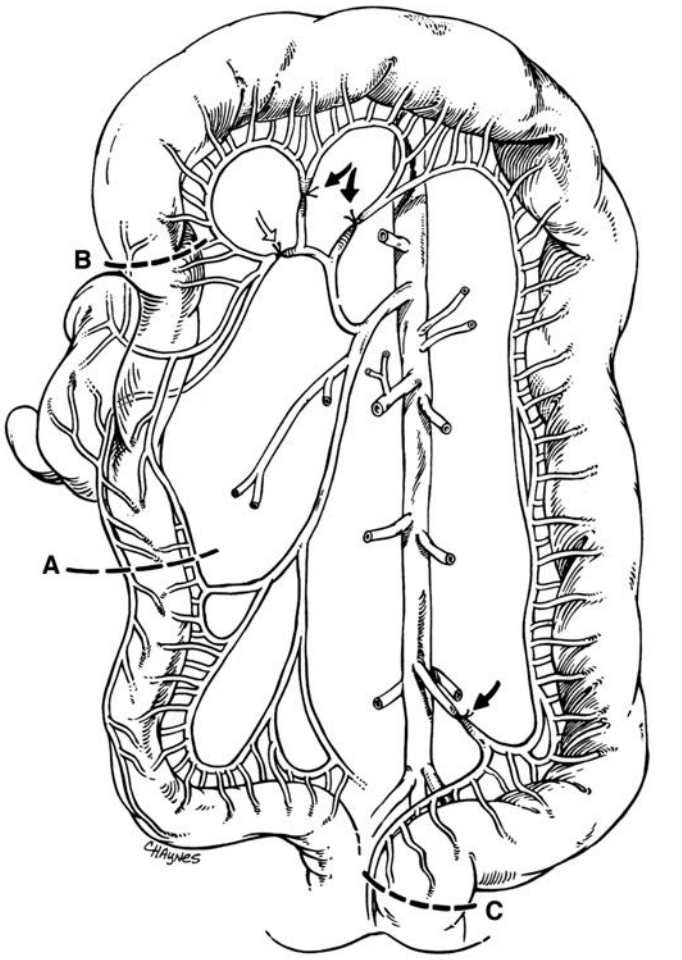


Figure 20-20. The appropriate colic and caudal mesenteric vessels (arrows) are ligated before division of the colon. If the ileocolic valve is removed, the ileocecocolic vessels (open arrow) need to be ligated as well. With the ileocolic valve preserved (my preference), a small length (I to 2 cm) of ascending colon remains after transecting the bowel *A.* Likewise, when transecting the distal colon *B.* a small remnant of colon or cranial rectum is left to anastomose to the proximal segment.

When preserving the ICV, a 2-3 cm segment of the proximal colon is preserved and anastomosed to the 1 to 2 cm segment of remaining distal colon just ahead of the pubic bone (Figure 20-21). Holding these segments together during the suturing process requires intestinal forceps. If there is lumen disparity between the two segments as when the ICV is resected, then the smaller lumen (ileum) can be spatulated to increase its circumference to match that of the opposite larger colonic segment (See Figure 20-14). Alternatively, the larger lumen segment can be oversewn until it matches the diameter of the smaller segment and the anastomosis is completed with a simple interrupted approximating suture pattern using 3 or 4-0 suture size (Figure 20-22). Following the anastomosis, an attempt is made to remove any remaining feces from the rectum by massaging the material distally followed by digital removal through the anus at the conclusion of surgery.

In lieu of the standard suturing technique for the anastomosis, a surgical stapler may be used with the placement via the rectum or transcecally (EEA stapler, U S Surgical). Recently a single-use biofragmentable anastomosis ring, BAR, (Valtrac, US Surgical) has been described and compared to conventional suture technique for restoration of bowel continuity. The BAR is a sutureless inverting anastomosis technique that has compared favorably with standard anastomosis techniques.

Following subtotal colectomy, tenesmus and/or hematochezia may be observed. This usually resolves within 7-10 days. A soft stool will be present indefinitely following this surgery and it appears that the return to a somewhat normal consistency occurs sooner when the ICV is preserved. Frequency of defecation usually increases and rarely is anastomotic stricture a problem postoperatively. Balloon dilation and the use of laxatives have been successful in treating stricture when it has occurred.

Most cats are greatly improved following a subtotal colectomy with normal bowel function. The need for medical management is unlikely. Some cats may continue to have bloody diarrhea and various degrees of discomfort when defecating. This may be related to a stricture at the site of anastomois or inflammatory bowel disease. Endoscopy and biopsy are required to confirm the etiology. Medical therapy is usually successful in improving signs related to inflammatory bowel disease and balloon dilatation and laxatives are usually successful in reversing signs related to stricture.

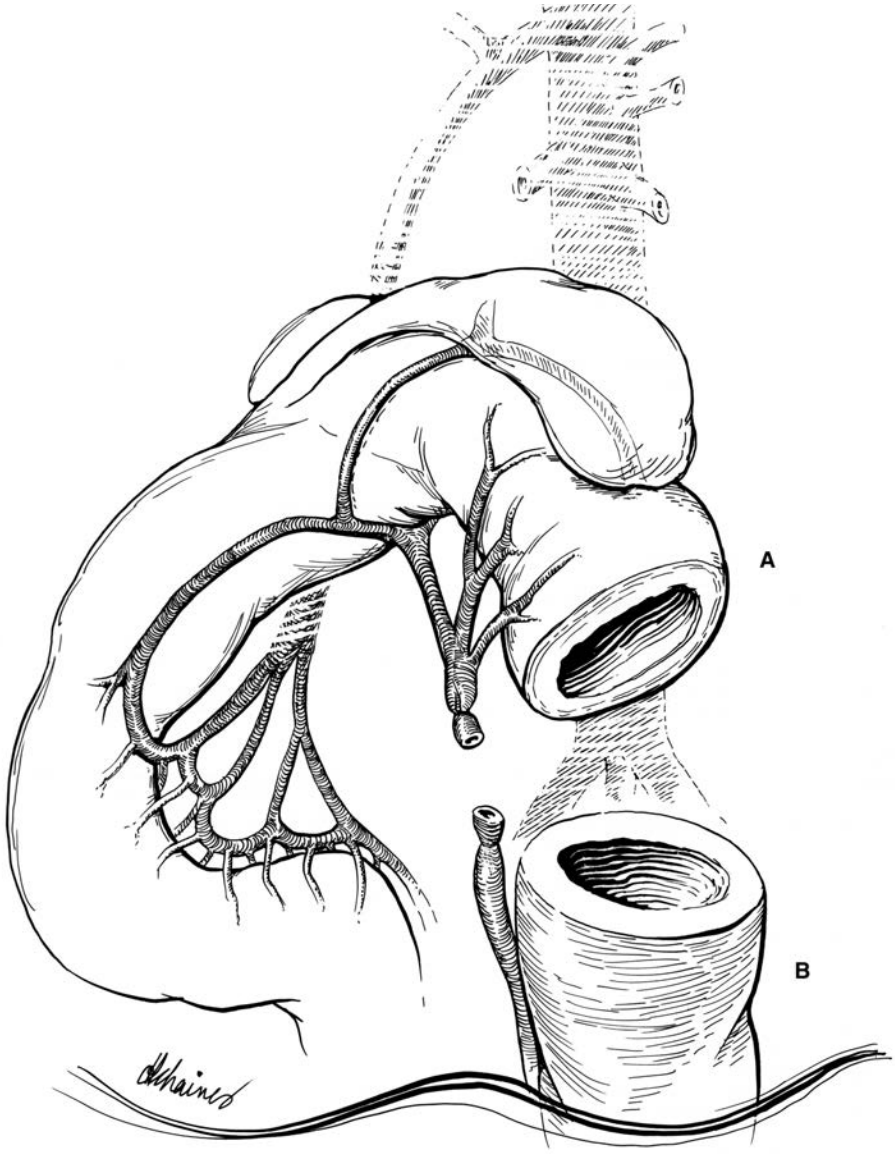


Figure 20-21. The mesenteric sides of the proximal *A.* and distal *B.* bowel segments are aligned before proceeding with the anastomosis.

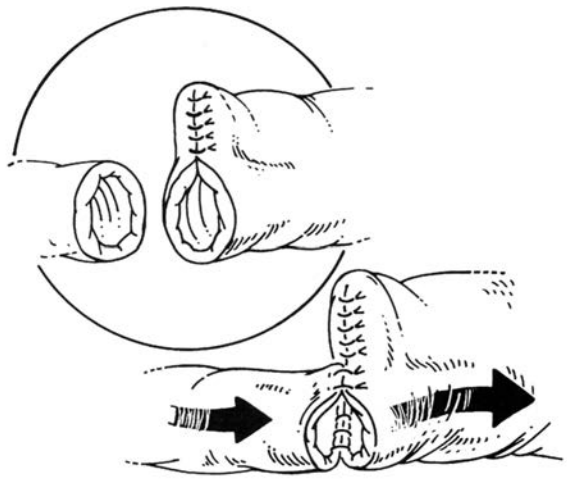


Figure 20-22. When lumen disparity exists between the two segments to be anastomosed, the larger lumen can be sutured closed until the remaining lumen approximates the size of the opposite segment.

I and others have used subtotal colectomy in dogs successfully. The most common indication is for pelvic malformation. Dietary discretion has also been the cause of megacolon in one dog. The prognosis is good in dogs but it appears that preservation of the ICV is much more important in the dog. Their ability to adapt to the absence of the colon and the ICV seems inferior to the cat.

Suggested Readings

Bertoy RW: Megacolon *In* Bojrab MJ, ed.: Disease mechanisms in small animal surgery. 2nd ed. Philadelphia: Lea and Febiger, 1993, p 262.

Bright RM: Subtotal colectomy for treatment of acquired megacolon in the dog and cat. *J AM Vet Med Assoc* 12: 1412, 1986.

DeNovo RC, Bright RM: Chronic feline constipation/obstipation. *In* Kirk RW, Bonagura JD, eds. Current Veterinary Therapy XI. Philadelphia: WB Saunders, 1992, p 619.

Hoskins JD. Management of feline impaction. *Compend Contin Educ Pract Vet* 12: 1579, 1990.

Kudish M, Pavleteic MM: Subtotal colectomy with surgical stapling instruments via a transcecal approach or treatment of acquired megacolon in cats. *Vet Surg* 22: 457, 1993.

Matthiesen DT, Scavelli TD, Whitney WO. Subtotal colectomy for the treatment of obstipation secondary to pelvic fracture malunion in cats. *Vet Surg* 20: 113, 1991.

Ryan, S. Comparison of a biogragmentable anastomosis ring and sutured anastomosis for subtotal colectomy in cats with megacolon. *Proceedings of the 4th Annual Scientific Meeting of the Society for Veterinary Soft Tissue Surgery.* June 2005.

Pozzi A, Smeak DM. Subtotal colectomy in the dog. Personal communication, 2005.

Surgery of the Colon and Rectum

Brian T. Huss

This topic is written based on the available literature through 2010 and does not cover the most current literature on this topic.

Introduction

Colorectal surgery in small animals can be performed with the same surgical success rates as other gastrointestinal surgery with the use of careful tissue handling techniques and modern surgical materials.

The large intestine of the dog and cat is shorter than the small intestine, ranging from approximately 20 to 35 cm in length.[1,2] As a general rule, the large intestine is approximately the length of the trunk in dogs and cats, with the small intestine measuring about four times the length of the trunk. Because of its shorter mesentery, the large intestine does not vary as much in length or position as the small intestine. The large intestine is, however, considerably larger in internal diameter than the small intestine, and has neither the tenia (longitudinal bands) nor haustra (sacculations) seen in other species. Classically, the large intestine has been divided into the cecum, colon (ascending, transverse, and descending), and rectum (Figure 20-23).

Microscopically, the colon is composed of five layers. From the inner luminal surface outward the layers of the colon are 1) mucosa, 2) submucosa, 3) circular muscle layer, 4) longitudinal muscle layer, and 5) serosa. The mucosa consists of columnar epithelial lining cells, mucus secreting goblet cells, and enteroendocrine cells. Intestinal villi are absent in the colonic mucosa; however, intestinal crypts (crypts of Lieberk¸hn) remain. Intestinal crypts are elongated and straight, opening onto the luminal surface of the colon. The submucosa is composed of collagen and elastin fibers arranged in an orderly honeycomb pattern, with submucosal glands and lymphoid tissue dispersed throughout this layer. The submucosa's high collagen and elastin content makes it the important suture holding layer of the intestine. Tunica muscularis is the term commonly given the combined smooth muscle layers of the intestine. Contraction of this group of muscles is responsible for intestinal motility. Finally, the tunica serosa consists of loose connective tissue covered with a layer of squamous mesothelial cells.

The large intestine is anchored to the sublumbar region by the mesocolon, which arises from the left side of the mesentery and is divided into the same parts as the colon that it suspends. The blood supply to the colon and rectum arises from the cranial and caudal mesenteric arteries supported in the mesocolon (See Figure 20-23). The cranial mesenteric artery supplies the cecum, ascending, transverse, and part of the descending colon. The caudal mesenteric artery supplies the remainder of the descending colon as well as the rectum.[1-4] Numerous perpendicular branches (vasa recta) split from the colic arteries, anastomosing with each other along the lesser curvature of the colon. Most of the large intestine is drained by the portal system through the ileocolic and caudal mesenteric veins.[1-4] The caudal rectal vein drains the anal canal and empties directly into the caudal vena cava.[1-4]

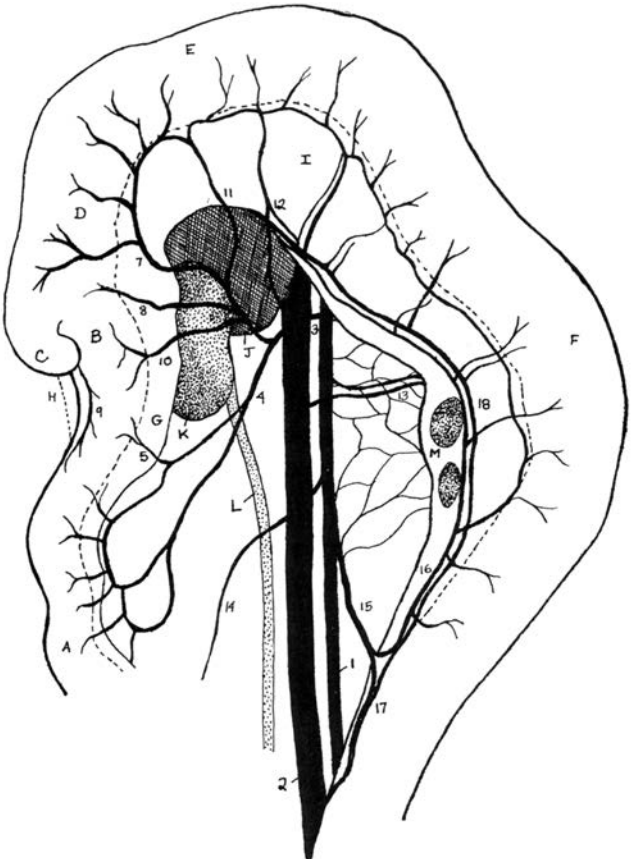


Figure 20-23. Surgical anatomy of the feline large intestine, ventral view. Legend: *A*-jejunum, *B*-ileum, *C*-cecum, *D*-ascending colon, *E*-transverse colon, *F*-descending colon, *G*-mesentery, *H*-ileocecal fold, *I*-mesocolon, *J*-caudate process of liver, *K*-right kidney, *L*-right ureter, *M*-caudal mesenteric lymph nodes, *1*-abdominal aorta, *2*-caudal vena cava, *3*-cranial mesenteric a., *4*-jejunal a., *5*-ileal a., *6*-ileocolic a., *7*-colic branch, *8*-cecal a., *9*-antimesenteric ileal branch, *10*-ileal mesenteric branch, *11*-right colic a., *12*-middle colic a., *13*-left renal vessels, *14*-testicular a., *15*-caudal mesenteric a., *16*-left colic a., *17*-cranial rectal a., *18*-middle colic v.

Indications for Surgery

The need for colonic surgery in small animals is not as common as the need for small intestinal surgery. Colonic surgery techniques involve primary closure of traumatic defects, resection and anastomosis, biopsies, and rarely, foreign body removal.

Trauma to the colon can result from intraluminal or extraluminal sources. Intraluminal causes of injury are rare, but such injury

can result from ingested sharp foreign bodies or improper use of transanal instruments. Colonic foreign bodies can often be gently milked through the colon to a point at which they can be grasped by an assistant using a transanal forceps. Rarely, a colotomy must be performed to retrieve a foreign body. Extraluminal sources of trauma are more common and include gunshot and knife wounds, and less commonly, penetrating bone fragments from pelvic fractures. Indirect or blunt trauma to the colon can also result in contusions, vessel thrombosis, colonic torsion, or even avulsions of the colon. Penetrating wounds of the colon require immediate treatment. Primary repair of clean lacerations, debridement and primary closure of more severe wounds, or resection and anastomosis of devitalized segments may be required to close colonic defects. In one study of dogs with rectal tears resulting from pelvic fractures, only dogs with tears repaired within 24 hours of trauma survived.[5]

Neoplasia of the colon is less common than in other parts of the alimentary system. Benign tumors of the colon commonly include leiomyomas, papillary adenomas, and adenomatous polyps. Malignant transformation of adenomatous polyps has been reported to occur in 18% of dogs in one study.[6] Malignant tumors of the colon commonly include lymphosarcomas, carcinomas, and adenocarcinomas. Metastasis of colonic tumors occurs most commonly to the regional lymph nodes and the liver. Intussusception of the large intestine occurs most commonly at the ileocecocolic junction. Intussusception of the body of the colon is rare. Intussusceptions of the large intestine are treated in the same manor as those occurring in the small intestine.

Colectomy, either partial or complete, may be the treatment of choice for patients with unresponsive megacolon, severe unresponsive inflammatory bowel disease, colonic ulcerations, colonic strictures, colonic torsion, and pelvic canal stenosis resulting from pelvic fracture malunion. Removal of the cecocolic valve has been advocated in the case of megacolon caused by pelvic fracture malunion, to create a soft stool. Most surgeons, however, recommend leaving the cecocolic valve in the treatment of other colonic diseases.

Surgical biopsy of the colon may be the diagnostic method of choice in some colonic diseases. Direct visualization of the entire colon, the ability to safely obtain multiple full thickness samples of colonic wall and regional lymph nodes, and commonly available surgical instrumentation make open colonic biopsy a viable diagnostic method.

Diagnostic Methods

Diagnosis of colorectal disease is based upon physical exam findings and various imaging techniques. Colonic masses can often be palpated in the central to caudal aspect of the abdomen. Rectal masses can often be felt upon digital rectal examination. Survey abdominal and pelvic radiographs are recommended in all patients with suspected large intestinal disease. Radiographs can give indications of regional lymph node size, luminal contents, including the degree of colonic filling and overall density of the luminal contents. Radiographs can also help to diagnose intraluminal or extraluminal foreign bodies, or space occupying lesions, and they give a rough estimate of intestinal wall thickness, as well as, plication or intussusceptions of the intestine. However, abdominal ultrasound provides a better view of the intestinal wall and has become the imaging method of choice for diagnosing intussusceptions. Ultrasonography also allows more detailed imaging of intra-abdominal structures when peritonitis is present and for biopsy and staging of patients with neoplasia. Positive-contrast enemas may be helpful diagnostic tools in selected cases; however, they are contraindicated when perforations or weakened intestinal walls are suspected.

Other diagnostic methods that may be of benefit in large intestinal diseases are proctoscopy, computed tomography (CT) scans and magnetic resonance imaging (MRI). Proctoscopy should be performed with care if weakened intestinal walls are suspected and it is contraindicated when large intestinal perforations are suspected. Computed tomography scans and MRI are most useful when staging patients with cancer to determine the extent and spread of disease.

Microscopic analysis of peritoneal fluid can provide a definitive diagnosis in the case of intestinal perforation. Fluid can be obtained via abdominal paracentesis or, ideally, by peritoneal lavage. A large number of neutrophils with intracellular bacteria are diagnostic of bacterial peritonitis. Less definitive are fluid samples with large numbers of degenerative neutrophils, free abdominal bacteria, or debris which would normally be found intraluminally. Inadvertent sampling of the intestinal lumen could account for these findings. A peritoneal lavage is recommended to confirm equivocal results.

Preoperative Preparation

Bacterial populations in the normal gastrointestinal tract increase dramatically from oral to aboral, changing from predominately aerobic to predominately anaerobic. A gram of feces from the colon contains up to 10^{11} organisms.[7] Aerobic bacteria in the large intestine normally include the Gram-positive genera *Streptococcus, Staphylococcus, Bacillus,* and *Corynebacterium* and Gram-negative members of the enterobacter family, especially *Escherichia coli, Enterobacter, Klebsiella, Pseudomonas, Neisseria,* and *Moraxella*.[7] Up to 90% of the bacteria in the large intestine are anaerobes, including members of the Gram-positive genera *Clostridium, Lactobacillus, Propionibacterium,* and *Bifidobacterium*; the Gram-negative anaerobic bacteria include *Bacteroides, Fusobacterium* and *Veillonella*.[7] The importance of anaerobic bacteria as pathogens in small animals, especially Bacteroides fragilis, has been demonstrated.[8,9]

Mechanical cleansing of the bowel when possible, decreases the risk of intraoperative bacterial contamination by decreasing the quantity of feces in the intestine while the lumen is opened. Mechanical cleansing, however, does not decrease the concentration of bacteria per gram of feces, only the quantity of feces present. The current veterinary regimen of choice for mechanical bowel cleansing is the technique used for colonoscopy preparation.[10,11] The lavage solutions Colyte (Reed & Carnick, Piscataway, NJ) or GoLytely (Braintree Labs, Inc, Braintree, MA) at 80 mg/kg are administered orally in two divided doses four

to six hours apart 18 to 24 hours prior to the procedure. These lavage solutions produce an osmotic diarrhea which cleanses the entire gastrointestinal tract. Potential problems with using mechanical cleansing are poor cleansing of the proximal colon when using enemas only, and watery intestinal contents which are more difficult to control once the intestinal tract is open. One human study comparing mechanical preparation alone prior to colorectal surgery demonstrated an over-all postoperative infection rate of up to 45% compared to mechanical preparation with some form of antibiotic solution at 18%.[12] To reduce infection rates to an acceptable level after colorectal surgery, some form of antibiotic prophylaxis is also recommended in human colorectal surgery.

Oral antibiotics used for prophylaxis in colorectal surgery are generally those that are poorly absorbed from the intestinal lumen. The purpose of oral antibiotics is to lower the concentration of bacteria within the intestine. To be effective, oral antibiotics should be active against the organisms most commonly found in the large intestine. Most oral antibiotic regimens include an aminoglycoside, such as neomycin or kanamycin, in combination with an antibiotic effective against anaerobic bacteria, like metronidazole, erythromycin, tetracycline, lincomycin, or clindamycin.[7,12-16] Neomycin used alone has actually been incriminated in higher postoperative infection rates.[16] When combined with mechanical bowel cleansing, oral antibiotic prophylaxis reduces postoperative infection rates to 5% to 18% in human patients undergoing colorectal surgery.[12,14,15] Oral antibiotic regimens should not be administered earlier than 24 hours prior to surgery to prevent possible resistant bacterial overgrowth.

Systemic antibiotics have been used alone or in combination with mechanical or oral antibiotic bowel preparation for surgical prophylaxis.[13,15-17] The rationale for systemic antibiotic prophylaxis is to obtain blood and tissue levels of antibiotic higher than the minimum inhibitory concentration of potential pathogens at the time of maximum tissue contamination. In cases of emergency gastrointestinal surgery, systemic antibiotics are the only feasible method of preoperative prophylaxis.

General recommendations for systemic antibiotic prophylaxis in colorectal surgery include using a drug, or drugs, that are effective against both the aerobic and the anaerobic bacteria found in the large intestine, and that can be administered by a bolus intravenous injection which can rapidly achieve peak serum levels. Bacteriocidal antibiotics with the most narrow effective spectrum, least cost, least toxic side effects, and easiest administration regimen should be used. Drugs should be given preoperatively to obtain effective target-tissue concentrations at the time of potential primary bacterial lodgement; generally they are administered approximately thirty minutes prior to the start of surgery. The pharmacokinetics of the drug should allow it to obtain effective levels against the expected pathogens in the target tissue. Antibiotics should be re-dosed approximately every two half-lives during surgery to maintain effective tissue levels. Finally, prophylactic antibiotics should be discontinued after surgery, with 24 hours being the maximum accepted duration. Continued postoperative antibiotic administration, or administering systemic antibiotics for extended periods prior to surgery, can result in bacterial antibiotic resistance and superinfections.

Systemic antibiotic prophylaxis for colorectal surgery can be broken into combination therapy regimens and monotherapy regimens. The most commonly used combination antibiotic regimens for human colorectal surgery are aminoglycosides, such as gentamicin, kanamycin, amikacin, or tobramycin along with lincomycin, clindamycin, or metronidazole.[14,18] Effective monotherapy drugs used for antimicrobial prophylaxis in colorectal surgery include cefoxitin, several third generation cephalosporins, and ampicillin/sulbactam.[8,14,19] Cefoxitin has been recommended by several authors as the systemic prophylactic antibiotic of choice for colorectal surgery in veterinary medicine.[20-22] The drug is a single agent intravenous antibiotic that has a low toxicity, is relatively inexpensive, and has good bacteriocidal effects against the primary bacterial pathogens. Cefoxitin dosage recommendations in small animals range from 6 to 30 mg/kg IM or IV given every eight hours.[21,23] With a half-life of 41 to 59 minutes, cefoxitin should be redosed every 1.5 to 2 hours as a surgical prophylaxis.

The above protocols are predominately based upon research on human colorectal surgery. While controversial, the author only uses first generation cephalosporins as a single agent systemic antibiotic prophylaxes, with no local oral antibiotics or mechanical cleansing. The author has not noted any increase in morbidity or mortality in dogs and cats using this minimal bowel preparation.

Surgical Techniques

Approaches

The colon and rectum can be approached through a ventral midline celiotomy, through a partial or complete pubic (ischial-pubic) osteotomy, by a dorsal approach, by a lateral perineal approach, by prolapsing the distal rectal mucosa, or by a rectal pull-through (Figure 20-24).

A caudal ventral midline celiotomy from 2 to 3 cm cranial to the umbilicus extending to the pubic rim permits access to the entire colon and the colorectal junction. The patient should be clipped and aseptically prepared from midthorax to beyond the caudal edge of the pubis. Laterally, the skin preparation should extend slightly beyond the flank folds. The prepuce of male dogs should be flushed with a dilute chlorhexadine or betadine solution.

Exposure to the proximal and middle rectum can be made by extending the caudal midline celiotomy through a partial or complete pubic osteotomy, respectively. The skin incision is extended caudally over the pubis. For a partial pubic osteotomy, the aponeurosis of the gracilis and adductor muscles are incised on the midline and reflected laterally (Figure 20-25A).[24] The obturator nerve and vessels lie at the cranial lateral edge of each obturator foramina, and must be protected. Drill holes are made on each side of the osteotomies to facilitate later repair of the defect (Figure 20-25B) and to the drill holes. Guarding the soft tissue, the pubis is then cut on both sides with a sagittal saw,

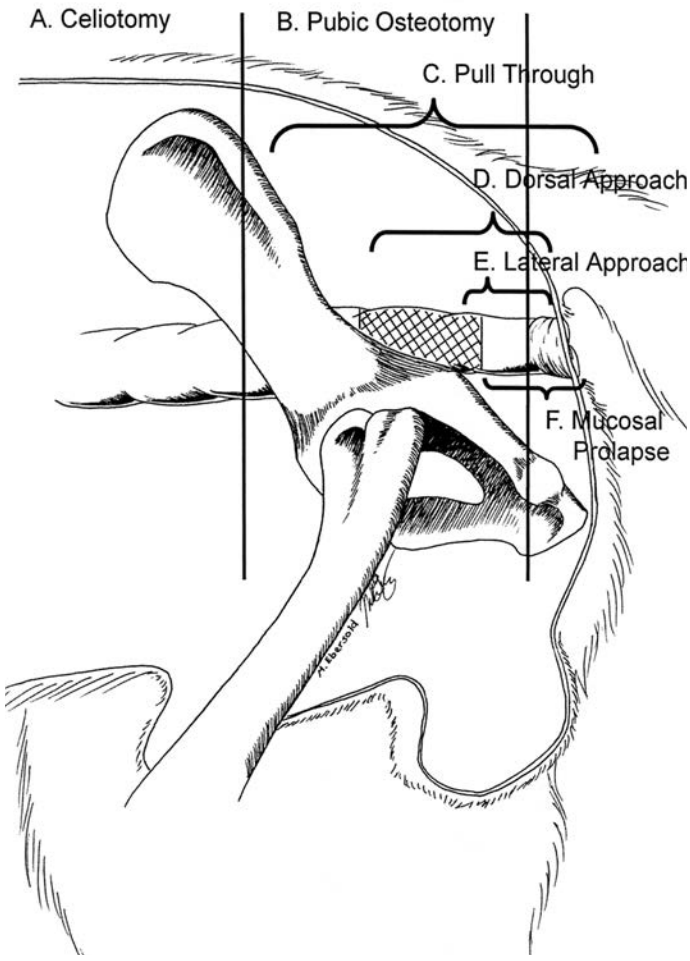


Figure 20-24. Approaches to the colon based on the area of interest (Cross hatched area is the middle 1/3 of the rectum). *A.* Celiotomy for any area of the colon to just cranial to the pubis. *B.* Pubic osteotomy for any area just cranial to and within the pelvic canal. This approach can be combined with a celiotomy. *C.* Rectal pull-through for any lesion caudal to the pelvic reflexion. This procedure will likely result in fecal incontinents. *D.* Dorsal approach for the middle 1/3 of the rectum to just cranial to the anus. *E.* Lateral approach for one side or the other of the distal middle 1/3 of the rectum to just cranial to the anus. *F.* Distal rectal mucosal prolapse for lesions of the distal 1/3 of the rectum and anus.

Gigli wire, osteotome, or bone cutter. The cut should be made 2 to 3 mm medial to the lateral edge of each obturator foramina. Leaving the periosteum and soft tissue attached caudally to the floor of the pelvis, a third osteotomy is made joining the caudal edges of the obturator foramina. The pubis is then hinged caudally as a caudally attached flap (Figure 20-25C). The flap is reattached with two orthopedic wires through the pre-drilled holes. Approach to the rectum through a complete pubic osteotomy is performed in a similar manor; however, the caudal osteotomies are made from the obturator foramina transversely through the caudal ischii.[25] The ischial-pubic flap is then hinged to one side (Figure 20-25D). Before the osteotomies, drill holes are made on each side of each osteotomy to facilitate repair of the flap. Drill holes craniaocaudally along one side of the pubic symphysis have been recommended to aid in reattachment of the muscle aponeuroses. A urinary catheter is used in male dogs to allow easy identification of the urethra so it can be protected.

The dorsal approach to the rectum is an easy one that allows good visualization of the middle and caudal rectum, but not the anal canal. The patient is placed in ventral recumbency with the pelvis elevated and the hindlimbs hanging over the back edge of the surgery table (Figure 20-26). The back edge of the table is padded to prevent pressure on the femoral nerves. The tail is fixed over the back with tape. A curvilinear incision is made dorsal to the anus from just above one ischiatic tuberosity to the other. The subcutaneous fat is dissected to the underlying muscles. The thick paired rectococcygeus muscles are identified dorsally, isolated, and transected (Figure 20-27). Depending on the amount of rectum that needs to be resected, circumferential dissection of the rectum can be performed. The levator ani muscles on either side of the rectum can be partially transected to the level of the caudal rectal nerves to aid in the rectal approach. The external anal sphincter can also be elevated caudally. Stay sutures are placed around the area of the rectum to be excised to keep tissue from retracting into the pelvic canal. Stay sutures can also be used to partially rotate the rectum and gain better exposure to the lateral and ventral surfaces. Full circumferential segments of rectum can be resected, or smaller masses, or lacerated tissue, can be resected with an elliptical incision in the rectum (Figure 20-28). The rectum is closed as previously described using sutures or staples. The transected muscle bellies and skin are closed routinely. Rarely, drains may be necessary in contaminated rectal lacerations, however, the drains should not touch the anastomosis as this may predispose the wound to dehiscence.

The lateral perineal approach is rarely indicated to expose one side or the other of the caudal portion of the rectum. The initial approach is identical to that used for repair of a perineal hernia. The rectum is approached by separating the external anal sphincter and the levator ani muscles.

Distal rectal masses that are small and noninvasive can be approached by prolapsing the caudal rectal tissue through the anus. This can be performed digitally or by placing a stay suture or allis tissue forceps oral to the mass (Figure 20-29). Stay sutures are used to retract the rectum while the affected tissue is resected. The rectum is closed in a single layer with a simple interrupted or a continuous suture pattern. The stay sutures are released to allow the rectum to retract into the pelvic canal.

Approaches to the middle and distal thirds of the rectum can be approached through various pull-through techniques. These techniques can involve prolapsing tissue, extensive tissue dissection, or a combination of the two.

Resection and Anastomosis

Resection and anastomosis of the colon are performed in a manner similar to that of the small intestine. After making an approach to the affected segment of colon, a complete exploration of the area is performed. To determine the extent of the disease process, regional lymph nodes and adjacent organs are carefully examined at surgery. Examination for unrelated, but potentially complicating disease processes should be performed during celiotomy approaches.

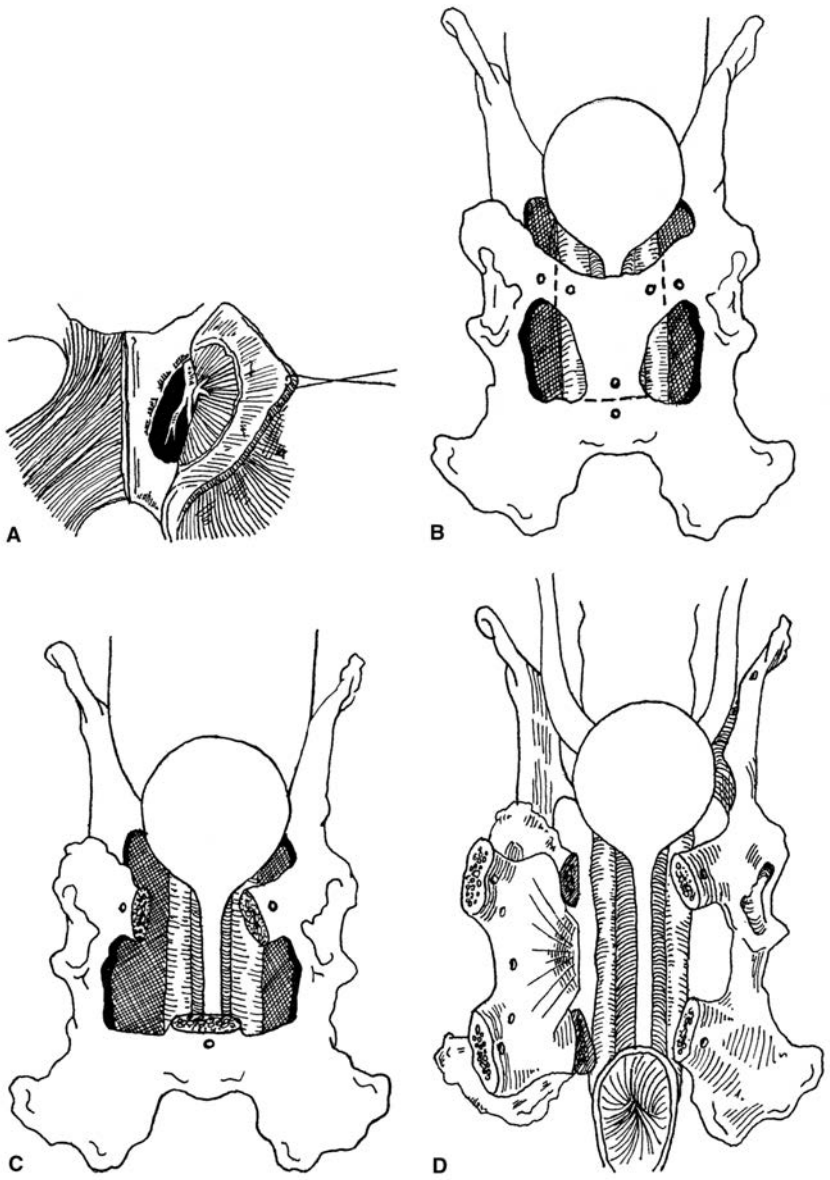


Figure 20-25. Approach to the colon and rectum through a pubic osteotomy. See text for details. **A.** The aponeurosis of the gracili and adductor muscles are incised on the midline and reflected laterally. Note the obturator nerve and vessels at the cranial lateral edge of the obturator foramina. **B.** Osteotomy sites and drill holes for a partial pubic osteotomy. **C.** After reflecting the pubic floor segment caudally, the rectum is visible under the urinary tract. **D.** Reflecting the pubic floor laterally after a complete osteotomy, the entire ventral rectum can be visualized.

The intestinal segment to be resected should be carefully isolated with laparotomy sponges moistened with warm isotonic saline (Figure 20-30A). The exposed tissue should be kept moist at all times to prevent desiccation and trauma. Two to three layers of laparotomy sponges or 4x4 sponges allows for removal of contaminated material with minimal chance for further contamination. Contaminated material should be removed from the sterile field as soon as possible to prevent further spread of contamination. An area for contaminated surgical instruments on the sterile field can be made with a dry lap sponge or drape. As soon as the instruments are no longer needed, they should be removed from the instrument table.

Once the affected colonic segment is isolated, the luminal contents should be milked from the areas that will be incised. The author prefers to remove the luminal contents with the resected intestinal segment or milk the contents aboral of the planned anastomosis site. The blood supply to the affected segment should then be double ligated using 3-0 to 4-0 suture material or ligation clips (Figure 20-30B). For short segments, only the vasa recta perpendicular to the colon need to be ligated, preserving the vessels running parallel to the colon. Resection of longer segments necessitates ligation of the main blood supply running parallel to the colon. Once the blood supply has been ligated, delineation between vascular and avascular segments of colon can be easily observed.

Carmalt forceps can be placed at the edges of the colonic segment to be resected. A minimum of 1 to 2 cm of healthy vascularized tissue should be included within the segment to be resected. Carmalt forceps can be placed perpendicularly across the colon, or they can be placed to back cut on the antimesen-

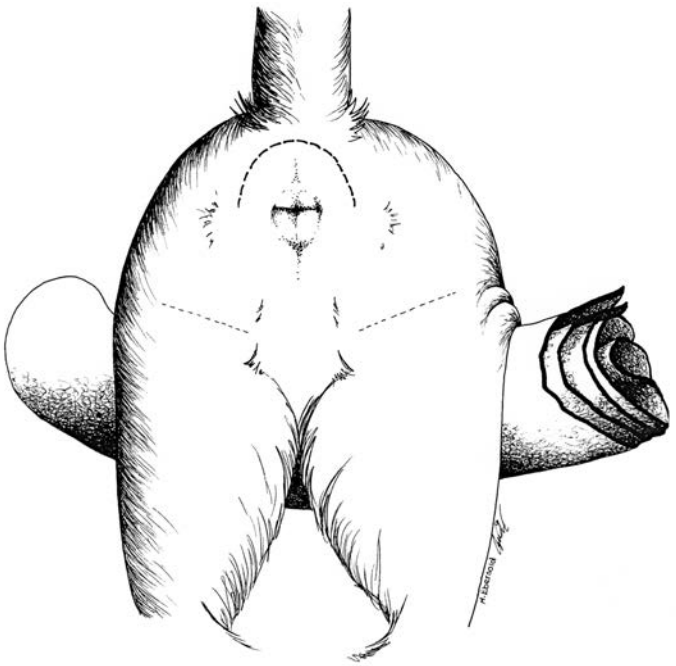


Figure 20-26. Patient positioning for a dorsal approach to the rectum (See text for details). The curved dotted line indicates the location of the incision.

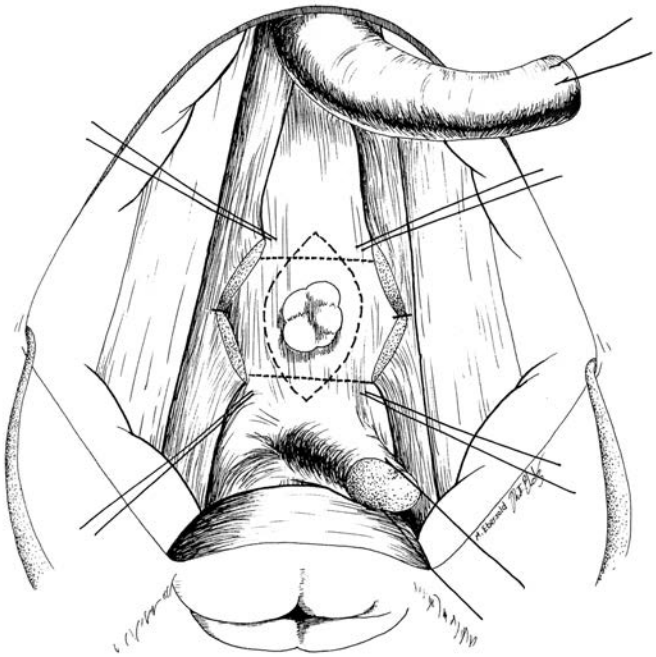


Figure 20-28. After cutting and retracting the rectococcygeus muscles the levator ani muscles on either side of the rectum can also be partially transected to expose the rectal lesion. The rectum can be resected with an elliptical incision or circumferentially as needed to remove the lesion (dotted lines). Make certain to use sufficient stay sutures in normal rectal tissue to keep the cut edges from retracting away from the surgery site.

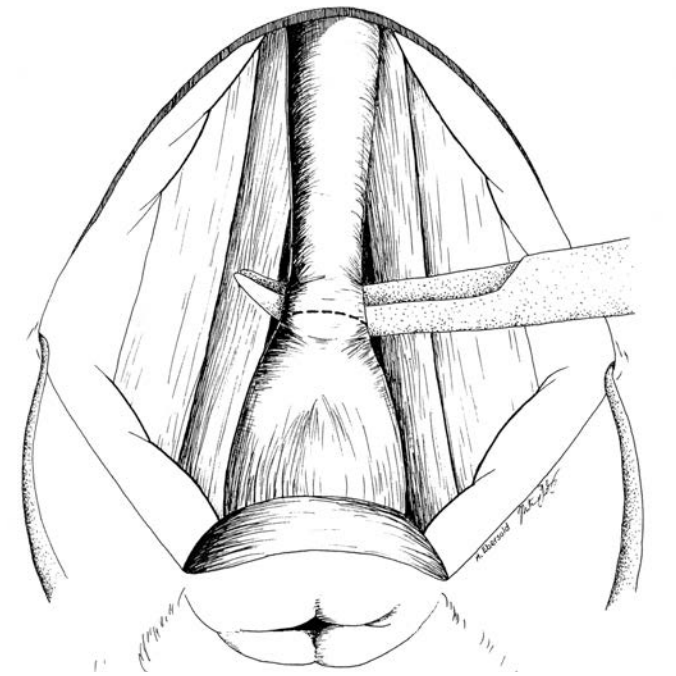


Figure 20-27. The taught thick paired rectococcygeus muscles (under forceps) are easily identified after the incision is made and subcutaneous fat is dissected. The muscles can be cut anywhere along the belly (dotted line) and distracted with stay sutures.

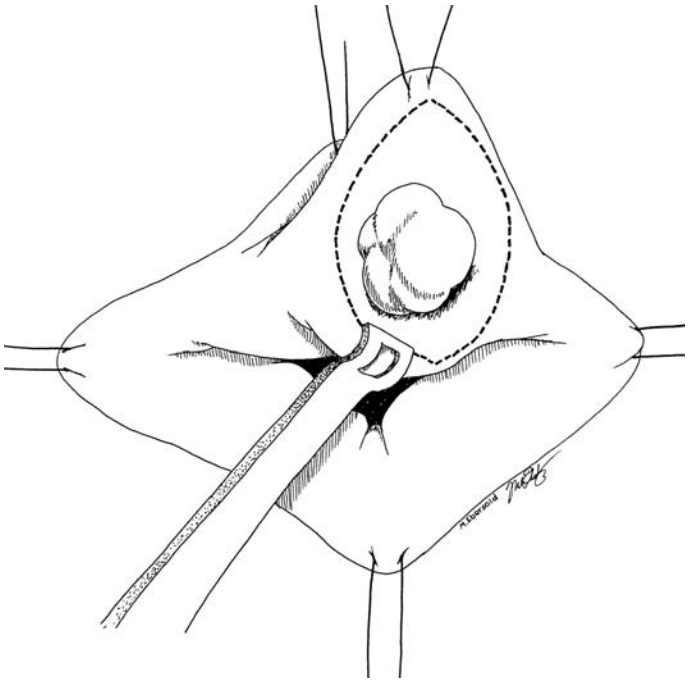


Figure 20-29. Prolapsing caudal rectal mucosa can be done by grasping the mucosa oral to the lesion with atraumatic forceps or stay sutures. Sufficient full thickness stay sutures in normal rectum should be placed to keep the cut edges well defined and prolapsed until the defect is closed.

teric side, creating a larger anastomotic diameter. Atraumatic clamps (Doyen forceps, vascular forceps, bobby pins, or an assistant's finger tips) are placed 4 to 5 cm to the outside of the Carmalt forceps. The atraumatic forceps keep luminal contents from leaking from the cut ends of the colon, as well as assisting in manipulation of the cut ends of the colon. Any remaining mesocolon is then resected as far from any vessels as possible. The affected colon segment can then be resected with a scalpel, using the outside edge of the Carmalt forceps as a guide. Colonic mucosa commonly everts over the cut edge of the intestine. It is easier to anastomose the colon if the mucosa is resected level to the cut edge of the outer colonic wall. This procedure is easily performed using Metzenbaum scissors. The colonic segments can then anastomosed using a variety of techniques listed below.

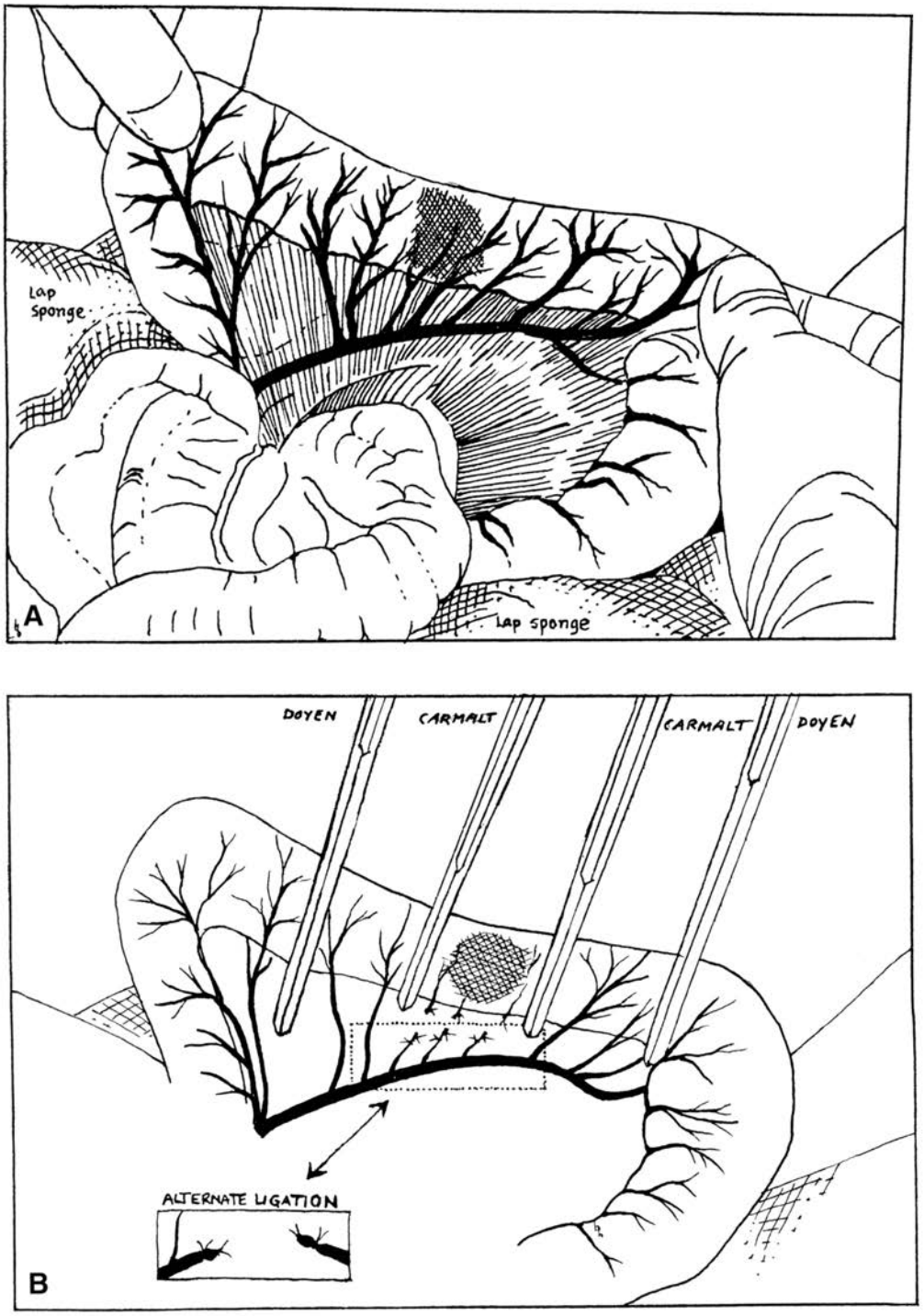


Figure 20-30. Preparation for colonic resection and anastomosis. **A.** Moistened laparotomy sponges are placed under the balfour retractor and wrapped around the base of the mesentery to isolate the affected colonic segment. **B.** The blood supply to the affected segment is double ligated. For short colonic segments, individual vasa recta should be ligated, preserving the longitudinal mesenteric vessels. For longer colonic segments, the longitudinal mesenteric vessels can be ligated. Carmalt forceps are placed oral and aboral to the segment of colon to be resected, making certain to include all of the avascular bowel. Atraumatic forceps are then placed outside the carmalt forceps. The affected colonic segment is now transected using the outside of the carmalt forceps as a guide.

After performing and pressure leak testing the colonic anastomosis, the anastomotic site is flushed with saline. Layers of laparotomy sponges can be removed in between flushing the anastomosis. Surgical gloves, instruments, and other contaminated equipment should be changed at this time. A sterile fenestrated drape can be placed over the surgery site. If there is no obvious contamination of the abdomen, abdominal lavage is not necessary. Otherwise, the abdomen should be lavaged with warm isotonic saline until the effluent is clear. The mesocolon should be closed with a continuous suture pattern of 3-0 or 4-0 absorbable material. Care should be taken so as not to damage the adjacent blood supply to the colon. The surgical approach is then closed in a routine manor.

Methods of Colonic Anastomosis

After intestinal resection, the continuity of the intestinal tract can be reconstructed using three basic anastomotic techniques: end-to-end, side-to-side, and end-to-side. When hand suturing is used, the end-to-end intestinal anastomosis is the easiest and quickest technique to perform and results in a more physiologic reconstruction. Side-to-side and end-to-side anastomosis of the intestine have also been incriminated with formation of blind pouches where bacterial overgrowth and resulting malabsorption can occur.

When a disparity of luminal diameters is present, especially as seen with ileocolic anastomoses, several techniques are available to aid in end-to-end anastomoses. A funneled closure is the simplest anastomosis if minor disparities of luminal diameters exist. Sutures are placed equidistant around the circumference of the lumen ends. This results in stretching of the smaller luminal opening and constricts the larger luminal opening (Figure 20-31A). With larger luminal disparities, the smaller diameter intestine can be cut at an angle, with more tissue removed from the antimesenteric border (Figure 20-31B). If a luminal disparity still exists, the antimesenteric border of the smaller-diameter intestine can be further incised 1 to 2 cm. Two triangular flaps of intestinal wall can then be cut off each side of the incision, leaving an ovoid stoma that can be anastomosed to the larger-diameter intestine (Figure 20-31C). Finally, if the smaller-diameter intestinal lumen cannot be opened widely enough, the larger-diameter intestine can be partially sutured closed until the luminal diameters are equal (Figure 20-31D).

Two-layer anastomotic closures of the colon are no longer advocated. Several studies have demonstrated there is no increase in intestinal dehiscence and actually an increased healing rate, using a single-layer closure versusa two-layer closure.[26,27] In fact, two-layer anastomotic closures have been demonstrated to have significantly greater incidences of dehiscence and stricture formation in the rectum because of avascular necrosis of the tissue incorporated in the inner suture pattern.[26] Leakage at the anastomosis site is not a problem if the omentum is healthy and intact and the patient is not hypoproteinemic. A fibrin seal will form at the anastomosis site within about 3 hours in most patients.[28]

Numerous intestinal anastomosis studies have been performed comparing simple continuous, simple interrupted, inverting, everting, or appositional suture techniques. The anastomosis techniques that are the easiest to perform, with the least leakage, the least adhesion formation, and the best histologic healing, have been the single-layer simple interrupted approximating techniques. In 1968 Poth and Gold described the crushing appositional anastomosis technique in human patients.[29] This technique involved a through-and-through suture, which was then tightened to cut through all the layers of the intestine except the tough submucosa (Figure 20-32A). This technique kept the suture from being exposed to the luminal surface, where it could become infected, and from exposure to the abdominal lumen and serosal surface, where adhesions could form. At about the same time the crushing technique was developed, DeHoff investigated the use of a simple interrupted approximating technique for intestinal anastomosis in dogs (Figure 20-32B).[30] Both appositional techniques maintain luminal diameter, diminish adhesion formation, and allow for rapid primary healing of the intestinal anastomosis. Some eversion commonly occurs with both these appositional techniques, resulting in adhesions and some altered healing.[28] The Gambee suture pattern helps eliminate the slight eversion caused by the simple appositional suture patterns (Figure 20-32C).

Various suture materials are used successfully for intestinal anastomosis, including monofilament and braided sutures of absorbable and nonabsorbable sutures. The monofilament absorbable sutures polydioxanone, polyglyconate, and poliglecaprone 25 are closest to the ideal suture material available for intestinal anastomosis today. Nonabsorbable monofilament suture material such as nylon or polypropylene may be useful in patients that are expected to have delayed tissue healing. The braided absorbable sutures polyglycolic acid and polyglactin 910 are absorbed in a relatively short period of time. These sutures have a constant absorption rate which is not affected by infection, so infected suture tracts and granulomas are of little concern. The biggest problem with the absorbable braided suture is the tissue trauma (drag or chatter) as they are pulled through tissue. The surface characteristics of braided sutures have been shown by electron microscopy to increase trauma to the tissue they have been pulled through, as opposed to smooth surfaced monofilament suture material.[31] In small animal colonic surgery, a size 3-0 to 4-0 suture should have sufficient tensile strength to hold intestinal tissue.

A swaged-on reverse cutting or taper-cut suture needle is recommended for colonic surgery. These suture needles facilitate penetration of the intestine's tough submucosa with the least effort and tissue trauma. Taper-point or narrow-taper needles have been suggested by some surgeons, because less intestinal leakage occurs around the suture tract. The increased trauma of passing the taper needle through the submucosa must be balanced with this minor benefit.

The number of sutures placed to form an anastomosis should be the minimum needed to prevent leakage of the anastomosis. Most intestinal anastomosis techniques describe placing sutures 2 to 4 mm from the cut serosal surface and 3 to 4 mm apart. This averages to approximately 12 to 16 simple interrupted sutures evenly spaced around the anastomosis. The first suture

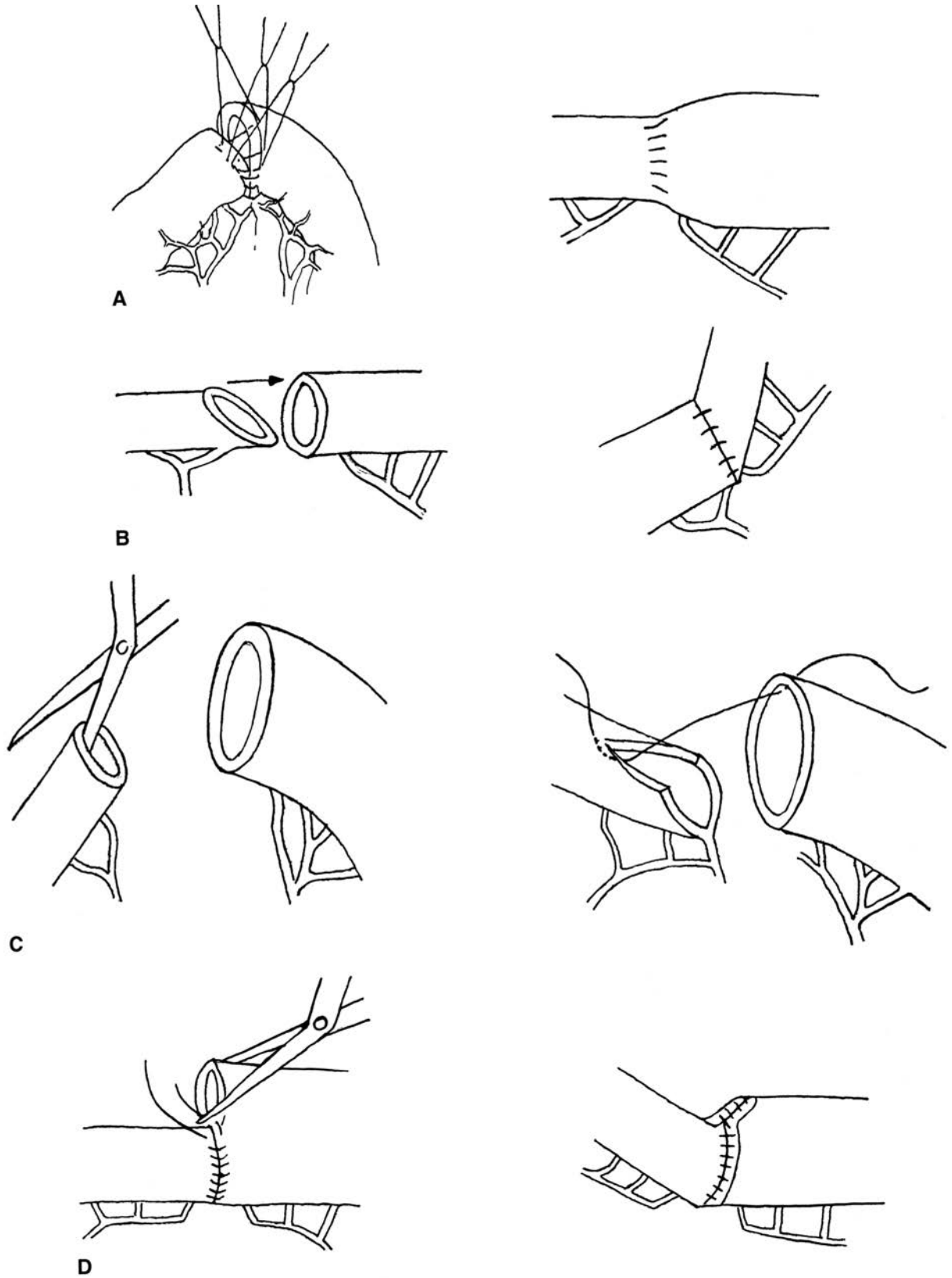


Figure 20-31. Anastomosis of dissimilar sized lumens. See text for details. **A.** Funneled closure. **B.** Oblique transection of the smaller lumen. **C.** Spatulated closure. **D.** Partial over-sew.

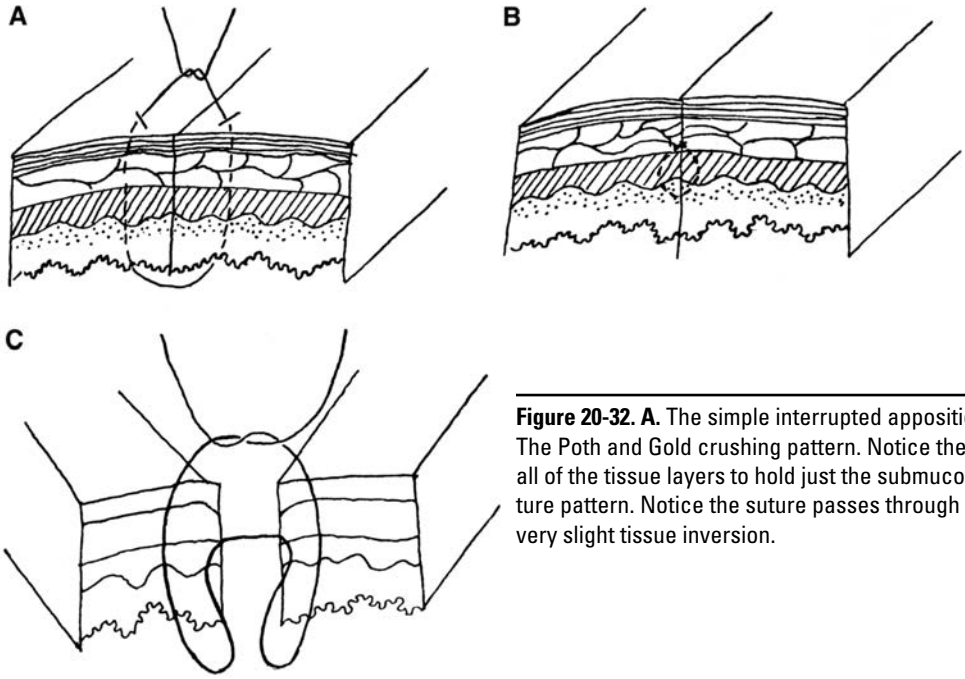


Figure 20-32. A. The simple interrupted appositional suture pattern. **B.** The Poth and Gold crushing pattern. Notice the suture crushes through all of the tissue layers to hold just the submucosa **C.** The Gambee suture pattern. Notice the suture passes through the mucosa and causes very slight tissue inversion.

is normally placed at the mesenteric border because this is the most difficult to see, and this area has the highest incidence of leakage and dehiscence (Figure 20-33A). The second suture is normally placed at the antimesenteric border, with the remaining sutures filling in the area between the first two sutures (Figure 20-33B). The anastomosis can be tested by filling the segment of intestine with saline under slight pressure, or milking luminal contents across the anastomosis and looking for leaks. Any anastomosis will leak if too much pressure is applied. Too many sutures decrease anastomosis healing by interfering with blood supply to the intestinal edges. Some authors recommend wrapping or even suturing the omentum around the anastomosis site. This is normally not necessary because the omentum naturally moves to cover any leaks in an intestinal anastomosis.

Surgical stapling is another method of intestinal anastomosis that has become increasingly popular. The device commonly used in colonic resection and anastomosis is the circular stapler manufactured by Ethicon (Proximate ILS, Ethicon, Inc., Somerville, NJ) or United States Surgical (CEEA, United States Surgical Corp., Norwalk, CT). The circular stapler inverts the intestinal ends and places two circumferential rows of staggered B-shaped sutures. The device then cuts out a donut-shaped section of the inverted tissue from the ends of the intestine being joined. The circular stapler can be inserted through the anus or through an access incision in the intestine. A modified Furness clamp, or purse string stapler, is used to place a purse string suture around the ends of the intestinal segments to be joined. One intestinal end is then slipped over the cartridge end, and the other intestinal segment is placed over the anvil. The purse string sutures are then tied to the movable central shaft between the cartridge head and anvil. The shaft is shortened, compressing the cartridge to the anvil with the intestinal ends in between. The stapler is then fired, forming the anastomosis and cutting out the purse string along with the tissue in the middle of the lumen (Figure 20-34). The circular stapler forms a true inverting anastomosis. Occasionally, the result is the same problem caused by a hand-sutured inverting anastomosis, that is, luminal strictures. The circular stapler is a technically demanding stapler to use. Improper usage of the stapler, or poor surgical technique, may result in anastomotic stricture or dehiscence. When performed by an experienced surgeon, the stapled anastomosis line has been demonstrated to leak less, to be better aligned, and to heal better than single-layer hand-sutured anastomoses.[32] Ordinary skin staplers have also been found to provide safe anastomoses.[33] Skin staplers are especially helpful in repairing multiple intestinal perforation caused by gunshot wounds. Various other sutureless intestinal anastomosis techniques have been studied through the years, from cyanoacrylate adhesives and fibrin glue, to laser welding and non-absorbable and absorbable anastomosis rings. For various reasons anastomosis techniques other than sutures and staples have not met with wide acceptance.

Colonic Healing

The colon follows the same stages of healing as skin and other soft tissue: inflammation, debridement, repair, and maturation.[34] A unique property of colonic healing, however, involves the balance of collagen synthesis and degradation. During the first 3 to 5 days after wounding, collagen synthesis is competing with collagenolysis.[34-36] This is important, because the collagen content of a wound has been directly correlated with wound strength.[36] There is an especially high turnover rate of collagen in the wounded colon.[34-37] Earlier work suggests that as much as 40% of the rat colon's original collagen content, throughout the entire colon, is lost to collagenolysis during the first 4 to 6 days after wounding.[37] However, early studies have over emphasized the drop in collagen content in colonic wounds. With the use of more advanced techniques in measuring the collagen content of a wound, researchers have found that the drop in collagen content is not as dramatic as originally thought.[38] Rapid gain occurs in colonic tensile strength between the third and seventh days after wounding.[38] Local factors in the colon can, however, shift a wound towards increased collagen lysis. Traumatic handling of colonic

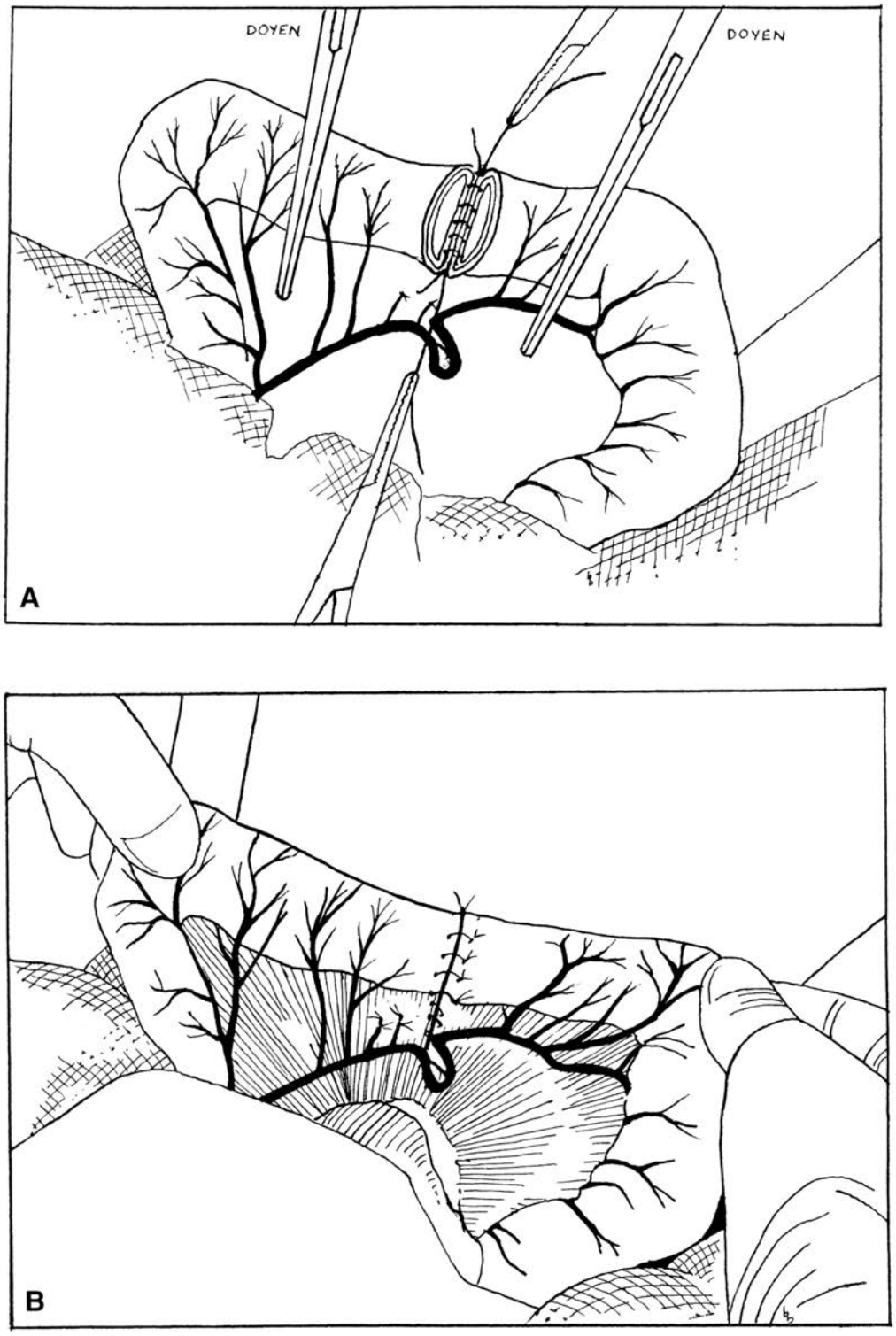


Figure 20-33. Technique for colonic anastomosis. **A.** The two colonic segments are held together with the aid of the atraumatic forceps as a mesenteric and then antimesenteric suture is placed to start the anastomosis. These first 2 sutures can be used as stay sutures to handle the bowel. **B**. The anastomosis is completed with a single layer appositional suture pattern filling in the sutures between the stay sutures. The mesentery is closed with a simple continuous suture pattern.

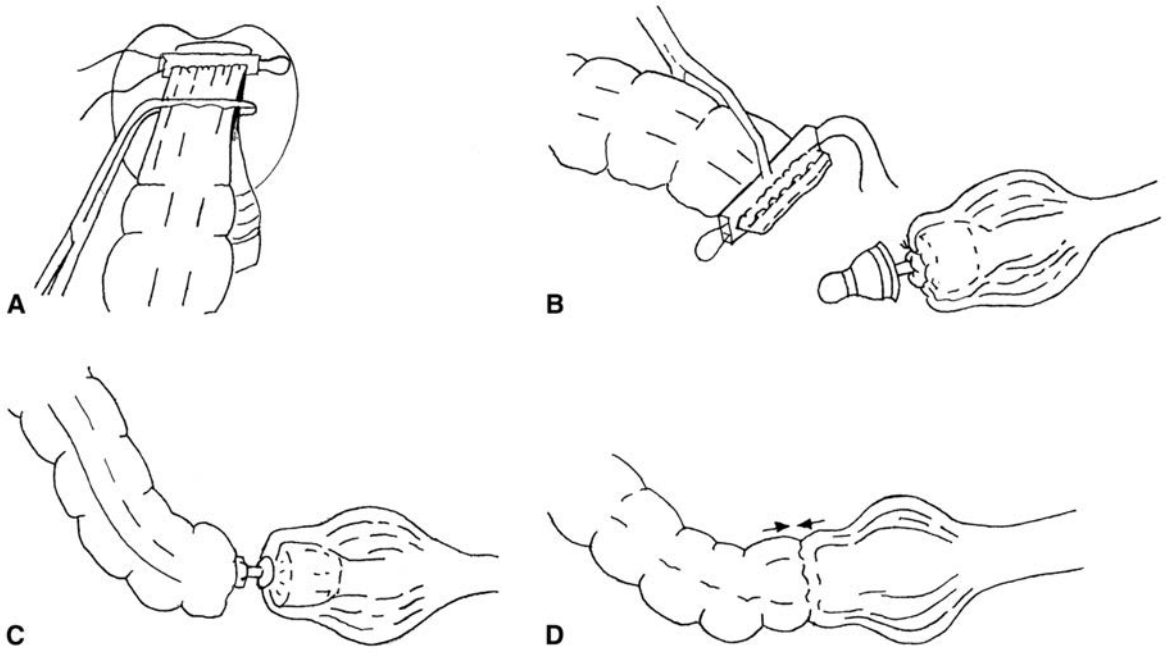


Figure 20-34. Distal colorectal anastomosis with a circular stapler. See text for details. **A.** A modified Furness clamp is used to place a purse string suture on the aboral intestinal segment (top of figure). The affected orad segment is isolated and resected. **B.** A transrectal circular stapler is placed to the level of the aboral purse string suture. The purse string is then tied around the center anvil of the stapler. **C.** A purse string suture around the orad intestinal segment is used to secure the segment to the circular stapler anvil cranial to the aboral segment. **D.** The circular stapler is then compressed and fired to form the anastomosis.

tissue, bacterial contamination, foreign material, and certain suture patterns used for intestinal anastomoses all increase the amount of collagenase produced locally in colonic tissue.

Biopsy

Full-thickness biopsy techniques of the colon are performed similar to those in the small intestine. Luminal contents are milked from the biopsy site, and the site is isolated with a moistened laparotomy sponge. A full-thickness longitudinal incision approximately 1 to 2 cm long is made in the antimesenteric colonic wall. A full-thickness segment approximately 2 to 3 mm wide is cut from the side of the incision. Care should be taken not to crush the sample with forceps. The colonic defect is then closed transversely using simple interrupted sutures (Figure 20-35). Large diameter round dermal punches have also been successfully used for full thickness biopsies. Care must be taken to only cut through one side of the intestine.

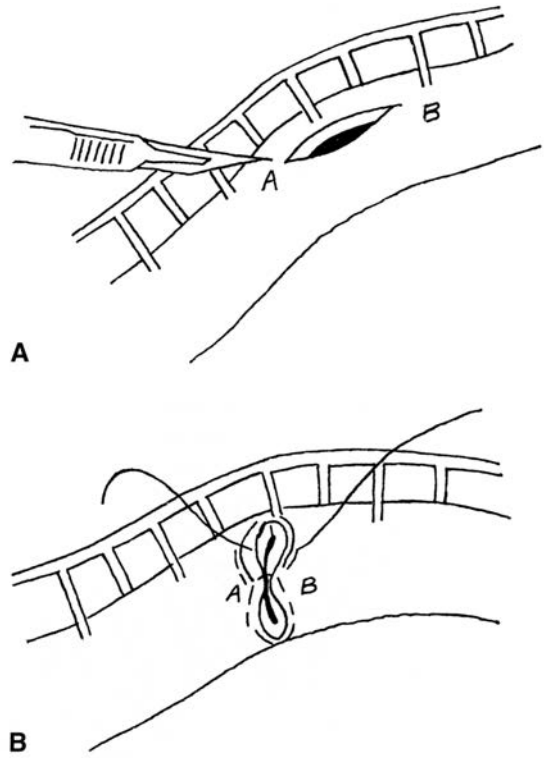


Figure 20-35. A. Longitudinal incisions in bowel can be closed transversely **B.** to prevent reduction of the luminal diameter.

Postoperative Care and Complications

Immediate Postoperative Care

Patients undergoing major colorectal surgery often require significant postoperative care. Intravenous fluids should be continued postoperatively until the patient is taking food and water by mouth and the patient's temperature is below approximately 103.6°F. Rectal thermometers should be used with care. Infrared ear thermometers are preferred in animals that have undergone rectal surgery. Patients should be observed for signs of peritonitis for the first 3 to 5 days after surgery. These signs including fever, depression, anorexia, abdominal pain, vomiting, and shock. Postoperative antibiotics are generally not recom-

mended unless intraoperative signs of established infection are present. Inappropriate use of antibiotics can mask signs of peritonitis and can result in superinfections. The author routinely administers injectable narcotics immediately after endotracheal extubation, with a pain protocol for subsequent doses as needed. Oral or transdermal narcotics and anti-inflamatories are dispensed for 3 to 5 days after surgery. Clinically, patients appear to be comfortable within 12 to 24 hours after surgery. Patients can be offered water once they are fully awake from anesthesia. A low-residue diet can be offered within 12 to 24 hours after surgery. This diet should be continued for the first 2 to 3 weeks, after which the animal's normal diet can be gradually introduced. Stool consistency, color, and presence of blood should be carefully monitored. The patient's first bowel movement commonly contains a large amount of soft to liquid, dark stool whith whole blood. Stool softeners can be administered as necessary to maintain a semifirm consistency. Patients that recover without complications are usually discharged on the second or third postoperative day.

Early Complications

The most serious early postoperative complications of colorectal surgery are infection and fecal incontinence. In a review of intestinal surgery in dogs and cats, patients with peritonitis had a morality rate of 31%.[39] Infection after colorectal surgery can result from preoperative trauma, interoperative contamination of the abdomen, and intestinal dehiscence. While rare, rectal perforations caused by pelvic fractures can be successfully treated if diagnosed before significant contamination of surrounding tissue occurs. In one small study of patients with rectal perforations caused by pelvic fractures, definitive surgical treatment performed within 24 hours of occurrence resulted in no mortality.[5] All patients with delayed diagnosis or treatment had fatal outcomes. Postoperative intestinal dehiscence is one of the most common causes of infection. In one study, dehiscence resulted in a mortality rate of 80%.[39] This same study found no significant difference between small and large intestinal dehiscence rates with an average of 7%. Many factors can result in colorectal dehiscence, including poor surgical technique, traumatic tissue handling, disrupted blood supply, poor suture placement, tension on the anastomosis, improper use of drains, delayed healing, and inappropriate postoperative care. Discriminant analysis in one study demonstrated a sensitivity of 91% with a specificity of 83% using a model where dogs having 2 or more risk factors (preoperative peritonitis, serum albumin concentrations less than or equal to 2.5 g/dL, and intestinal foreign bodies) resulted in intestinal anastomotic leakage.[40]

The clinical signs of peritonitis have been described previously. Diagnostic procedures for postoperative peritonitis and dehiscence may include abdominocentesis or peritoneal lavage, gentle rectal palpation, complete blood count, plain abdominal and pelvic radiographs, and abdominal ultrasonography. Contrast radiographs or proctoscopy are contraindicated and may result in further abdominal contamination.

If signs of peritonitis or intestinal dehiscence are present, the animal should be supported with appropriate intravenous fluids and started on an appropriate therapeutic regimen of antibiotics based on culture and sensitivity testing. The surgeon should not hesitate to perform a "second-look operation" if indicated. Patients with peritonitis do not generally stabilize without adequate abdominal drainage and, if necessary, repair of leaking intestine. Open abdominal drainage is one successful method of surgical drainage that also allows serial evaluation of the affected colorectal segment. For recurrent dehiscence, or areas of questionable vascularity, the use of omental flaps, jejunal patch grafts, and peritoneal muscle flaps have been reported in the veterinary literature. The use of diversional colostomies have been reported in the human and equine literature. This technique has been reported in dogs, and may be a viable treatment option in selected small animal cases.[41,42]

Fecal incontinence, while not in itself fatal, often results in euthanasia of house pets. Fecal incontinence can be divided into reservoir and sphincter incontinence.[43] Patients with reservoir incontinence generally have a conscious, but frequent, need to defecate. This condition is in contrast to unconscious anal dribbling of feces found in patients with sphincter incontinence. Reservoir incontinence can be caused by colorectal irritability, decreased rectal capacity or compliance, increased propulsive motility, and increased fecal volume. One author suggests that fecal continence will be retained if less than 4 cm of rectum is resected, or greater than 1.5 cm of distal rectum is retained in the dog.[44] Treatment for surgically induced reservoir incontinence includes anti-inflammatory drugs, drugs that slow intestinal transit time, dietary manipulation to decrease fecal volume, and surgical techniques that increase rectal capacity. Some animals, over time, may develop ileoanal continence. This is where the ileum distends, taking over the reservoir function of the colon and rectum. The causes of sphincter incontinence are not fully understood, but they include neurologic and muscular trauma or disease. Along with the external anal sphincter, studies have demonstrated muscles of the pelvic girdle, especially the levator ani, play an important role in fecal continence. Treatment for surgically induced sphincter incontinence may include the same medical treatments used for reservoir incontinence. Surgical treatments for sphincter incontinence include reconstruction of the pelvic girdle and external anal sphincter, sphincteroplasty, replacing muscles of continence with muscle flaps or synthetic material, and ileal J-pouch anal anastomoses.

Late Complications

The most common late complication of colorectal surgery is lumenal stricture. Most intestinal anastomoses result in some degree of lumenal stricture. Single-layer and double-layer inverting suture patterns have been reported to result in 39% and 54% lumenal stricture respectively. This was compared with 4% lumenal stricture using an approximating Gambee pattern closure.[45] In another study, colonic anastomoses created with a 25 mm circular stapler where found to result in an average 32% decrease in lumenal diameter at the anastomosis.[46] Too much tissue inversion, suture patterns that restrict the luminal diameter, tension at the anastomosis, and extra lumenal adhesions can result in excessive lumenal stricture. Diagnosis of colorectal stricture include clinical signs, rectal or abdominal palpation,

contrast radiographs, abdominal ultrasound, and proctoscopy. Most commonly, colorectal strictures are treated medically with diet change and stool softeners. Treatment of severe colorectal strictures may require resection and anastomosis of the strictured segment, or, less commonly, mechanical dilation may be attempted. Mechanical dilation can be achieved digitally, by bougienage, or with balloon catheters. Care should be taken not to perforate the intestinal lumen using dilation techniques.

A less common long term complication is associated with the use of nonabsorbable suture material when it is used in a continuous suture pattern.[47] The nonabsorbable suture can be extruded partially into the intestinal lumen where foreign bodies have been reported to attach causing intestinal obstructions. The use of absorbable suture is recommended when making intestinal anastomoses with a continuous suture pattern.

References

1. Taylor, W.T., Weber, R.J.: Functional Mammalian Anatomy (with special reference to the cat). Toronto, D. Van Nostrand Co., Inc., 1951.

2. Evans, H.E., Christensen, G.C.: Miller's Anatomy of the Dog. 2nd Ed. Philadelphia, W.B. Saunders Co., 1979.

3. Schaller, O., Constantinescue, G.M.: Illustrated Veterinary Anatomical Nomenclature. 1992.

4. Goldsmid, S.E., Bellenger, C.R., Hopwood, P.R., et al: Colorectal blood supply in dogs. Am. J. Vet. Res., 54:1948-1953, 1993.

5. Lewis, D.D., Beale, B.S., Pechman, R.D., et al: Rectal perforations associated with pelvic fractures and sacroiliac fracture-separations in four dogs. J. Am. Anim. Hosp. Assoc., 28:175-181, 1992.

6. Valerius, K.D., et al: Adenomatous polyps and carcinoma in situ of the canine colon and rectum: 34 cases (1982-1994). J. Am. Anim. Hosp. Assoc., 33:156, 1997.

7. Greene, C.E.: Infectious Diseases of the Dog and Cat. Philadelphia, W.B. Saunders Co., 1990.

8. Dow, S.W.: Management of anaerobic infections. Vet. Clin. N. Am. S.A. Pract., 18:1167-1182, 1988.

9. Boothe, D.M.: Anaerobic infections in small animals. Prob. Vet. Med., 2:330-347, 1990.

10. Richter, K.P., Cleveland, M.vB.: Comparison of an orally administered gastrointestinal lavage solution with traditional enema administration as preparation for colonoscopy in dogs. J. Am. Vet. Med. Assoc., 195:17271731, 1989.

11. Burrows, C.F.: Evaluation of a colonic lavage solution to prepare the colon of the dog for colonoscopy. J. Am. Vet. Med. Assoc., 195:1719-1721, 1989.

12. Peck, J.J., Fuchs, P.C., Gustafson, M.E.: Antimicrobial prophylaxis in elective colon surgery: Experience of 1,035 operations in a community hospital. Am. J. Surg., 147:633-637, 1984.

13. Penwick, R.C.: Perioperative antimicrobial chemoprophylaxis in gastrointestinal surgery. J. Am. Anim. Hosp. Assoc., 24:133-145, 1988.

14. Burnakis, T.G.: Surgical antimicrobial prophylaxis: Principles and guidelines. Pharmacotherapy., 4:248-271, 1984.

15. Condon, R.E., Bartlett, J.G., Greenlee, H., et al.: Efficacy of oral and systemic antibiotic prophylaxis in colorectal operations. Arch. Surg., 118:496-502, 1983.

16. Washington, II J.A., Dearing, W.H., Judd, E.S., et al.: Effect of preoperative antibiotic regimen on development of infection after intestinal surgery: Prospective, randomized, double-blind study. Ann. Surg., 180:567-572, 1974.

17. Baum, M.L., Anish, D.S., Chalmers, T.C., et al.: A survey of clinical trials of antibiotic prophylaxis in colon surgery: Evidence against further use of no-treatment controls. N. Eng. J. Med., 305:795-799, 1981.

18. Onderdonk, A.B., Bartlett, J.G., Louie, T., et al.: Microbial synergy in experimental intraabdominal abscess. Infect. Immun., 13:22-26, 1976.

19. De La Hunt, M.N., Karran, S.J., Chir, M.: Sulbactam/ampicillin compared with cefoxitin for chemoprophylaxis in elective colorectal surgery. Dis. Colon Rectum, 29:157-159, 1986.

20. Bright, R.M.: Treatment of feline colonic obstruction (megacolon). *In*: Current Techniques in Small Animal Surgery, 3rd Ed.. Edited by M.J. Bojrab. Philadelphia, Lea & Febiger, 263-265, 1990.

21. Rosin, E., Dow, S., Daly, W.R., et al.: Surgical wound infection and use of antibiotics. *In*: Textbook of Small Animal Surgery, 2nd Ed.. Edited by D. Slatter. Philadelphia, W.B. Saunders Co.84-95, 1993.

22. Huss, B.T., Payne, J.T., Wagner-Mann, C.C., et al.: Pharmacokinetic disposition of cefoxitin in serum and tissue during colorectal surgery in cats. *In preparation*, 1996.

23. Plumb, D.C.: Veterinary Drug Handbook, 3rd Ed.. White Bear Lake, PharmaVet Pub 117-118, 1995.

24. Walshaw, R.: Removal of rectoanal neoplasms. *In*: Current Techniques in Small Animal Surgery, 3rd Ed. Edited by M.J. Bojrab. Philadelphia, Lea & Febiger, 274-290, 1990.

25. Allen, S.W., Crowell, W.A.: Ventral Approach to the pelvic canal in the female dog. Vet. Surg., 20:118-121, 1991.

26. Everett, W.G.: A comparison of one layer and two layer techniques for colorectal anastomosis. Br. J. Surg., 62:135-140, 1975.

27. Ballantyne, G.H.: The experimental basis of intestinal suturing: Effect of surgical technique, inflammation, and infection on enteric wound healing. Dis. Colon Rectum, 27:61-71, 1984.

28. Ellison, G.W.: End-to-end anastomosis in the dog: A comparison of techniques. Compend. Contin. Ed. Pract. Vet., 3:486-494, 1981.

29. Poth, E.J., Gold, D.: Intestinal anastomosis: A unique technic. Am. J. Surg., 116:643-647, 1968.

30. DeHoff, W.D., Nelson, W., Lumb, W.V.: Simple interrupted approximating technique for intestinal anastomosis. J. Am. Anim. Hosp. Assoc., 9:483-489, 1973.

31. Lord, M.G., Broughton, A.C., Williams, H.T.G.: A morphologic study on the effect of suturing the submucosa of the large intestine. Surg. Gynecol. Obstet., 146:211-216, 1978.

32. Stoloff, D., Snider, III T.G., Crawford, M.P., et al.: End-to-end colonic anastomosis: A comparison of techniques in normal dogs. Vet. Surg., 13:76-82, 1984.

33. Coolman, B.R., Erhart, N., Pijanowsk, G., et al: Comparison of skin staples with sutures for anastomosis of the small intestine in dogs. Vet. Surg., 29:293-302, 2000.

34. Ravo, B.: Colorectal anastomotic healing and intracolonic bypass procedure. Surg. Clin. N. Am. S. A., 68:12671294, 1988.

35. Ellison, G.W.: Wound healing in the gastrointestinal tract. Sem. Vet. Med. Surg. S.A., 4:287-293, 1989.

36. Ballantyne, G.H.: Intestinal suturing: Review of the experimental foundations for traditional doctrines. Dis. Colon Rectum, 26:836-843, 1983.

37. Cronin, K., Jackson, D.S., Dunphy, J.E.: Changing bursting strength and collagen content of the healing colon. Surg. Gynecol. Obstet., 126:747-753, 1968.

38. Irvin, T.T., Hunt, T.K.: Reappraisal of the healing process of anastomosis of the colon. Surg. Gynecol. Obstet., 138:741-746, 1974.

39. Wylie, K.B., Hosgood, G.: Mortality and morbidity of small and large intestinal surgery in dogs and cats: 74 cases (1980-1992). J. Am. Anim. Hosp. Assoc., 30:469-474, 1994.

40. Ralphs, S.C., Jessen, C.R., Lipowitz, A.J.: Risk factors for leakage following intestinal anastomosis in dogs and cats: 115 cases (1991-2000). J. Am. Vet. Med. Assoc., 223:73-77, 2003.

41. Swalec-Tobias, K.M.: Rectal perforation, rectocutaneous fistula formation, and enterocutaneous fistula formation after pelvic trauma in a dog. J. Am. Vet. Med. Assoc., 205:1292-1296, 1994.

42. Chandler, J.C., Kudnig, S.T., Monnet, E.: Use of laparoscopic-assisted jejunostomy for fecal diversion in the management of a rectocutaneous fistula in a dog. J. Am. Vet. Med. Assoc., 226:746-751, 2005.

43. Guilford, W.G.: Fecal incontinence in dogs and cats. Compend. Contin. Ed. Pract. Vet., 12:313-326, 1990.

44. Holt, D., Johnston, D.E., Orsher, R., et al.: Clinical use of a dorsal surgical approachto the rectum. Compend. Contin. Ed. Pract. Vet., 13:1519-1528, 1991.

45. Hamilton, J.E.: Reappraisal of open intestinal anastomoses, Ann. Surg., 165:917, 1967.

46. Yamane, T., Takahashi, T., Okuzumi, J., et al.: Anastomotic stricture with the EEA stapler after colorectal operation in the dog. Surg. Gynecol. Obstet., 174:41-45, 1992.

47. Milovancev, M., Weisman, D.L., Palmisano, M.P.: Foreign body attachment to polypropylene suture material extruded into the sm all intestinal lumen after enteric closure in three dogs. J. Am. Vet. Med. Assoc., 225:17131715, 2004.

Management of Rectal Prolapse

Mark H. Engen

Although rectal prolapse can occur with any condition that causes prolonged tenesmus, it is most common in heavily parasitized animals that have severe diarrhea and tenesmus. Other causes of straining resulting in rectal prolapse are dystocia, urolithiasis, intestinal neoplasms and foreign bodies, prostatic disease, perineal hernia, constipation congenital defects, and postoperative tenesmus after anal or perineal surgery.

Diagnosis

The diagnosis of rectal prolapse is made by visual observation of a tubelike mass, of varying length, protruding from the anus. If rectal prolapse is diagnosed early, the protruding tissue may be short, and the prolapsed mucosa will appear bright red and nonulcerated. In patients with rectal prolapse of long duration, the protrusion is longer, and the mucosa appears red or black and is either ulcerated or necrotic.

True rectal prolapse must be differentiated from prolapsed intussusception of the intestine or colon. These conditions can be differentiated by passing a probe between the anus and the prolapsed mass. The probe can be passed if an intussusception is present, but it cannot be passed if a rectal prolapse has occurred. To achieve a permanent cure for rectal prolapse, the underlying cause of tenesmus must be diagnosed and treated.

Nonsurgical Treatment

Treatment to correct a rectal prolapse depends on the viability of the exposed tissue and the size of the prolapse. A small prolapse with viable-appearing mucosa usually can be replaced by using a finger or bougie to reposition the bowel. Topical application of hypertonic sugar solution for 20 to 30 minutes may be helpful in relieving edema, so the prolapse can be reduced more easily. When the prolapse has been reduced, an anal pursestring suture is used to prevent recurrence. General anesthesia or epidural analgesia is used in some patients to facilitate reduction of the prolapse and placement of the anal pursestring suture (Figure 20-36).

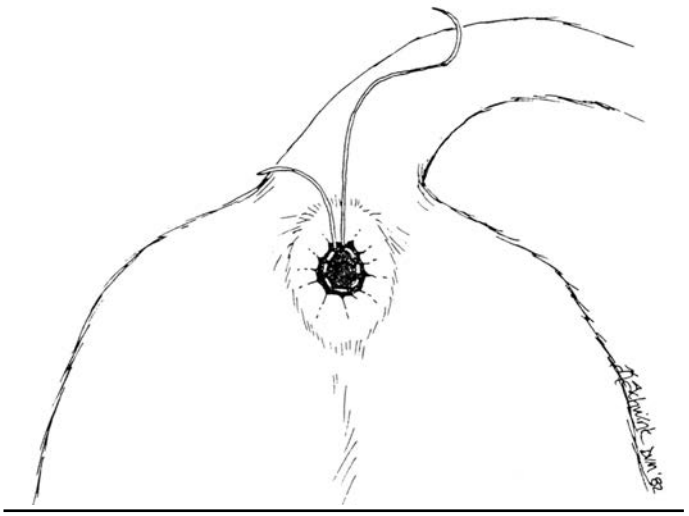


Figure 20-36. Placement of anal pursestring suture after reduction of rectal prolapse by manipulation.

After reduction of the prolapse, epidural analgesia prevents straining for several hours. Periodic rectal application of a local anesthetic ointment (1% dibucaine [Nupercainal ointment, Ciba Pharmaceutical, Ciba-Geigy, Summit, NJ]) may be done initially and after removal of the anal pursestring suture to prevent further straining. The anal pursestring suture is left in place for a minimum of 24 to 48 hours, and the animal is given only fluids orally during this time.

Surgical Treatment

When a rectal prolapse cannot be reduced by manipulation and the lack of tissue viability contraindicates reduction, rectal resection and anastomosis are performed. This procedure is performed under general anesthesia or epidural analgesia. The patient is positioned and draped (Figure 20-37A and B). A test tube or a saline-soaked sponge is placed into the lumen of the bowel to prevent fecal contamination. Three stay sutures are placed through the full thickness of both layers of the prolapse to form a triangle (Figure 20-37C and D). The prolapse is then resected 1 to 2 cm from the anus. The anastomosis is performed with a single-layer closure using a simple interrupted suture pattern (Figure 20-37E). Synthetic absorbable suture (3-0 or 4-0) is preferred. The sutures are placed through the full thickness of the incised ends of the bowel. The sutures must pass through the submucosa to ensure proper holding strength. The stay sutures are then removed, and the anastomosis is reduced manually inside the anus.

When the rectal prolapse cannot be reduced by external manipulation, but the rectal tissue is still viable, a celiotomy is performed, and the prolapse is manually reduced by gentle traction on the colon (Figure 30-38A). A colopexy is performed after reduction of the prolapse to prevent recurrence using

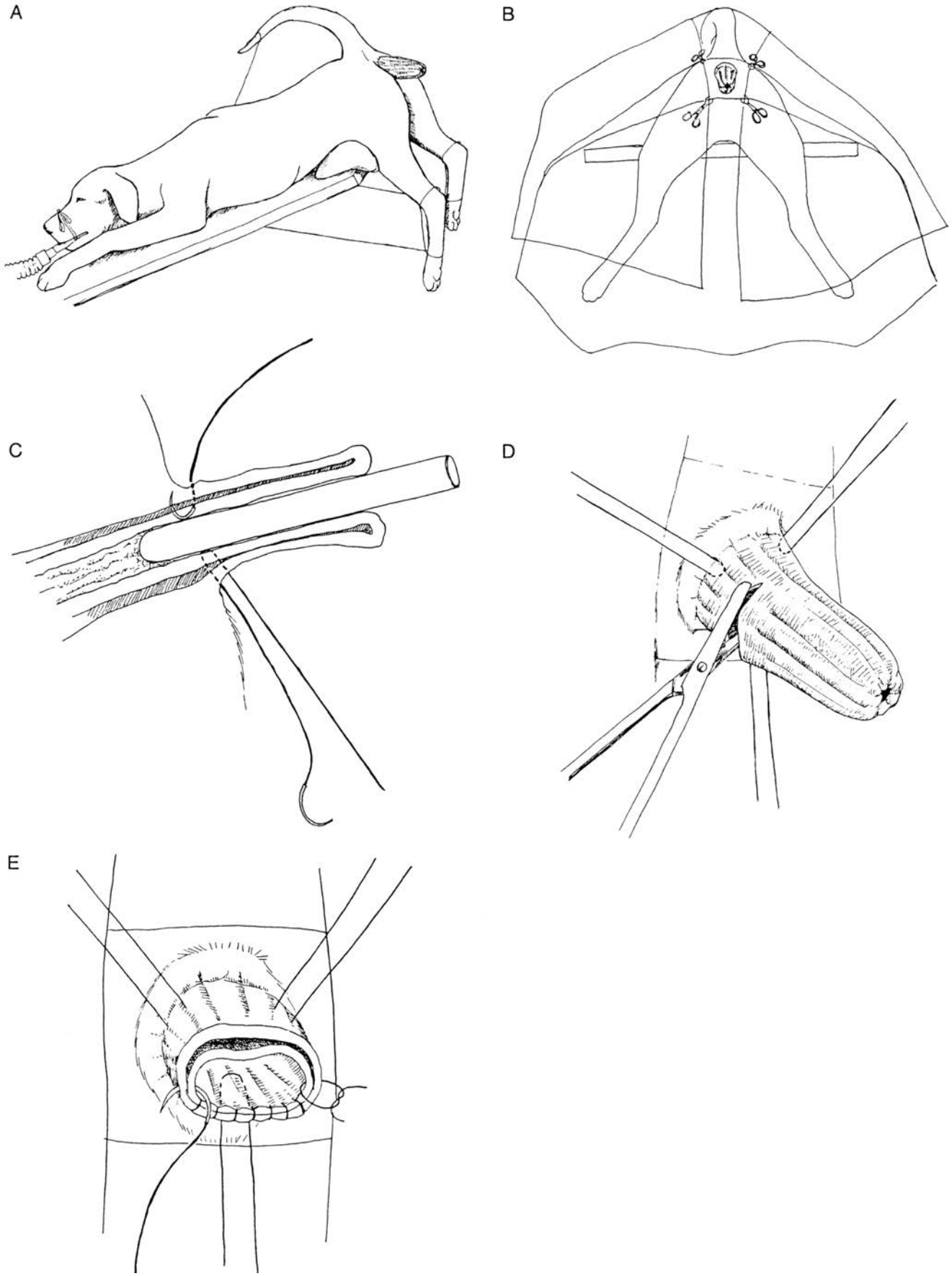


Figure 20-37. Rectal resection and anastomosis to correct prolapse. **A.** Positioning of patient on a perineal stand. **B.** Sterile draping of the prolapse. **C.** Insertion of test tube into rectum and placement of stay sutures. **D.** Excision of the prolapsed mass. **E.** Full-thickness anastomosis of the rectal lumen.

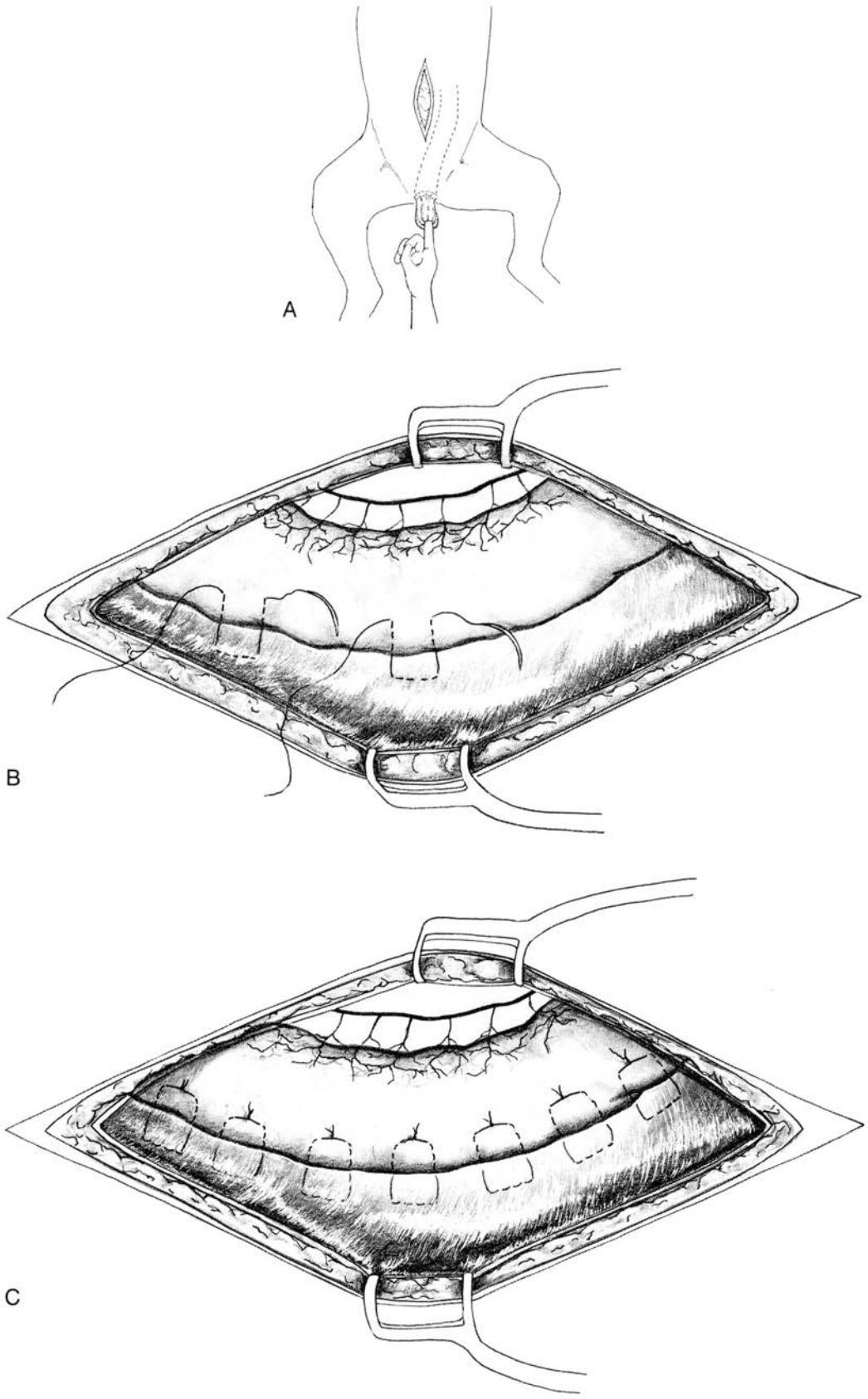


Figure 20-38. Celiotomy and colopexy for treatment of rectal prolapse. **A.** Abdominal incision and digital replacement of the prolapsed tissue. **B.** Placement of colopexy mattress sutures. **C.** Six to eight mattress sutures are placed to complete the colopexy.

synthetic absorbable suture (2-0 or 3-0) (Figure 30-38B and C). A colopexy may also be performed in cases of recurrent rectal prolapse that can be reduced by external manipulation. Such a colopexy is rarely needed, however, if the cause of straining has been diagnosed and eliminated.

Postoperative Care

Topical anesthetic (1% dibucaine) ointment is instilled rectally after correction of any rectal prolapse to prevent further tenesmus. The patient may be fed on the day after the operation. A diet of soft food and a fecal softener (dioctyl sodium sulfosuccinate) also may be administered for 1 week postoperatively. Diarrhea should be treated with neomycin, intestinal coating agents, and anticholinergic drugs. Feces should be examined, and antihelminthic agents should be administered, based on results of fecal examinations for parasitic ova.

In conclusion, once a rectal prolapse has been corrected by surgical or nonsurgical means, recurrence is rare if the cause of the tenesmus has been diagnosed and resolved (e.g., removal of intestinal parasites by worming).

Suggested Readings

Aronson L. Rectum and anus. In: Slatter D, ed. Textbook of small animal Surgery. Philadelphia: Saunders, 2003.

Popovitch CA, Holt D, Bright R. Colopexy as a teatment for rectal prolapse in dogs and cats; a retrospective study of 14 cases. Vet Surg 1994:23:115.

Anal Sac Disease and Removal

Roy F. Barnes and Sandra Manfra Marretta

Introduction

Anal sac disease occurs with an approximate incidence of 12% in the canine, with small breeds being overrepresented compared to large breeds. Cats are infrequently afflicted with anal sac disorders. Conditions which require anal sacculectomy include relief from chronic and recurrent episodes of anal sac impaction or infection, adjunctive treatment of perianal fistulas and local treatment of apocrine gland anal sac adenocarcinoma and other malignant neoplasms.

Anatomy

The anal sacs are cutaneous diverticula ventral and lateral to the anus, between the internal and external anal sphincters. Anal sacs of the dog and cat are composed of large coiled apocrine glands. In addition, the feline anal sac includes a complex series of sebaceous glands. Despite the species difference, all glands will coalesce to form a sac and from the sac, a keratinized epithelial duct arises to carry material to the external environment. In the dog, the anal ducts open into the inner cutaneous zone of the anus while in the cat, the ducts open into a pyramidal prominence 2.5 mm lateral to the anus. Regardless of the duct opening, the anal sacs are typically located at the 4 and 8 o'clock positions with reference to the anus proper.

The blood supply to the anal sac arises from the caudal hemorrodial, perineal and caudal gluteal arteries and veins. The innervation to the anal sac and external anal sphincter is via the pudendal nerve.

Preoperative Care

Prior to anal sacculectomy, patients with anal sac impaction or infection should undergo medical therapy. Failure to resolve any inflammation associated with the anal sac disease prior to surgery may increase the potential for postoperative complications.

Medical therapy consists of expression of the anal sacs and the concurrent instillation of an oil-based antibiotic and corticosteroid-containing ointment into the anal sac. Broad spectrum antibiotics are utilized in animals with severe infection or abscessation of the anal sac. Warm compresses and hydrotherapy are applied to the perineum to improve lymphatic drainage, and cleanse the region. All animals with a suspected neoplasm of the anal sac should undergo appropriate clinical staging with emphasis on determining the potential for local and distant metastasis. Hypercalcemia, if present, should be treated with appropriate medical therapy prior to the induction of general anesthesia. Consideration should also be given to the possibility of postoperative hypocalcemia.

Surgical Technique

Several surgical techniques have been described in the veterinary literature for removal of the anal sacs. Surgeries are divided into open, modified open or closed techniques. The major difference between the techniques is whether or not the anal sac and its duct are incised, thus exposing the lumen. The closed technique is described here. It is imperative that a closed anal sacculectomy be performed for the treatment of apocrine gland anal sac adenocarcinoma or any other malignancy of the anal sac or duct.

Regardless of which surgical technique is performed, the protocol for surgical preparation is similar. The diseased anal sac is expressed to expel its contents with subsequent instillation of a dilute antiseptic, such as chlorhexidine or povidone-iodine solution. Neoplastic conditions of the anal sac may not allow anal sac expression and the instillation of antiseptic solutions. The patient is placed in a padded perineal stand (Figure 20-39). Proper position on the stand will help prevent circulatory compromise, neuropraxia and exacerbation of chronic osteoarthritis of the rear limbs. Several gauze sponges are placed into the patient's rectum. The perineum is clipped and scrubbed according to acceptable standard aseptic techniques. The surgical site is draped routinely to protect the surgical wound.

In preparation for a closed anal sacculectomy some surgeons may elect to fill the anal sac with a groove director, self-hardening gel or resin, string, umbilical tape, plaster of Paris or dental acrylic to assist in the dissection of the anal sac and associated duct (Figure 20-40A). In larger dogs, a #6 Foley urinary catheter can be inserted into the anal sac and the balloon inflated. It should be noted that filling of the anal sac with material can only be performed in non-neoplastic diseases.

Based upon the described anatomy, a vertical skin incision is made over the anal sac, approximately 3 to 4 cm in length and 5 to 10 mm lateral to the mucocutaneous junction (Figure 20-40B and Figure 20-41). The subcutaneous tissue is incised equidistant with the skin. Blunt dissection and digital palpation is used to locate the anal sac. Blunt and sharp dissection using Steven's tenotomy scissors, metzenbaum scissors and cotton-tipped applicators can be used to isolate the anal sac and duct (Figure 20-40C and Figure 20-42). Dissection of the anal sac from the internal and external anal sphincter can be difficult. The caudal rectal branch of the pudendal nerve should be avoided. Hemorrhage can be controlled using judicious use of electrocautery, ligatures and direct digital pressure. Once the anal sac and duct is dissected, the anal duct is ligated close to its termination at the anus and transected (Figure 20-40D). Alternatively, the anal duct can be transected at its termination at the anus (Figure 20-43). The anal mucosa is everted and subsequently closed using absorbable suture material (Figure 20-44).

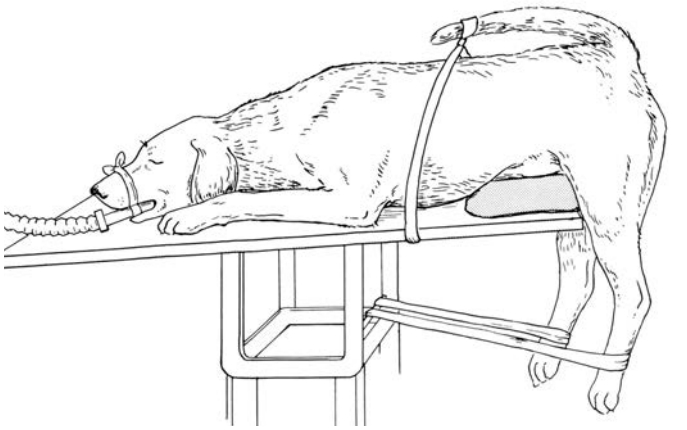


Figure 20-39. A routine perineal stand involves placing the animal in ventral recumbency with the table slightly tilted forward. Adequate padding should be placed beneath the abdomen and at the caudal edge of the surgery table. The animal's legs and tail are loosely tied to the surgery table.

Once transected, all tissue should be submitted for histopathological analysis. The surgical site should be lavaged thoroughly with sterile physiologic saline. The external anal sphincter should be closed using a synthetic, absorbable, monofilament suture, such as PDS or Maxon. The subcutaneous and subcuticular tissues should be apposed in a routine manner. If skin sutures are utilized, trim the ends of the sutures so that irritation to the adjacent anus and perineum will be minimized (Figure 20-40E and

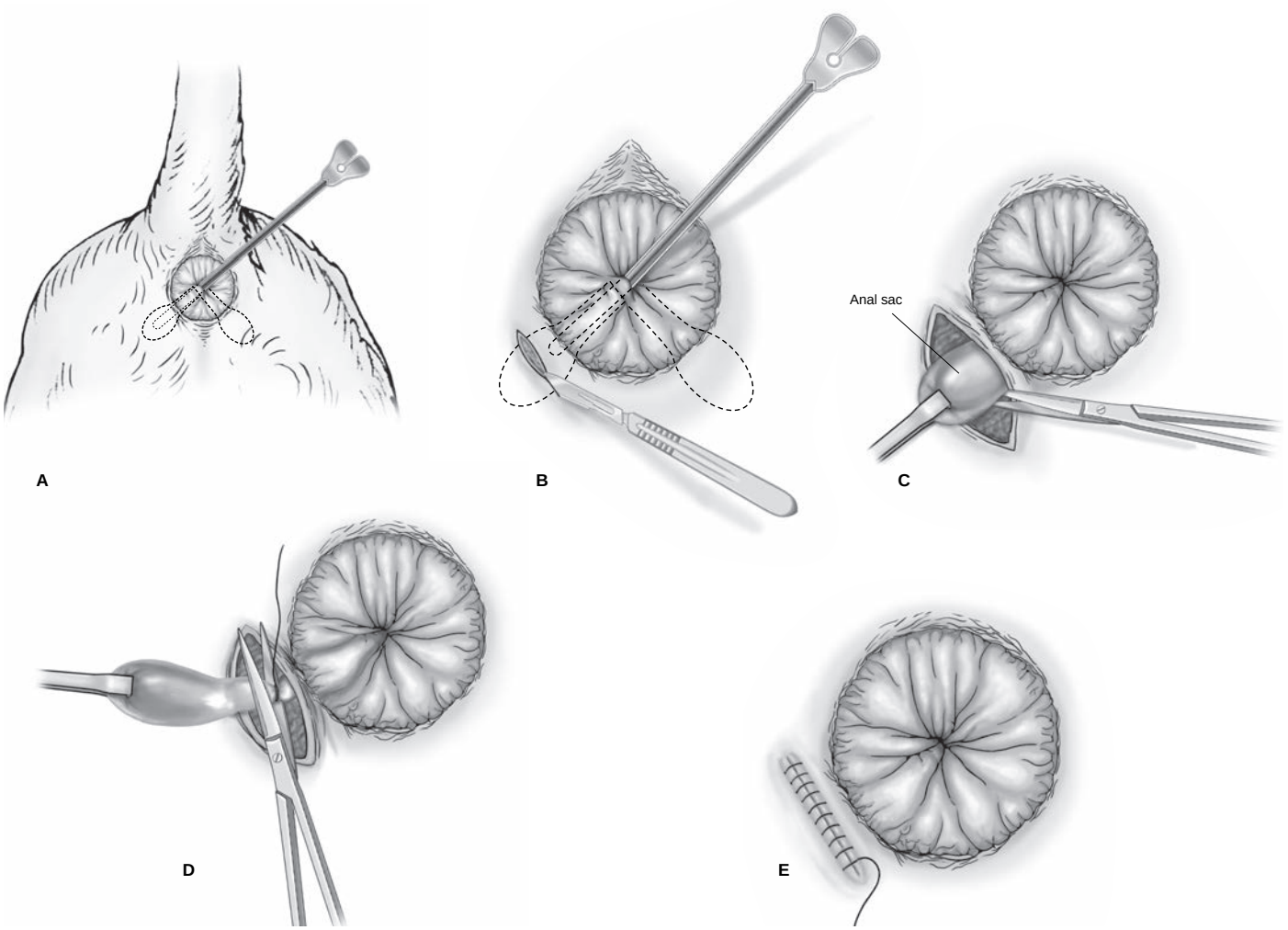


Figure 20-40. Closed technique tor anal sac removal, **A.** A groove director is used to identify the anal sac. The anal sac can be filled to delineate it from surrounding tissues. **B.** An incision is made over the anal sac. **C.** The anal sac is dissected out from surrounding tissues, **D.** The duct is ligated, and the sac is removed, **E.** Routine closure. (Courtesy of Dr. Pamela Whiting.)



Figure 20-41. Initial skin incision, just lateral to the anus.



Figure 20-42. Dissection of the anal duct. Forceps are pointing to the anal duct. Note the presence of retractors in the surgical field.



Figure 20-43. Forceps are depicting the opening of the anal duct at the level of the inner cutaneous zone.

Figure 20-45). After surgery, a rectal exam should be performed. At this time, any defect in the rectal mucosa should be made apparent and if present, repaired appropriately.

Postoperative Care

An Elizabethan collar is recommended to prevent self-mutilation of the surgical site. Broad spectrum antibiotics should be administered immediately preoperatively and for the next 7 to 10 days due to the classification and location of the surgical wound. Cold compresses should be applied three to four times daily to the wound for the first 36 to 48 hours. After discontinuation of cold compresses, warm compresses should be applied two to three times daily until suture removal. Alternatively, hydrotherapy can be administered during the period of warm compresses. Hydrotherapy will not only help with any post-operative swelling, but will help keep the surgical site clean. Skin sutures, if present, are removed in 10 to 14 days.

Analgesics are paramount in the post-operative period. A full



Figure 20-44. Apposition of the anal mucosa after transection of the anal duct.



Figure 20-45. Apposed skin and anal mucosa. Note the short sutures along both apposed incisions.

agonist opioid, such as hydromorphone or oxymorphone, should be utilized for the first 24 to 36 hours. If medically appropriate, a non-steroidal anti-inflammatory drug, such as carprofen or etodolac, can be administered for additional analgesia. A high-fiber diet or stool softeners may be utilized to provide a soft, but formed stool. Either therapy can be useful in the post-operative period to help limit constipation associated with the administration of opioids or to help offset any potential tenesmus.

Preoperative conditions, such as hypercalcemia, should be monitored closely. If the hypercalcemia is secondary to a malignant neoplasm, such as an apocrine gland anal sac adenocarcinoma, the hypercalcemia should resolve if there is no local or distant tumor burden. However, if the hypercalcemia persists in the post-operative period, then either the tumor has metastasized or there is another disease process present. If the persistent hypercalcemia is secondary to a malignant neoplasm, consultation with a medical oncologist is recommended. Regardless of the presence of hypercalcemia, any patient suffering from a neoplasm of the anal sac or duct should be evaluated by a medical oncologist to determine if ancillary therapy is warranted.

Postoperative Complications

Short-term complications (< 14 days) after a closed anal sacculectomy include drainage, seroma formation, inflammation, hemorrhage, infection, and tenesmus or dyschezia. Drainage and seroma can be minimized by meticulous and delicate tissue handling and apposition of incised tissues. Inflammation can be minimized by avoidance of traumatic tissue handling, desiccation of exposed tissues, judicious use of electrocautery and proper identification of anatomy. Hemorrhage can be avoided if subcutaneous, muscular and parenchymal vessels are ligated using appropriate techniques and the use of electrocautery. If mild postoperative hemorrhage is present, a cold compress and sedation with acepromazine may provide relief. If hemorrhage is severe, immediate exploration of the surgical wound is indicated. Infection rates associated with a closed anal sacculectomy are low. However, if infection occurs, it will become apparent within the first 48 to 72 hours after surgery. The treatment of infection consists of removing the ventral sutures in the surgical wound to allow drainage and the application of dilute antiseptic solutions (chlorhexidine or povidone-iodine). Hydrotherapy performed twice daily and the administration of broad spectrum antibiotics (based on proper pharmacokinetics and suspected pathogen) pending results of bacterial culture and sensitivity testing is recommended.

Long-term complications of a closed anal sacculectomy can include fecal incontinence, chronic fistula formation, anal stricture and reoccurrence of local disease. The first three complications can be minimized with careful intraoperative technique and attention to anatomical structures. Fecal incontinence may result from excessive surgical trauma to the external anal sphincter (> 50% of its diameter) or direct damage to the caudal rectal branch of the pudendal nerve. Treatment of fecal incontinence includes dietary changes and the potential for muscle pedicle transpositions. Chronic fistula formation usually appears a few weeks to months after surgery. The cause of fistula formation is incomplete removal of the anal sac or duct. Treatment of the fistula includes surgical exploration of the draining tract and subsequent removal of any remaining secretory tissue. Anal stricture is an infrequent complication of closed anal sacculectomy due to the surgical approach. Clinically, anal strictures will appear weeks to months after surgery and clinical signs usually reveals tenesmus. Treatment of anal strictures includes stool softeners, balloon dilation, and if severe, surgical resection of the stricture. Local disease reoccurrence may occur in the case of anal sac neoplasms. Ancillary therapy, such as radiation therapy for local disease or chemotherapy for distant metastasis may be necessary for neoplasms. Complete staging of the neoplasm coupled with consultation with a medical oncologist is recommended.

Selected Readings

Aronson L. Rectum and anus. In: Slatter DH, ed. Textbook of small animal surgery. 3rd ed. Philadelphia: WB Saunders, 2002: 682-708.

Lipowitz A. Perineal Surgery. In: Lipowitz AJ, Caywood DD, Newton CD, et al, eds. Complications in small animal surgery. Baltimore: Williams & Wilkens, 1996: 527-540.

Van Sluijis FJ. Anal sacculectomy. In: van Sluijis FJ, ed. Atlas of small animal surgery. New York: Churchill Livingstone, 1992: 114-115.

Hill LN, Smeak D. Open versus closed bilateral anal sacculectomy for treatment of non-neoplastic anal sac disease in dogs: 95 cases (1969-1994). JAVMA 2002; 221: 662-665.

Van Duijkeren E. Disease conditions of canine anal sacs. JSAP 1995; 36: 12-16.

Nonsurgical Management of Perianal Fistulae

Dean Fillipowicz

Introduction

Dogs afflicted with anal furunculosis (perianal fistula, fistulae or fistulas; perianal hidradenitis) suffer from painful, malodorous and suppurative ulceration and sinus tract formation of the skin and subcutaneous tissues of the perineum. The etiology of this chronic and progressive inflammatory condition is unknown, but an immune mediated cause is likely. Previously regarded as a surgical disease, medical management is now the primary mode of treatment, with surgery reserved for recalcitrant cases and animals whose lesions are no longer responsive to immunosuppressive therapy. Goals of therapy include eliminating discomfort, ameliorating other associated clinical signs, and preventing recurrence.

Signalment and Clinical Signs

German Shepherd dogs are most commonly affected making up 89%,[1] 85%,[2] 81%,[3] 79%,[4] 96%,[5] 75%,[6] and 100%[7] of recent studies. Other breeds that have been reported include Labrador Retrievers, Irish Setters, Old English Sheep Dogs, Border collies, Bulldogs, Bouvier des Flandres, beagles, various spaniels, and mixed breeds.[5,8-13] The mean age of presentation is between four and seven years old, but reports exist of patients aged between

one and fourteen years old.[12,13] A sex predisposition has not been substantiated; reports exist of increased male prevalence,[4,7,14-18] increased female prevalence,[19] and an equal sex distribution.[3,6,20,21]

Clinical signs most commonly reported include tenesmus, pain, dyschezia, excessive licking of the perineum, and a malodorous, purulent discharge, but self-mutilation, hematochezia, fecal incontinence, constipation or diarrhea, flatulence, and weight loss may also be seen.[1-8,10,15,21]

Patients present with varying degrees of ulceration and sinus tract formation radiating around the anus. In mild cases, the affected region may encompass an arc of 90° or less with focal, erythematous, superficial lesions. More advanced cases may have diffuse, deep, epithelial lined, communicating tracts extending 360° circumferentially with possible involvement of the anal sacs. True anocutaneous and rectocutaneous fistulae have been reported. Fortunately, they are uncommon in the canine species, with most dogs being presented with moderate to severe ulceration and multiple sinuses.[5,10-13] Many dogs have advanced forms of the disease before initial presentation, possibly because the wide tail base and dense, thick hair coverage of many afflicted dogs prevents frequent observation of affected areas by owners.

Pathogenesis

Though the etiology of anal furunculosis is uncertain, several factors have been proposed as contributing to development of the disease: low tail carriage, broad tail base, and dense tail fur resulting in increased perianal humidity and contamination, anal sacculitis with concomitant spread of infection, anal crypt or gland fecalith impaction with subsequent abscessation, perianal trauma, and foreign body reaction. Though it is likely that these conditions may exacerbate inflammation and lesion formation, no strong evidence exists supporting any of these as a primary cause of the disease.[2,9,10,13] Involvement of the anal sacs and subsequent infection, abscessation, and ulceration is common in advanced cases, but appears to be a secondary development rather than a primary cause of the disease.[9,12] A correlation with hypothyroidism has been proposed, but remains unsubstantiated.[17] In the same study, no immunologic abnormalities were found between affected and normal dogs.[17]

A failure in immune modulation is accepted to be the most likely cause of perianal fistulae, and evidence exists supporting this hypothesis. Most notably, anal furunculosis and Crohn's disease in humans have similar clinical appearances and demonstrate similar positive responses to immunomodulatory medications.[2-7,10,12,15,19,20,22] In addition, it has been shown that mRNA expression of those cyctokines associated with TH-1 T-cells is heightened in perianal tissue taken from dogs with anal furunculosis.[23] However, a simple immunological defect, at least in German Shepherds, has not been found.[24]

Diagnosis and Evaluation

The diagnosis of anal furunculosis is based on signalment, history, physical examination findings, and exclusion of differential diagnoses. Severe local pain makes a thorough examination of the perineum difficult in affected animals and can seldom be done without general anesthesia. Prior to anesthesia, it is important to assess anal tone, as incontinence can be seen with advanced disease and as a post-operative complication. Once the patient is anesthetized, the perineal area should be liberally clipped to aid in assessment and subsequent cleaning of diseased tissue. Tracts should be gently probed with a sterile, blunt instrument to assess size, depth, and possible communication with nearby structures. At least one of the anal sacs is often secondarily involved or may become so before a response to therapy is seen. Both structures should be evaluated for involvement, rupture, or abscessation. Palpation, expression of the sacs if un-involved, and flushing with sterile saline to identify previously unobserved tracts is important. If occluded, the anal sac ducts should first be cannulated with a lacrimal duct cannula or small urinary catheter. Fine needle aspiration of grossly enlarged anal sacs may help identify abscessation or neoplasia.

A thorough rectal examination is necessary. The concurrent presence of a perineal hernia, or rectal dilation, or sacculation affects prognosis for both disease processes. Gently probing the fistulous tracts while performing the rectal examination may identify rectocutaneous fistulae. Care should be taken to identify thickening of the external anal sphincter and rectal and anocutaneous tissues, particularly in those patients suffering from tenesmus. Anorectal stenosis or stricture caused by chronic disease will also adversely affect prognosis.

Superficial cytology and culture gives little useful information, though culture and sensitivity of deep sinus tracts will aid in antibiotic selection for those cases responsive to medical management. Sinus tract biopsies can give histological support of a diagnosis of anal furunculosis, but more importantly, may identify neoplastic disease.

An association has been suggested between colitis and perianal fistulae.[16,20] It is therefore further recommended to obtain colonic biopsies as the two disease entities present similarly, and treatment of fistulae is complicated by concurrent large bowel disease.

Additional diagnostics may include complete blood count, chemistry panel, and urinalysis for overall health assessment, fecal floatation to help identify endoparasites, and thoracic radiographs if neoplasia or fungal infection is suspected as contributing to the perianal ulceration. Other perineal disease entities to rule out include anal sac abscessation, fungal infection, pythiosis, lagenidiosis, perianal adenoma, apocrine gland adenocarcinoma, squamous cell carcinoma, caustic injury, and trauma.[10,25]

Medical Management–Systemic

It is important for owners to be aware that therapy is directed at control of the disease and its clinical signs and that a cure is seldom attained. In addition, owners must be well informed about the potential complications of management and should be committed to long-term aftercare.

Previously an exclusively surgically-managed disease, medical management is now the cornerstone of therapy for anal furunculosis. The goals of treatment are initially to eliminate discomfort and pain followed by reduction in lesion volume. Long term therapy is directed at prevention of disease recurrence. Four components make up medical management: regional hygiene, elimination/reduction of secondary infection, immunomodulatory therapy, and dietary modification. Surgery is indicated in recalcitrant cases and in those cases where no further improvement from medical management is noted. However, medical therapy should be be attempted first to reduce lesion severity; subsequent surgery may then be associated with fewer complications such as incontinence, stricture, and disease recurrence.[13,19]

As therapy is initiated, attention to perianal hygiene should only be attempted with the aid of chemical restraint. As lesions and pain diminish, the patient may learn to tolerate disease care without sedation. Frequent clipping is initially necessary to remove debris and allow cleaning and monitoring of the affected area. Later in the course of management, the area should remain clipped and clean to prevent recurrence and allow application of topical medication.

Systemic antibiotics are indicated as most cases have some degree of secondary infection. Bacterial culture and sensitivity results should dictate the antibiotic of choice. However while results are pending, empiric therapy with an antibiotic that affords gram negative and anaerobic coverage such as amoxicillin-clavulanic acid is appropriate. Systemic therapy should continue for five days past the disappearance of gross evidence of infection. Topical antibiotic therapy such as mupirocin ointment (Bactoderm, Pfizer) once every twelve to twenty-four hours can be used once patient compliance allows application. This can be used to prevent and reduce bacterial colonization, and can be used concurrently with systemic antibiotics. Lesion resolution negates the need for continued antibiotic therapy. Hygiene and antibiotic therapy alone are unsuccessful in the management of this disease, and are considered to be palliative at best.[9]

Immunomodulatory therapy is the primary and most important aspect of the medical management of anal furunculosis, and several regimens are available. As discussed later, systemic cyclosporine coupled with ketoconazole followed by topical tacrolimus is the currently preferred method of management. However, reasonable success has been attained with cheaper, more commonplace immunosuppressives such as glucocorticoids, azathioprine, and metronidazole. Table (20-1) summarizes drug regimens recently as offering some success with less expensive drug combinations.

The advantages of glucocorticoid administration are ease and low cost. Unfortunately, side effects with this medication can be severe and include polydypsia, polyuria, polyphagia, decreased resistance to infection, slower wound healing, muscle wasting, and insulin antagonism. In addition, glucocorticoid administration for perianal fistulae may show no, poor, or transient response. Advantages of the metronidazole/azathioprine regimen include low cost, absence of untoward side effects, and reduced risk of post-operative complications previously reported.[19] Though side effects were not seen in the cases of this report, this drug regimen is not innocuous. Azathioprine suppresses both humoral and cell mediated immunity and can result in gastrointestinal upset, pancreatitis, hepatotoxicity, and bone marrow suppression.[26] Metronidazole is an antiprotozoal with immunomodulatory effects but can result in vomiting, anorexia, hepatotoxicity, and central vestibular signs.[27]

Table 20-1. Summary of Drug Regimens for Treatment of Perianal Fistulae

Reference #	Sample size	Medication Regimen	Lesion resolution	Clinical sign resolution	Notes
16	27 GS w/PF & colitis	Pred: 2 mg/kg SID x 2 wks→1 mg/kg SID x 4 wks→1 mg/kg EOD x 8-16 wks	Complete in 1/3 Partial in 1/3	11/16 regardless of lesion resolution	Caution as to GC usage
10		Pred: 3-4 mg/kg SID-BID x 3-6 wks PLUS Azathioprine: 1.5-2.2 mg/kg SID x 2-4 wks OR Metronidazole: 10-15 mg/kg BID	Reasonable success in reducing lesion size and associated pain and inflammation though data is lacking		GCs tapered over weeks to months. Azathioprine tapered to EOD x 4 wks. Caution as to GC and Azath or Metronid usage
19	5 dogs	Metronidazole: 400 mg/dog SID AND Azathioprine: 50 mg/dog SID	Significant improvement with no additional progress after 4-6 wks	Significant improvement in all w/in 2 weeks	Sx at end of regimen followed by addl. 3-6 weeks immunomodulatories. 5/5 dz free 7-10 months post-op

The similarities in clinical appearance between Crohn's disease in humans and canine anal furunculosis led to the discovery that encouraging treatment results can be achieved when affected dogs are treated with the same immunomodulating drug used in human medicine.[2-7,10,14,15,22,28] Cyclosporine acts by reversible inhibition of calcineurin, an enzyme normally partially responsible for cytokine synthesis, among other functions. The end result is inhibition of cell mediated immunity and T-cell (T-helper and T-cytotoxic) activation and proliferation.[10,22] The microemulsion (ME) formulation of this drug (Atopica, Novartis) is given because of improved bioavailability and decreased inter-individual serum levels. Because of delayed absorption when given with food (even with the ME formulation), it is recommended that cyclosporine be administered two hours before or after a meal.[22]

Several reports have shown the benefits of the sole use of cyclosporine in the treatment of anal furunculosis, and several conclusions have been reached: faster remission and higher recovery rates are seen with higher dosages, clinical signs may be more likely to return after cessation of high dose treatment, and longer administration (thirteen weeks) decreases the rate of relapse.[2,4-7,11,14,15,29] Unfortunately, a definitive dosing regimen has not been found. A recent review recommends initially treating at 4 to 8 mg/kg PO q 24h for eight to sixteen weeks until a marked resolution of clinical signs has occurred. At that point, it has been suggested to decrease the dose by 20 to-40% or decrease the frequency of administration to every forty-eight hours with further tapering based on clinical response and lack of recurrence.[10]

Though encouraging results have been obtained with the use of cyclosporine, difficulties still exist as to the appropriate dosage, schedule, and duration of therapy. Initial dose schedules were extrapolated from human medicine where cyclosporine was used to prevent renal allograft rejection. Because of the high doses required to prevent organ rejection and the relatively small margin of safety this drug has in humans (hypertension and nephrotoxicity are not uncommon side effects), dosing adjustments in transplant patients are necessary and are made based on serum trough levels. The treatment of canine anal furunculosis requires lower doses of cyclosporine than is required to prevent organ rejection. In addition, recent studies in dogs with anal furunculosis treated with cyclosporine failed to find a relationship between trough concentrations and treatment efficacy.[5,7] Therefore, though monitoring trough levels in transplant patients assists in fine tuning those treatment regimens, the practice provides no additional information in the treatment of most cases of anal furunculosis in which a favorable clinical response is seen to cyclosporine alone.

Serious side effects are rare with cyclosporine administration in dogs, but long term studies are needed to assess its full effects.[22] Side effects noted in recent clinical reports include hair shedding that may be followed by increased hair growth, gastrointestinal effects (vomiting and diarrhea, inappetance), lethary, and lameness.[2-5,15] The most common side effects, hypertrichosis and vomitting/diarrhea, were mild and resolved spontaneously during treatment or after cyclosporine administration had stopped. Gingival hyperplasia and papillomatosis have also been reported.[28] Though there is an increased risk in humans of developing lymphoma after cyclosporine usage, there are only two case reports in the veterinary literature (one cat after renal transplant surgery and one dog with anal furunculosis) that suggest lymphomagenesis may be associated with cyclosporine administration.[30] There is no evidence that administration of cyclosporine in dogs, or in humans with dermatologic conditions, has been associated with an increased risk of infection.[22]

Unfortunately, cyclosporine is expensive, particularly when treating the large breeds affected by anal furunculosis. By inhibiting the cytochrome P450 system, ketoconazole has been used to decrease the hepatic clearance of cyclosporine resulting in increased serum levels. Lesser amounts of cyclosporine are then needed at a significant cost advantage to the owner. Increases in serum cyclosporine levels are proportional to ketoconazole doses when the latter is dosed between two and twelve mg/kg.[31] Unfortunately, the amount of increase in cyclosporine blood concentration due to hepatic inhibition from ketoconazole is individually variable, necessitating dose adjustments for most patients. This is an indication for measuring cyclosporine serum trough levels. Trough levels can be evaluated by high pressure liquid chromatography (HPLC), fluorescent polarization immunoassay (FPIA) or radioimmunoassay (RIA). These last two assays, though faster and cheaper, use antibodies that cross react with cyclosporine metabolites, and can overestimate the cyclosporine blood concentration. In fact, cyclosporine blood concentrations when measured with FPIA are nearly twice those measured with HPLC. This latter assay is more expensive and less widely available, but more accurate.[22]

A previous review suggests an initial starting dose of ketoconazole at 5-10 mg/kg PO q 24h in conjunction with a moderate starting dose of cyclosporine at 5mg/kg PO q 24h.[10] With resolution of lesions and other clinical signs, the cyclosporine dose is tapered starting six to ten weeks after initiation of therapy. Higher doses may be required in some recalcitrant cases or in more severe, chronic cases. The goal of therapy is the lowest dose and frequency of both drugs that will prevent recurrence of lesions or clinical signs. Some animals may only require topical medication (described below) as maintenance therapy, while others will require life long cyclosporine treatment with or without topical therapy. Trough cyclosporine levels, measured ideally with HPLC, should be assessed if the patient is not or is no longer responding to treatment. Dosing should be increased in these cases if trough levels below 400 ng/ml are found. Serum trough levels to monitor dose reductions are also necessary when signs of cyclosporine toxicosis are noted.

Because large variations (10 to 60%)[4,7] in blood cyclosporine concentrations exist between dogs on the same dose of cyclosporine given both cyclosporine and ketoconazole for the treatment of anal furunculosis, definitive dosing regimens are unavailable, and the above is given as a starting point. However, encouraging results have been reported with the use of this drug combination (Table 20-2).

Side effects noted in clinical reports of combination therapy included vomiting, diarrhea, inappetance, weight loss, hypertrichiasis, hypoalbuminemia, lameness, and gingival hyperplasia. Most effects were transient during initial treatment and resolved spontaneously or with minimal intervention. Those side effects

TABLE 20-2. Results using Cyclosporinte and Ketoconazole for Treatment of Perianal Fistulae

Ref #	Sample Size	Medication Regimen	Response	Long Term	Notes
7	16	CSA 1mg/kg BID Ketoconazole 10mg/kg SID	50% sinus depth reduction and area of ulceration w/in 2 weeks	93% in full remission @ 14 weeks 50% disease free @ 1 year	Dosages decreased to maintain 200 ng/ml trough levels by HPLC. Suggested that starting CSA @ 0.5 mg/kg BID may allow fewer dosage adjustments but still therapeutic serum levels and steady maintenance level
6	12	8K9: CSA 2.5 mg/kg BID Keto 8 mg/kg SID 4K9: CSA 4 mg/kg SID Keto 8 mg/kg SID	100% full resolution of clinical signs in 9 weeks	Full remission in 8/12. 5/8 suffered recurrence @ mean of 12.4 weeks past cessation of tx. 5/5 complete resolution of clinical signs with same tx. Significant improvement in severity of lesions in 4/12 but persistent lesions	CSA dosages adjusted to maintain 400-600 ng/mL (checked monthly). B/c of keto involvement, CSA dose reductions of 50-75% appreciated resulting in savings of 36-71%. Those w/ relapse more likely to have suffered clinical signs longer hinting @ more severe dysregulation of immune system.
4	19	CSA @ 0.5, 0.75, 1, or 2 mg/kg Keto 5.3-8.9 mg/kg BID	Resolution in all within 3-10 weeks	12/19 remained in remission. 4/4 of those with recurrence achieved full resolution after 2 nd course of therapy.	Radioimmune assays weekly w/adjustments to achieve 400-600 ng/mL. Dogs on higher 2 dosages had trough levels persistently above target range indicating that dosages of 0.5-0.75 mg/kg BID may be sufficient. Savings of up to 70% realized compared to earlier study.

which were more recalcitrant resolved with cessation or reduction of administration and were not intolerable.[4,6,7,32] Hepatotoxicity is a suggested side effect of ketoconazole and may be idiosyncratic or dose dependent, though none of the previous reports describe this complication.[33]

Medical Management–Topical

In 2000, Misseghers et al.reported on once to twice daily topical application of tacrolimus (0.1%) to treat canine anal furunculosis in ten dogs.[34] Like cyclosporine, this drug is used to inhibit T-cell activation through inhibition of calcineurin. Tacrolimus is ten to one hundred times more potent than cyclosporine, is absorbed topically better than cyclosporine, and doesn't require systemic levels to be effective. Side effects are typically reported at the same frequency as those of cyclosporine. However none of the animals described in the initial study showed untoward side effects. Five of the ten dogs (50%) achieved full remission of between one and eight months duration after cessation of treatment, and nine of ten (90%) dogs showed complete resolution of clinical signs with at least a 50% reduction in lesion volume. This report suggested that once daily administration of tacrolimus should be considered a low cost alternative to cyclosporine in mild to moderate cases of anal furunculosis or as maintenance therapy after cyclosporine induced remission of disease.

There is little in the literature that describes the concurrent use of both calcineurin inhibitors, but combination therapy should have a role in treatment. One group has reported good results in "normal" cases of anal furunculosis with twice daily application of tacrolimus that was started once tapering of cyclosporine has begun.[10] Anecdotally, the tacrolimus seems to speed cyclosporine tapering. This paper suggests that some patients can be weaned entirely off systemic cyclosporine/ketoconazole and be managed with tacrolimus applied topically every 24 to-72 hours. In very mild cases of disease, tacrolimus alone may be sufficient. Whether topical medication may be required for life long management[10] or should only be continued for four weeks past resolution of clinical signs[34] in these cases is uncertain. If tacrolimus is not used because of client or patient concerns, the lowest dose and frequency of cyclosporine and ketoconazole (or other immunomodulator combination) that controls clinical signs is recommended.

Dietary Management

To my knowledge, there have been no prospective studies which show a definitive response to restrictive diets. However, anecdotally, many authors agree that the introduction of a novel antigen diet is a component of treatment.[10,16,20,25] An association between colitis and anal furunculosis has been suggested.[16] Thirty-three percent (9/27) of dogs with perianal fistulas in a study of 27 German Shepherd dogs with a concurrent diagnosis of colitis experienced complete lesion resolution, 33% experienced an improvement in lesion severity, and the remainder were unchanged[16] when treated with corticosteroids and a novel protein diet. In another study, 50% (9/18) of dogs had histological diagnoses of colitis when they were presented for perianal fistulae. Several theories have been proposed for this association, but our lack of understanding of either disease precludes a definitive etiology without further study.

Summary

Life long medical management can reduce the severity of or prevent the recurrence of clinical signs. Systemic and/or topical medication have shown good results in decreasing the severity of disease. The importance of recheck evaluations should be stressed to owners. Rectal examinations should be performed biannually unless there are clinical problems that recur sooner. Adjunctive surgical intervention should only be attempted after medical options have been explored and owners have been advised of possible surgical complications.

Anal furunculosis has historically been a surgically managed disease. Surgery is still indicated in those rare cases that are completely unresponsive to immunomodulators and in those in which no further response is appreciated despite appropriate drug dosing adjustments. The trend away from surgical therapy has been a result of the high rates of fistulae recurrence and potential serious surgical complications regardless of the technique employed.

References

1. Milner, H.R., *The role of surgery in the management of canine anal furunculosis. A review of the literature and a retrospective evaluation of treatment by surgical resection in 51 dogs.* N Z Vet J, 2006. 54(1): p. 1-9.

2. House, A.K., et al., *Evaluation of the Effect of Two Dose Rates of Cyclosporine on the Severity of Perianal Fistulae Lesions and Associated Clinical Signs in Dogs.* Veterinary Surgery, 2006. 35(6): p. 543-549.

3. Hardie, R.J., et al., *Cyclosporine treatment of anal furunculosis in 26 dogs.* J Small Anim Pract, 2005. 46(1): p. 3-9.

4. O'Neill, T., G.A. Edwards, and S. Holloway, *Efficacy of combined cyclosporine A and ketoconazole treatment of anal furunculosis.* J Small Anim Pract, 2004. 45(5): p. 238-43.

5. Doust, R., L.G. Griffiths, and M. Sullivan, *Evaluation of once daily treatment with cyclosporine for anal furunculosis in dogs.* Veterinary Record, 2003. 152(8): p. 225-+.

6. Patricelli, A.J., R.J. Hardie, and J.E. McAnulty, *Cyclosporine and ketoconazole for the treatment of perianal fistulas in dogs.* J Am Vet Med Assoc, 2002. 220(7): p. 1009-16.

7. Mouatt, J.G., *Cyclosporin and ketoconazole interaction for treatment of perianal fistulas in the dog.* Aust Vet J, 2002. 80(4): p. 207-11.

8. Ellison, G.W., *Treatment of perianal fistulas in dogs.* J Am Vet Med Assoc, 1995. 206(11): p. 1680-2.

9. Killingsworth, C.R., et al., *Bacterial population and histologic changes in dogs with perianal fistula.* Am J Vet Res, 1988. 49(10): p. 1736-41.

10. Patterson, A.P. and K.L. Campbell, *Managing anal furunculosis in dogs.* Compendium on Continuing Education for the Practicing Veterinarian, 2005. 27(5): p. 339-+.

11. Mathews, K.A., et al., *Cyclosporine Treatment of Perianal Fistulas in Dogs.* Can Vet J, 1997. 38: p. 39-41.

12. Day, M.J. and W.B. M., *Pathology of Surgically Resected Tissue from 305 Cases of Anal Furunculosis in the dog.* J Small Anim Pract, 1992. 33: p. 583-589.

13. Matushek, K.J. and E. Rosin, *Perianal Fistulas in dogs.* Compendium on Continuing Education for the Practicing Veterinarian, 1991. 13(4): p. 621-627.

14. Griffiths, L.G., M. Sullivan, and W.W. Borland, *Cyclosporin as the sole treatment for anal furunculosis: preliminary results.* J Small Anim Pract, 1999. 40(12): p. 569-72.

15. Mathews, K.A. and H.R. Sukhiani, *Randomized controlled trial of cyclosporine for treatment of perianal fistulas in dogs.* J Am Vet Med Assoc, 1997. 211(10): p. 1249-53.

16. Harkin, K.R., R. Walshaw, and T.P. Mullaney, *Association of perianal fistula and colitis in the German shepherd dog: response to high-dose prednisone and dietary therapy.* J Am Anim Hosp Assoc, 1996. 32(6): p. 515-20.

17. Killingsworth, C.R., et al., *Thyroid and immunologic status of dogs with perianal fistula.* Am J Vet Res, 1988. 49(10): p. 1742-6.

18. Vasseur, P.B., *Results of surgical excision of perianal fistulas in dogs.* J Am Vet Med Assoc, 1984. 185(1): p. 60-2.

19. Tisdall, P.L., et al., *Management of perianal fistulae in five dogs using azathioprine and metronidazole prior to surgery.* Aust Vet J, 1999. 77(6): p. 374-8.

20. Jamieson, P.M., et al., *Association between anal furunculosis and colitis in the dog: preliminary observations.* J Small Anim Pract, 2002. 43(3): p. 109-14.

21. Ellison, G.W., et al., *Treatment of perianal fistulas with ND:YAG laser--results in twenty cases.* Vet Surg, 1995. 24(2): p. 140-7.

22. Guaguere, E., J. Steffan, and T. Olivry, *Cyclosporin A: a new drug in the field of canine dermatology.* Vet Dermatol, 2004. 15(2): p. 61-74.

23. House, A.K., S.P. Gregory, and B. Catchpole, *Expression of Cytokine mRBA in Canine Anal Furunculosis Lesions.* Veterinary Record, 2003. 153(354-358).

24. Day, M.J., *Immunopathology of Anal Furunculosis in the Dog.* J Small Anim Pract, 1993. 34: p. 381-389.

25. Ettinger, S.J. and E.C. Feldman, *Textbook of Veterinary Internal Medicine. 5th ed. Diseases of the Large Intestine, ed.* A.E. Jergens and M.D. Willard. Vol. 2. 2000, Philadelphia: W. B. Saunders.

26. Plumb, D.C., *Veterinary Drug Handbook. 4 ed. Azathioprine, ed.* D.C. Plumb. 2002, Ames: Iowa State University Press. 86-88.

27. Plumb, D.C., *Veterinary Drug Handbook. 4 ed. Metronidazole, ed.* D.C. Plumb. 2002, Ames: Iowa State University Press. 549-552.

28. Daigle, J.C., *More economical use of cyclosporine through combination drug therapy.* Journal of the American Animal Hospital Association, 2002. 38(3): p. 205-208.

29. Hardie, R.J., et al., *Cyclosporine Treatment of Perianal Fistulae in 26 Dogs.* Vet Surg, 2000. 29(5): p. 481.

30. Blackwood, L., et al., *Multicentric lymphoma in a dog after cyclosporine therapy.* J Small Anim Pract, 2004. 45(5): p. 259-62.

31. Myre, S.A., T.J. Schoeder, and V.R. Grund, *Critical Ketoconazole Dosage Range for Ciclosporin Clearance Inhibition in the Dog.* Pharmacology, 1991. 43: p. 233-241.

32. Dahlinger, J., C. Gregory, and J. Bea, *Effect of ketoconazole on*

cyclosporine dose in healthy dogs. Veterinary Surgery, 1998. 27(1): p. 64-68.

33. Plumb, D.C., *Veterinary Drug Handbook. 4 ed, ed.* D.C. Plumb. 2002, Ames: Iowa State University Press. 465-470.

34. Misseghers, B.S., A.G. Binnington, and K.A. Mathews, *Clinical observations of the treatment of canine perianal fistulas with topical tacrolimus in 10 dogs.* Can Vet J, 2000. 41(8): p. 623-7.

Excisional Techniques for Perianal Fistulas

Gary W. Ellison

Introduction

Since the last edition of this text was published, dramatic improvements have been made in the medical management of perianal fistulas to the point that surgical therapy is currently considered a secondary treatment for this confounding disease. Current theory is that the disease may be immune mediated resembling Crohns disease in people. The term "immune mediated proctitis" may be a better term for this syndrome than perianal fistulas. The presence of concomitant inflammatory bowel disease and recent reported success of immunosuppressive therapy with drugs such as oral prednisone, oral cyclosporine, combination oral cyclosporine and ketoconizole, combination oral azathioprine with metronidazole and topical tacrolimus lend further support to this hypothesis. Early infiltration of the circumanal glands with lymphocytes and plasma cells may occur prior to the more traditional secondary histologic changes which include inflammation and necrosis of the apocrine glands, infection of circumanal glands or hair follicles, impaction and infection of the anal sinuses or anal crypts and anal sac infection or abscessation. Ultimately the normal regional anatomy is permanently disrupted and gross lesions include fistulas of the anal sinuses, submucosal fistulas and ruptured anal sacs in addition to cutaneous perianal fistulas. In these advanced cases medical therapy is more likely to fail and surgery is indicated.

Indications for Surgery

Although an estimated 85% to 90% of perianal fistulas show improvement or complete resolution after eight to twelve weeks of immunosuppressive therapy, those lesions associated with anal sac rupture or disruption of the anal sac ducts often will not completely respond, or are subject to recurrence after cessation of appropriate medical therapy. Recurrence rates of 40 to 60% are reported especially in those cases where anal sac drainage is impaired. In the authors experience, residual or recurrent lesions are most often located ventral and lateral to the anus. Surgical excision of fistulas with concurrent anal sacculectomy is indicated in these cases as well as those where large areas of the anal circumference are involved and continued tenesmus or dyschezia with obstipation is caused by anal stenosis. Potential limitations of excision include the inability to remove all of the tracts if they extend too far peripherally and the danger of creating fecal incontinence if the tracts deeply invade the external anal sphincter. However, if an anal stricture is present due to a deep-seated invasion of the external anal sphincter by the fistulas, or if extensive fibrosis has occurred, then incision or excision of the areas of fibrosis is usually necessary for release of the constriction and for relief of painful defecation.

Preoperative Medical Treatment

For recurrent fistulas I prefer to treat the patient for two to four weeks preoperatively with 2 to 3 mg/kg of cyclosporine (Neoral, Novartis NA, East Hanover, NJ) PO every 12 hours or with a combination of 0.25 to 0.5 mg/kg cyclosporine and 10 mg/kg of ketaconazole (Nizoral, Janssen, Titusville, NJ) PO once daily. Pre-treatment CBC and blood chemistries should be drawn to establish baseline values for liver and renal function. Cyclosporine dosages often need to be adjusted to achieve a target range concentration of 200 ng/L on a 12 hour trough serum sample. The goal of presurgical therapy is to reduce existing fistulas to a negligible size and therefore reduce the volume of diseased tissue that needs to be excised. Reduction in diseased tissue will also allow the surgeon to better visualize the involved anal sacs and aid in their complete removal. If perianal fistula disease is chronic in a dog, abdominal radiographs should be taken to rule out the presence of secondary megacolon. Biopsies may be indicated in some cases to rule out neoplastic disease before extensive surgical therapy is performed.

Surgical Technique

The perianal area and tail base are clipped extensively after the animal has been placed under general anesthesia. A thorough digital rectal examination should be performed to determine how much of the rectal circumference is diseased, to identify the severity of anal sphincter stenosis and to determine how far the fistulas extend peripherally. The fecal contents of the rectum are evacuated digitally. Enemas are usually not administered prior to surgery unless significant fecal impaction is present. Culture of the fistulous tracts usually is not warranted since a mixed culture of gram positive cocci and gram negative coliform bacteria are usually isolated. The animal can be positioned in ventral or dorsal recumbency with the tail pulled over the back or below the table, respectively. The rectum is packed with chlorhexidine soaked tampons and routine surgical preparation of the perianal region is performed.

The fistulas and anal sacs are carefully probed with a groove director to determine their extent and depth. When the anal sacs are not diseased, they are removed prior to fistulectomy. More commonly, the anal sacs are ruptured or abscessed, and are best excised concurrently with the fistulous tracts. A circular incision is made around the periphery of the fistulas using a #10 blade, needle tipped electrosurgical unit or surgical laser (Figure 20-46). A plane is established deep to the fistulas and dissection is carried medially toward the anal canal. The dissection plane must stay as close to the fistulas as possible to preserve the external anal sphincter but it is important to dissect deep to the fibrous tracts (Figure 20-47). Hemorrhage is moderate and is controlled with electrocoagulation or laser ablation. Any remaining anal sac lining is carefully dissected from the surrounding fibers of the external anal sphincter with mosquito hemostats or fine dissection scissors (See Figure 20-47 inset). The entire secretory lining of the anal sac must

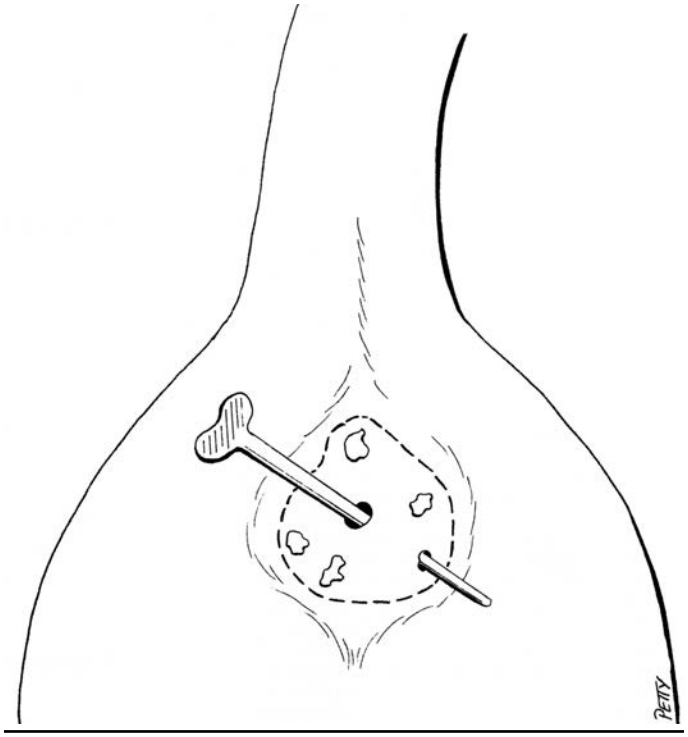


Figure 20-46. A groove director is used to probe the fistulous tracts and also check for patency of the anal sacs. An incision is made around the perimeter of the tracts with a #10 scalpel, needle tipped electrosurgical unit or laser unit.

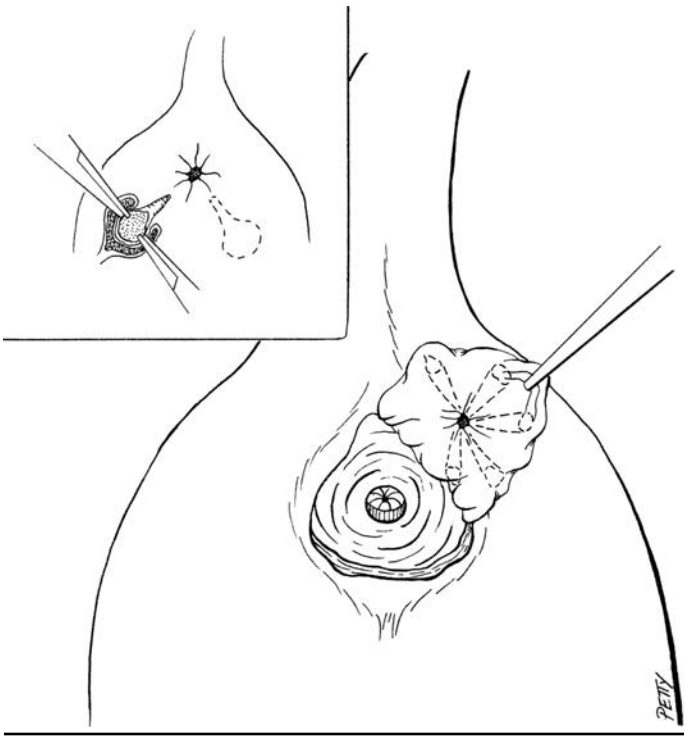


Figure 20-47. The dissection is continued deep to the tracts with efforts at preserving as much of the anal sphincter. Residual anal sacs lining should be removed by blunt dissection using mosquito hemostats or fine tipped scissors (inset).

be removed or sinus tracts may develop postoperatively. The dissection is carried medially to the anal canal and a circular incision is made in healthy rectal mucosa cranial to any rectal or anal sinuses (Figure 20-48). The excised fistulous tracts and a portion of rectal mucosa should be submitted for histopathology to rule out neoplasia and to check for evidence of inflammatory bowel disease. Eight to ten simple interrupted sutures of 3-0 synthetic monofilament absorbable sutures are used to appose the rectal submucosa to the subcutis. The rectal mucosa is then sutured to the skin with simple interrupted 3-0 monofilament nylon or polypropylene sutures (Figure 20-49 and inset). Often there are areas where the fistulas extend so far peripherally that direct skin to mucosal apposition is not possible. In these cases the adjacent areas of skin can be apposed or the wound can be left open to heal by second intention.

Laser excision–A Nd:YAG contact-tip laser has been used to successfully treat perianal fistulas. A frosted, synthetic sapphire tip and a continuous impulse of 13 to 15 watts was used to excise the fistulas, and the wound was closed primarily. Anal tone was reduced, flatulence was increased in 60% of the dogs, and 20% developed fecal incontinence. However, fecal incontinence when present was effectively managed by means of diet modification. The overall success rate for resolution of fistulas was 95% during a mean follow-up time of 22.9 months. Surgical treatment by laser excision of fistulas was particularly effective in relieving pain in those dogs with preexisting anal stenosis. Other authors have successfully used the CO_2 laser for fistulectomy.

Postoperative Care and Complications

Dogs may experience significant postoperative pain the day of surgery and injectable morphine, hydromorphone or bupivacaine or morphine epidural analgesia is often prescribed in addition to injectable NSAIDS (See Chapter 9). NSAIDS should not be administered to patients that have recently received prednisone. Pain

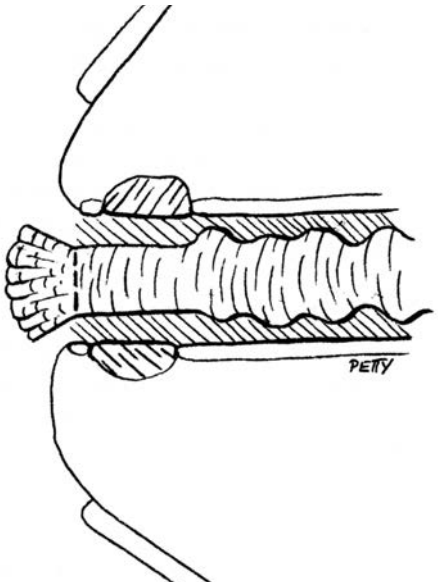


Figure 20-48. Cross section of the anus and rectum showing excision of the fistulas with preservation of the external anal sphincter. The fistulas are transected through the rectal mucosa cranial to the anocutaneous junction.

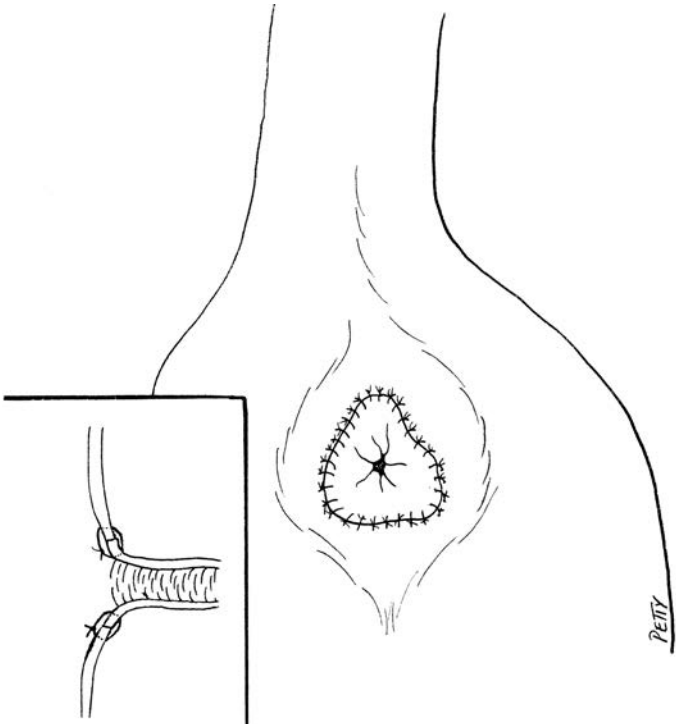


Figure 20-49. After apposing the deep subcutaneous tissues with simple interrupted sutures the rectal mucosa is apposed to the skin with simple interrupted sutures. It is important to closely approximate the rectal mucosa with the skin *(inset)*.

usually resolves rapidly and often within 48 hours animals are less painful than they were preoperatively. Drainage of serosanguineous fluid from the wound edge is expected for several days. Perioperative antibiotics may be indicated since fecal contamination may occur during surgery. Intravenous cefazolin (22 mg/kg IV every 8 hours) in combination with metronidazole (15 mg/kg IV every 8 hours) is initiated prior to surgery and continued for 24 hours. Oral cephalexin (10 mg/kg every 12 hours) and metronidazole (15 mg/kg every 12 hours) is then continued for five days postoperatively. The area is gently cleaned twice daily and sutures are removed in 10 days. Partial wound dehiscence is not uncommon. If wound dehiscence occurs, it is managed by local wound flushes and parenteral antibiotics as needed. Most open wounds heal by second intention in two to three weeks. Stool softeners are only used if preoperative constipation was present. Various degrees of fecal incontinence or flatulence may occur after the procedure. Fecal incontinence is usually less common with first time surgical procedures, but tends to occur more commonly when multiple procedures have been performed. When present, fecal incontinence is often successfully managed by feeding diets with high digestibility. The reported long-term success rates of excision techniques varies from 46 to 95%. However, many animals undergoing surgery have had other procedures performed prior to the excision technique. Postoperative anal strictures are rare with this technique. Periodic clipping and daily cleaning of the perianal region should be performed by the owners during the remainder of the dog's life. All dogs should undergo reexamination every two months to look for early signs of recurrence. Recurrent superficial ulcerations when treated early, usually respond to two to four weeks of cyclosporine therapy without further surgery.

Suggested Readings

Day MJ, Weaver BMQ: Pathology of surgically resected tissue from 305 cases of anal furunculosis in the dog. J Sm Anim Pract 33:583, 1992.

Ellison GW: Treatment of perianal fistulas in dogs. J Am Vet Med Assoc 206:1680, 1995.

Ellison GW, Bellah JR, Stubbs WP: Treatment of perianal fistulas with ND/YAG laser-results of 20 cases. Vet Surg 24:140, 1995.

Harkin KR, Walshaw RW, Mullaney TP: Association of perianal fistula and colitis in the German Shepherd dog: Response to high dose prednisone and dietary therapy. J Am Anim Hosp Assoc 35:515, 1996.

Mathews KA, Sukiana HR: Randomized controlled trial of cyclosporine for treatment of perianal fistulas in dogs. J Am Vet Med Assoc 211:1249, 1997.

Misseghers BS, Binnington AG, Matthews KA: Clinical observations in the treatment of perianal fistulas with topical tacrolimus in 10 dogs. Can Vet J 41:623, 2000.

Mouatt JG: Cyclosporin and ketaconazole interaction for treatment of perianal fistulas in the dog. Aust Vet J 80:207, 2002.

Shelley BA: Use of the carbon dioxide laser for perianal and rectal surgery. Vet Clin North Am Small Anim Pract 32:621, 2002.

Tisdale PL, Hunt GB, Beck JA, et al: Management of perianal fistulae in five dogs using azathioprine and metronidazole prior to surgery. Aust Vet J 77:374, 1999.

Vasseur PB: Results of surgical excision of perianal fistulas in dogs. J Am Vet Med Assoc 185:60, 1984.

Chapter 21

Liver, Biliary System, Pancreas

Hepatobiliary Surgery

Robert Martin and Mike King

Liver Surgery

Anatomy

The liver is the largest glandular organ in the body, consisting of between 3% and 5% of bodyweight in dogs and cats. Blood draining from the gastrointestinal tract passes through hepatic cells prior to returning to the general circulation of the body.

Positioned in the cranial abdomen, the canine liver is bound by the diaphragm cranially, and the stomach, intestines and spleen caudally, and lies transversely within the abdomen, with a slight majority of its mass located on the right of midline. The organ is divided into 6 lobes: left lateral, left medial, quadrate, caudate, right medial and right lateral (Figure 21-1A). The caudate lobe is further divided into caudate and papillary processes and is positioned transversely across the abdomen. The papillary process extends to the left where it lies in the lesser curvature of the stomach and the caudate process to the right where it contacts the cranial aspect of the right kidney. The portal vein lies ventrally and the vena cava dorsally to the caudate lobe. The quadrate lobe is situated between the right medial and left medial lobes, with the gallbladder located in a fossa formed between the quadrate and right medial lobes.[1,2]

The cranial surface of the liver follows the curve of the diaphragm, and the right and left coronary ligaments attach it to the diaphragm caudolateral to the vena cava. The right and left triangular ligaments extend from their respective crus of the diaphragm, attaching to the adjacent lateral lobes. The visceral surface consists of several visceral impressions; the most prominent is to the left of midline, formed by the stomach. The dorsal border extends more caudally than the ventral border, with the cranial pole of the right kidney located within a renal impression formed on the caudate process of the caudate lobe. The normal liver does not usually extend caudal to the costal arch.[1,2]

Blood supply to the liver arises from both the hepatic artery (a branch of the celiac), and the portal vein (formed from tributaries that drain the gastrointestinal tract, pancreas, and spleen). Branches of both these vessels supply the connective tissue of the liver as they divide and course through the parenchyma ending at the hepatic sinusoids. Blood is carried away from the liver first via central veins of the hepatic lobules which then form hepatic veins that finally empty into the vena cava. Innervation of the liver is maintained by both periarterial plexuses (sympathetic) and the vagal trunks (parasympathetic).

Bile is secreted by the hepatocytes into canaliculi within hepatic lobules. Canaliculi drain into interlobular ducts which unite to form lobar ducts that exit from each liver lobe as extrahepatic bile passages termed hepatic ducts. Hepatic ducts may vary in number and terminate in the bile duct (Figure 21-1B).

In addition to the production of bile the liver has other functions, including metabolism of protein, fat, carbohydrates, as well as many drugs. Patients with liver disease may suffer from hypoproteinemia, hypoglycemia, and decreased levels of clotting factors. Patients with liver disease to be treated surgically are less than ideal anesthetic candidates, as hypotension, increased risk of hemorrhage, and more profound reaction to many anesthetic agents may be seen. Preoperative hemogram, serum chemistries, strict attention to intravenous fluid support (often with

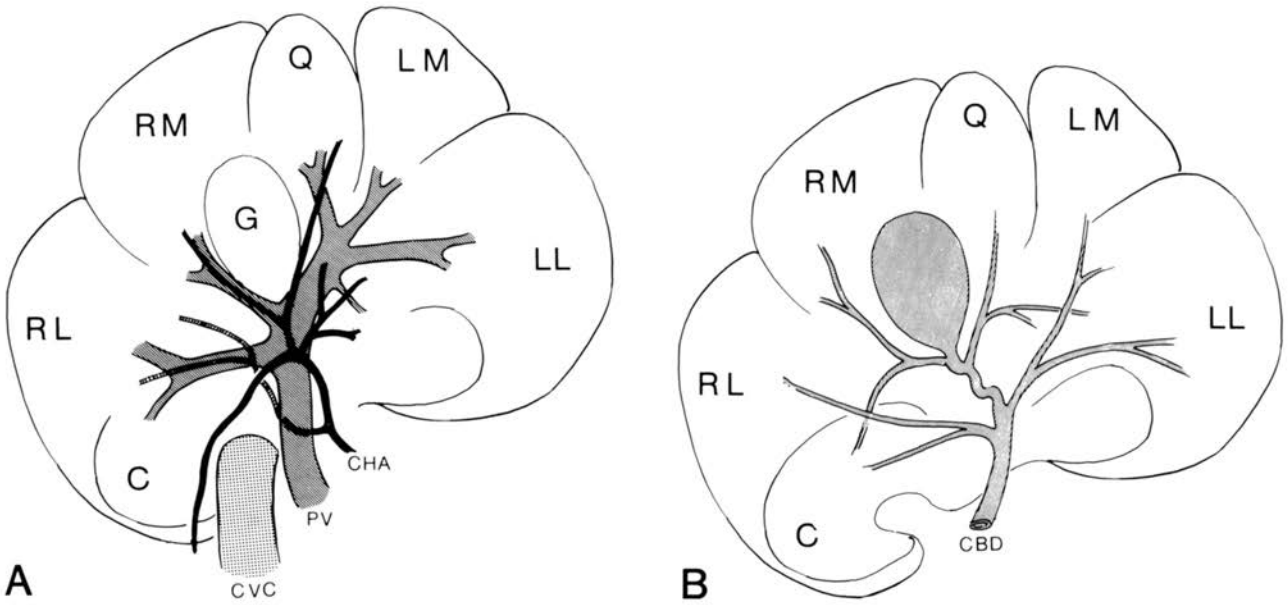


Figure 21-1. Anatomic relationship of the lobes of the liver (*C,* caudate; *LL,* left lateral; and *LM,* left medial; *Q,* quadrate; *RL,* right lateral; *RM,* right medial) and gallbladder *(G)* as viewed from the caudoventral perspective. **A.** Afferent vascular supply of the liver (*CHA,* common hepatic artery; *CVC,* caudal vena cava; *PV,* portal vein). **B.** Biliary system (*CBD,* common bile duct).

colloids to maintain osmotic pressure in a hypoalbuminemic patient) and careful attention to hemostasis are essential as is formulation of an appropriate anesthetic protocol.

Biopsy Techniques

Cytological evaluation of samples obtained by fine needle aspiration can be useful in diagnosis of some diffuse diseases. Care should be taken in the interpretation of such samples because the accuracy of liver cytology is markedly less than that of histopathological evaluation, especially in inflammatory hepatic disease.[3-5]

Ultrasound-guided needle biopsy is a commonly used technique for percutaneous liver biopsy (Tru-cut biopsy instrument).[6,7] This allows the clinician to obtain multiple samples for histopathological assessment with low risk of complications such as excessive hemorrhage.[8] Needle biopsy samples are not as accurate in yielding a diagnosis as larger wedge biopsies and laparoscopic liver biopsy is currently the best percutaneous technique.[9] Laparoscopic biopsy allows direct visualization of the liver, especially when the disease is not generalized, and provides for a larger sized tissue sample.[7] General anesthesia, specific equipment and expertise is required for the procedure.

A variety of techniques have been described for obtaining a liver biopsy during celiotomy. In cases of generalized disease or where a lesion exists at the apex of a lobe, the guillotine method is useful.[6,7] A single loop of absorbable suture material is placed around the tip of a lobe and tightened (Figure 21-2A and B). The suture cuts through the parenchyma and tightens around the resulting pedicle of tissue which contains any vessels large enough to require ligation. A scalpel or dissecting scissors are used to transect the liver tissue distal to the ligature, producing the biopsy sample. A 2 to 3 mm tag of tissue should remain distal to the suture to avoid it loosening and becoming dislodged when the biopsy sample is excised. The edge of the lobe at the transection site should be examined for excessive hemorrhage. Hemorrhage can be controlled with direct electrocoagulation or placement of additional ligatures. For a larger biopsy sample along a lobe margin, a series of multiple interlocking sutures or a mattress suture pattern can be used. These can provide greater hemostasis than a single encircling ligature.[6] The sutures should be pre-placed across the lobe or around the lesion and tightened before removing the biopsy sample.

In cases where a biopsy of a specific region or lesion is required, or when the disease process is not located at the margin of a lobe, a punch biopsy may be useful.[6,7] Once the region of interest has been identified on the convex (ventral) surface, a 6 mm cutaneous biopsy punch is directed into the lesion, taking care to not penetrate more than 50% of the thickness of the lobe. This avoids larger hepatic veins situated near the concave surface of the lobe. To complete the biopsy the punch is positioned at a slight oblique angle to the direction it was first inserted and then driven a short distance further. The resulting defect in the liver defect can be filled with absorbable gelatin foam (Gelfoam, VetSpong) or omentum to contain hemorrhage. Placement of a mattress suture around the defect can also provide hemostasis, if necessary.

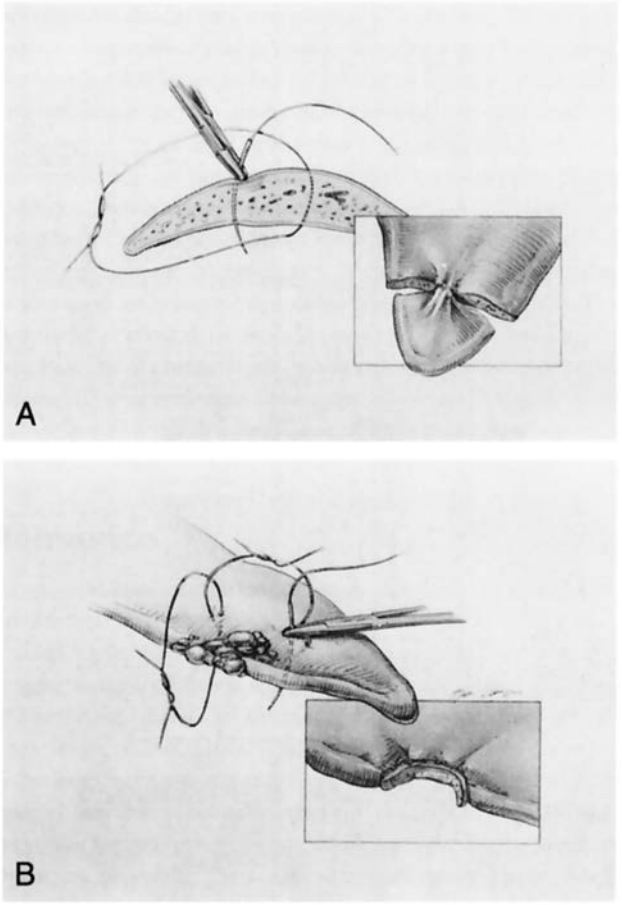


Figure 21-2. Interlocking sutures of an absorbable material are pre-placed to isolate the proposed biopsy site. Although two sutures are often adequate for biopsies obtained from the tip of the liver lobe **A.** multiple sutures may be needed for other areas **B.** The sutures are tightened and tied, and the biopsy sample is removed by sharply incising the tissue a few millimeters from the suture line.

Regardless of technique employed, care is taken to avoid crushing the sample with tissue forceps or other instruments since this can cause histological alterations, possibly affecting the diagnosis.

Liver Lobectomy

Complete or partial liver lobectomy is indicated in a variety of clinical situations such as hepatic abscess, neoplasia, lobe torsion, and vascular alterations.[6,7,10,11]

For partial lobectomy the liver capsule is sharply incised along the planned point of resection. The parenchyma is bluntly dissected using a Bard scalpel handle, Doyen clamp, or digital pressure, leaving isolated vascular structures intact.[6,7] Small structures can then be occluded by electrocoagulation while larger vessels (> 2 mm in diameter) should be ligated with suture or vascular occluding staples before transection.[7] Surgical suction is useful in maintaining a hemorrhage-free field during dissection, allowing better visualization of vessels that require ligation. More pronounced hemorrhage can be controlled by temporary

vascular inflow occlusion using the Pringle maneuver.[12] A finger is passed around the free edge of the lesser omentum into the epiploic foramen where the hepatic artery, portal vein, and bile duct can be compressed between the thumb and forefinger. Occlusion of the hepatic artery and portal vein can be maintained safely in this manner for up to 15 minutes while the hemorrhage is controlled.[12] A bulldog vascular clamp can be used to occlude these vessels, providing less interference to surgical exposure of the liver. Upon completion of a partial lobectomy the exposed parenchyma should be free of hemorrhage. Omentum can be sutured over the raw hepatic surface, though this is not necessary as omental adhesions will form spontaneously.[7]

Partial liver lobectomy can also be performed with specialized surgical stapling equipment, though this is dependent on lobe thickness and width.[7,13,14] The Thoracoabdominal (TA™) series of stapling instruments were designed for use in pulmonary and gastrointestinal surgery and are also effective for hepatic surgery.[7,13] Stapling devices are faster, provide more complete hemostasis, and are thought to cause less tissue inflammation than dissection and ligation techniques.[13] The TA stapling instruments use preloaded disposable cartridges that produce a staggered double row of staples 30, 55, or 90 mm in length.[14] The appropriate size instrument is selected based on lobe width at the desired point of transection. The liver capsule is incised, and the stapler is used to crush the parenchyma, compressing vessels and bile ducts between the jaws of the instrument. The staples are discharged and the parenchyma excised distal to the staple line.[7,14] Application of the TA stapler can be simplified by crushing the liver parenchyma digitally or with a crushing instrument (Carmalt or Doyen intestinal forceps), leaving the vascular pedicle intact for stapling.

Complete liver lobectomy can be a challenging procedure. For complete lobectomy of the left liver lobes, the triangular ligament is transected, allowing surgical access to the hilus. In small dogs and cats the tissue around the hilum can be crushed using digital pressure, and a single encircling ligature placed, prior to transection of the lobe distal to the suture.[6,7] Mass ligatures are not recommended for use in central or right division lobectomy or in larger dogs for left liver lobectomy as severe hemorrhage can occur should the ligature become dislodged.[6,7] Complete lobectomy of central or right division lobes requires dissection of hepatic parenchyma from the caudal vena cava. Care must be taken to not damage this structure. The lobe must be freed from attachments to surrounding tissues or organs, and any parenchyma remaining at the hilus is crushed. If the right medial and/or quadrate lobes are to be removed, the gallbladder has to be preserved.[7,14] Once the vascular supply and biliary duct(s) of the lobe to be removed have been identified, they should be isolated and individually ligated. The lobe is then transected distal to these ligatures and removed. The hilus is examined for any signs of persistent hemorrhage and additional ligatures placed, if necessary.

Use of surgical stapling devices can avoid the need for individual dissection and ligation of hilar vessels. Once the lobe has been freed from its attachments the instrument can be applied at the hilus and the staples deployed. After the lobe has been excised and the stapler removed, the hilus should be assessed for any persistent hemorrhage which may require additional attention with suture or large vascular clips.[7,13,14]

Extrahepatic Biliary Tract Surgery

Anatomy of the Extrahepatic Biliary System

The gallbladder, a pear-shaped structure located between the quadrate and right medial liver lobes, varies in size depending on the size of the dog. Cats have a relatively consistent gallbladder size but are more prone to anatomic variations. In a beagle-sized dog, the gallbladder measures 5 cm long and 1.5 cm wide at its widest area with an approximate 15 ml volume storage capacity of bile.[15] Anatomic regions of the gall bladder include a fundus, body, and a neck that continues as a cystic duct, the first structure of the biliary duct system (Figure 21-3).[15] The bile duct is the main excretory channel to the duodenum that begins where the cystic duct joins with the first biliary tributary (hepatic duct) from the liver.[15] Four hepatic ducts drain functional divisions of the liver and empty into the bile duct along its free portion (5 or more cm) as it courses to the duodenum through the hepatoduodenal ligament and lesser omentum (Figure 21-4).[7,15] The central liver division (right medial and quadrate lobes) usually contribute 2 hepatic ducts that empty into the origin of the bile duct along with the cystic duct. The left division (left lateral and medial lobes, papillary process of the caudate lobe) usually gives rise to a single hepatic duct that enters midway along the free portion of the bile duct. The right division (right lateral and caudate lobes) usually gives rise to a single duct that is the last hepatic duct to enter the bile duct before it enters the duodenal wall where it courses for about 2 cm through the duodenal wall as the intramural portion of the bile duct. The intramural bile duct is surrounded by a double layer of smooth muscle as it passes terminally into the major duodenal papilla through a smooth muscle funnel. Bile is discharged into the duodenal lumen primarily as a result of duodenal motility with digestion but also by a coordinated active gallbladder contractile process.[7,15] Variations in hepatic duct number (usually 3 to 5), liver division drainage, and hepatic duct entry into the bile duct can occur.

The frequent use of abdominal ultrasound (U/S) examination in dogs and cats has led to identification of asymptomatic biliary conditions such as gallbladder sludge (up to 50%), choleliths (about 5%), mucocoele (1 to 2%), and gallbladder wall thickening (1 to 2%) as incidental findings in dogs that do not have clinical signs of biliary tract disease.[a] Abnormal ultrasound findings can be significant if accompanying clinical signs and laboratory abnormalities (hemogram, serum chemistries) support a diagnosis of biliary tract obstruction. Only when ultrasonographic evidence of biliary obstruction (dilatation of the extrahepatic biliary system) is seen in a clinically ill patient does the role of infection become a likely contributor to biliary tract disease.

Surgical manipulation of the extrahepatic biliary tract is only part of the overall management of patients with clinical evidence of an extrahepatic biliary tract disease. The decision for surgical exploration should be made cautiously in clinically ill patients where morbidity has been induced by a biliary obstructive process (cholecystitis, inspissated bile, cholelithiasis, mucocoele,

[a] Personal Communication, Dr. Martha M. Larson and Dr. Colin C. Carrig

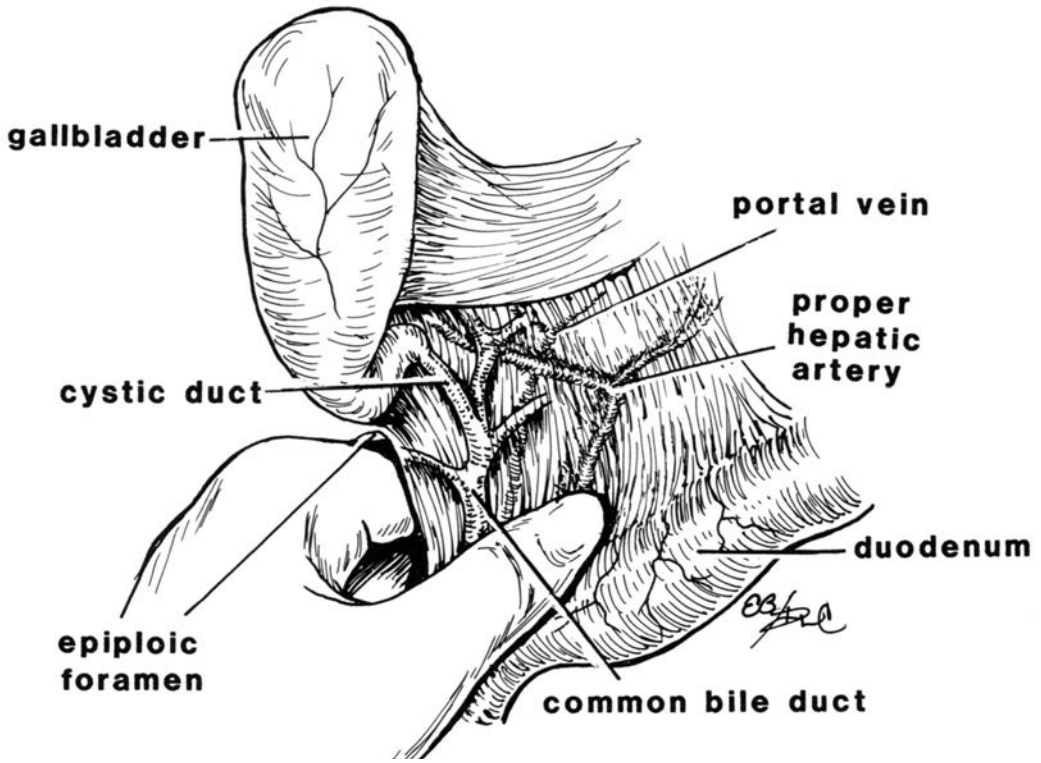


Figure 21-3. Palpation of the hepaticoduodenal ligament and intimate portal vein, common bile duct, and proper hepatic arteries. (Redrawn from Nora PF, ed. Operative surgery. Philadelphia: Lea & Febiger, 1972.)

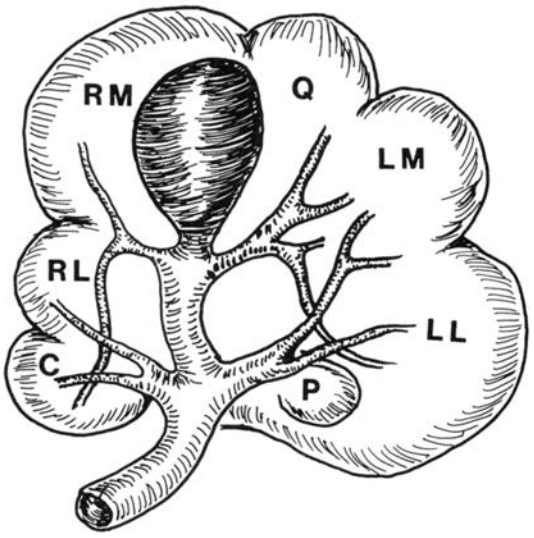


Figure 21-4. Schematic diagram of the usual bile duct distribution of the dog. Lobes of the liver are indicated as follows: *C,* caudate; *LL,* left lateral; *LM,* left medial; *P,* papillary process of caudate; *Q,* quadrate; *RL,* right lateral; *RM,* right medial.

neoplasia, fibrosing pancreatitis, other).[7,16] The selection of a surgical procedure and timing of intervention become critical factors that often affect patient survival. Stress of disease, anesthesia and prolonged surgery in these patients frequently results in death. **Cholecystocentesis** with U/S guidance is a minimally invasive procedure that can provide temporary biliary decompression for management of biliary obstructive disease in a sick patient.[17] If patient stabilization can be achieved by fluid and electrolyte replacement, appropriate antibiotic administration, and nutritional support, then definitive surgical management can be undertaken with a better prognosis. In diseases such as cholecystitis with gallbladder necrosis and septic peritonitis, the surgeon may have little choice but to operate on an unstable patient. Even these patients could possibly be better managed by ingress/egress abdominal infusion of warm balanced electrolyte fluids after placement of a multifenestrated catheter for fluid retrieval. These patients have a guarded prognosis with immediate surgical intervention whereas stabilization over a period of hours or days prior to surgery might improve survival. In stable patients that show only mild to moderate clinical signs of biliary tract disease, surgery can be performed before the patient status deteriorates.

Surgical diseases of the extrahepatic biliary system can be divided into traumatic or obstructive processes. While sharp or missile-penetrating trauma can lacerate the biliary system, blunt force trauma (automobile, kick) is the most frequent cause of traumatic disruption. A delay of days to weeks between blunt trauma and recognition of bile peritonitis is a common occurrence.[7] Animals are either presented in a stable state with abdominal effusion (chemical peritonitis only) or with varying degrees of illness and abdominal effusion (mixed chemical/bacterial peritonitis likely). Abdominocentesis is most often diagnostic when bilious fluid (green-tinged) is aspirated. The Ictotest® (Bayer HealthCare, Elkhart, IN) reagent tablets for detection of bilirubin in urine can be used to confirm the presence of bile in an abdominal fluid aspirate as can the less sensitive Multistix® 9 and Bili-Labstix® reagent strips (Bayer HealthCare, Elkhart, IN) used for standard urinalysis screening of bilirubin. Direct measurement of the bilirubin level may also be performed; if the bilirubin concentration of the

effusion is at least twice that of peripheral blood, a diagnosis of biliary disruption is confirmed.[7] Surgical exploration is indicated either immediately in a stable patient or should be delayed (hours) while steps are taken to improve the unstable patient's surgical status. Most frequently, omentum will have formed adhesions in the vicinity of the biliary rupture that must be broken down to identify the site of rupture to determine what appropriate surgical steps should be taken.[16]

Bile peritonitis can also occur following gallbladder rupture from obstruction or infarction.[7,18] These patients are often very ill and have a high mortality rate as a result. Surgical timing should coincide with an initial delay while attempts are made to improve patient stability over a period of hours, not days. A delay in owner recognition and subsequent presentation of a pet becoming ill from a biliary obstruction with bile peritonitis usually exists and time becomes a critical factor for patient survival in making the diagnosis and electing surgical intervention.[18]

Extrahepatic biliary obstruction occurs when disease processes interfere with the normal flow of bile from the liver and gallbladder into the duodenum. Biliary obstruction without rupture can occur from benign or neoplastic causes (benign – pancreatitis with periductal fibrosis[7,8] edema, and/or abscess obstructing the bile duct, sludge, mucocoele, choleliths/choledocholiths, cysts, parasitic [flukes in cats in tropical zones], congenital cysts or atresia, and granulomas; inspissated bile, suppurative cholangitis; neoplastic–gastric, pancreatic, duodenal, biliary, and hepatic).[7,16] Obstruction may be partial or complete, and intermittent or continuous. Consequences of extrahepatic biliary tract obstruction include impaired function of the reticuloendothelial system, increased absorption of endotoxins into the portal and peripheral circulations, depletion of coagulation factors, acquired platelet dysfunction, and an increased incidence of postoperative renal failure.[17] Bile salts enhance absorption of the fat-soluable vitamins (A, D, E, and K) and chronic biliary obstruction can result in prolongation of coagulation related to vitamin K-dependent coagulation factor deficiencies (Factors II, VII, IX, and X).[7,17] However, obstruction-related coagulopathy is unlikely in most cases of biliary obstruction in dogs and cats.[7] Parenteral vitamin K administration should be considered for 8 to 12 hours prior to surgery when PT and PTT are prolonged.[7,17,19] If coagulation is abnormal at the time of surgery, fresh whole blood (cross-matched) or fresh frozen plasma should be administered.[7] Clinical signs include icterus, abdominal pain, vomiting, anorexia, depression, fever, dehydration, acholic feces, and weight loss.[17] Most patients are debilitated on presentation from a chronic obstructive process.[7,16,17] In general, diseases involving the gallbladder should be treated with cholecystectomy rather than cholecystotomy with content evacuation unless the gallbladder wall is healthy and it is required for construction of a bile flow diversion procedure.

Primary obstructive diseases of the bile duct can be treated primarily (choledochotomy or cholecystotomy for stone removal, with anthelmintics for flukes in cats, using stents for temporary obstructions and primary repair) or by bile flow diversion (neoplasia, traumatic avulsion, fibrosing pancreatitis and granulomas). Either stents or bile flow diversion procedures can be used for both palliative and curative intent. A bile sample is always taken for routine culture and antibiotic sensitivity testing and a liver biopsy is standard for biliary tract surgery. Moist laparotomy sponges are routinely used to pack around the surgical site to contain bile spillage. Gauze sponges with a radiopaque marker (Vistec X-ray Detectable Sponges, Tyco Healthcare/Kendall, Mansfield, MA) are counted immediately prior to a celiotomy and immediately prior to closure to prevent leaving a sponge in the abdomen. Abdominal lavage with warm physiologic fluid is a standard part of surgical management of extrahepatic biliary tract disease prior to celiotomy closure. The surgeon should consider use of supplemental feeding techniques postoperatively (esophageal feeding tube, gastrostomy tube, jejunostomy tube; jugular catheter for total parenteral nutrition) to promote nutritional health. Laparoscopic equipment, if available, can be used efficiently to visualize the extrahepatic biliary system and assist in performing temporary decompression procedures, liver biopsy, or cholecystectomy.

Ultrasound-guided Percutaneous Cholecystocentesis

Goals of percutaneous cholecystocentesis are to provide rapid preoperative relief of jaundice, to allow control of biliary sepsis, and to allow time to improve the nutritional status of the patient before definitive surgery, especially in severely ill patients.[17] Evidence of a ruptured gallbladder is a contraindication for percutaneous cholecystocentesis. Recent reports of percutaneous cholecystocentesis have demonstrated the value of temporary decompression in patients until stabilized by fluid, electrolyte, antimicrobial, and nutritional management, resulting in a more favorable risk/benefit ratio for a successful surgical outcome.[19] Repeated cystocentesis can eliminate the need for definitive surgery in acute, temporary obstructions (e.g. acute pancreatitis) that resolve after intermittent biliary decompression.[17,19] An 18- or 20-gauge, 3.5 inch spinal needle (Becton Dickinson, Franklin Lakes, NJ), is easily inserted into a dilated gallbladder under U/S guidance and usually has a large enough internal diameter to allow aspiration of tenacious bile without leaving a large hole that results in excessive bile leakage once the biliary tract is decompressed and the needle is removed. Leakage always occurs to some degree and resulting morbidity is partially dependent upon patient status, amount of bile leakage, and bile sepsis. Daily or even twice daily cholecystocentesis should be employed over 3 or more days in sick patients with biochemical and ultrasonographic evidence of obstructive biliary tract disease until patient stability can be achieved to improve the prognosis for surgical intervention.

A Cook™ spiral catheter is attractive as a temporary percutaneous implantable catheter for use over several days in selected patients to minimize the necessity of multiple sedations and percutaneous needle placements but its use for percutaneous cholecystocentesis has not been reported. Accordion-type catheters have been described for use as an indwelling catheter after percutaneous placement.[17] An esophageal feeding tube should also be considered for nutritional support in the initial preoperative management of these patients.

Hepatic Duct Ligation

Avulsion of a single hepatic duct can occur following blunt abdominal trauma. Bile peritonitis results and a significant delay (10 to 20 days) between the time of trauma and onset of clinical signs is common.[7,16] Surgical management usually involves ligation of the avulsed duct.[7] Marked elevation in serum alkaline phosphatase will result (usually present with bile peritonitis), peaking at 10 to 14 days, and declining subsequently.[20] In some cases, an auxiliary retroportal network of bile ducts will develop to drain bile from the affected liver lobe (s) whereas, in other cases, diffuse microscopic biliary cirrhosis results.[7,16,20] If the avulsion is directly off the bile duct (often), either the bile duct tear is oversewn with 6/0 monofilament suture with or without a stent or the bile duct is ligated and a bile flow diversion procedure is performed.[7,16]

Tube Cholecystostomy

In situations where the clinician does not have the capability of providing frequent cholecystocentesis, tube cholecystostomy can be employed as a percutaneous placement or by relatively quick surgical intervention to achieve biliary decompression without performing a prolonged definitive corrective procedure (Figure 21-5).[16,17,20] Because surgical time can be a critical factor in a patient's survival, tube cholecystostomy should be selected only as a temporary procedure for rapid surgical biliary decompression until patient stabilization permits a definitive correction of extrahepatic biliary tract obstruction. The Hawkins needle-guide system (22-ga cannulated needle with stylet and guidewire; Cook, Inc., Bloomington, IN) and a 6.5-Fr polytetrafluoroethylene self-retaining accordion catheter with side holes has been described for percutaneous placement through the right abdominal wall caudal to the costal arch.[17] The catheter is secured to a Tuohy-Borst fitting and functions as a self-retaining catheter.[17]

A right paracostal celiotomy provides direct access to the gallbladder but ventral midline celiotomy is the more common approach for biliary surgery. Following creation of a cranial midline celiotomy, the falciform ligament is separated but not removed to minimize surgical time and blood loss. A self-retaining retractor (Gelpi for small dogs and cats; Balfour [pediatric and standard]) is used most efficiently to maintain body wall retraction for access to the gallbladder. A cutaneous incision is made ventral to the tip of the 13th rib on the right lateral body wall and a hemostatic forceps (Crile, Kelly, mosquito) is pushed with its tip from intraabdominal toward the skin incision. A Bard scalpel blade is used to sharply incise over only the tip of the forceps until its jaws pass completely through the body wall at that site. The tip of a 7- to 14-Fr balloon catheter (Foley catheter, Tyco Healthcare/Kendall, Mansfield, MA) or mushroom-tipped catheter (Bard Urological Catheter, CR Bard, Inc, Covington, GA; excise the tip of the mushroom catheter to improve bile drainage) is grasped with the forceps and pulled through the body wall and into the abdomen. The catheter is then passed through a layer of omentum.[7,16,17] Avoid bunching omentum such that it impairs surgical manipulation of the gallbladder. Using 3/0 monofilament absorbable suture material, a pursestring suture is placed in the

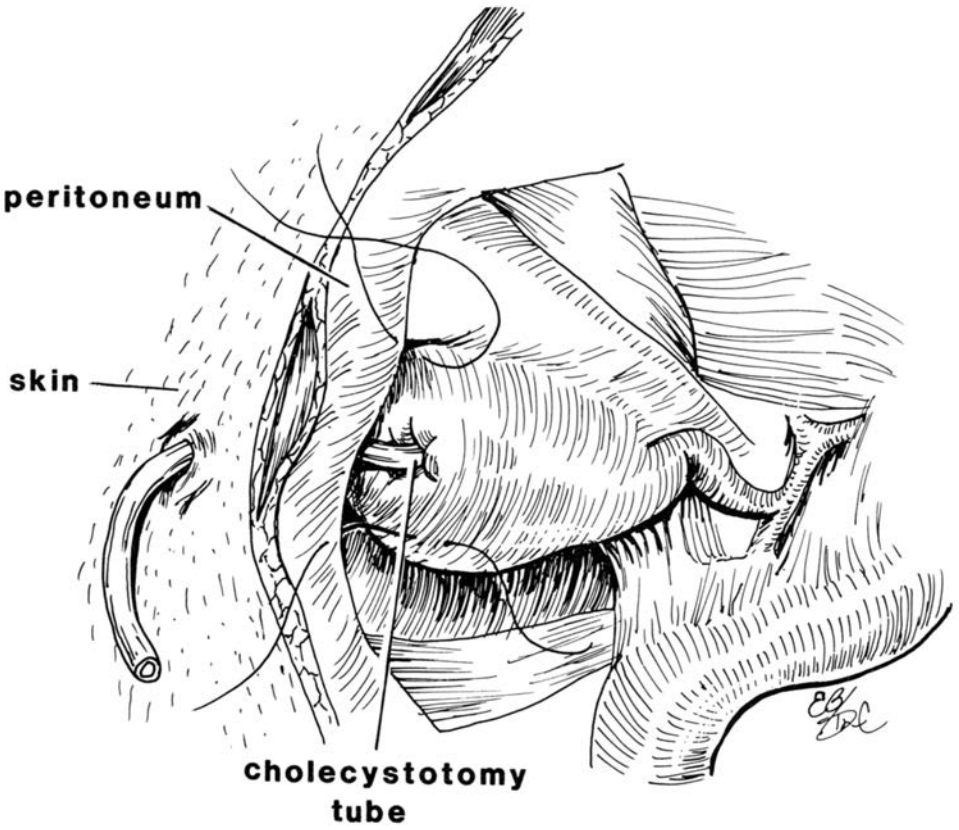


Figure 21-5. A cholecystostomy tube is maintained in the gallbladder with a pursestring suture. Two (of five or six) chromic catgut sutures are placed through the serosa of the gallbladder and peritoneum at the place of exit through the skin.

fundus of the gallbladder. The gallbladder is not dissected from its hepatic fossa[7,16] nor is it necessary to pexy the gallbladder fundus to the body wall at the site of tube entry into the abdomen.[7] Once the pursestring suture is placed, a stab incision (caution to avoid cutting the pursestring suture) is made with an 11 Bard blade into the center of the pursestring suture and bile is aspirated using suction. Alternatively, a large bore needle (14 gauge or teat cannula) connected to a 35 ml syringe can be introduced into the gallbladder from inside the pursestring suture to aspirate bile sufficiently to avoid leakage when the cholecystotomy is made for catheter tip introduction. Insert the catheter tip, inflate the balloon with sterile saline if a Foley® catheter is used, and tie the pursestring suture securely. Using a 4mm skin biopsy punch, take a liver biopsy from the ventral surface of a liver lobe, place a gelatin foam hemostatic sponge (Gelfoam®, Upjohn Company, Kalamazoo, MI; VETSPON®, Ferrosan A/S, Soeborg, Denmark) plug in the biopsy site to control hemorrhage, and close the celiotomy wound with an appropriate size absorbable monofilament suture material in a simple continuous pattern. The tube is secured to the skin at the exit site using 2/0 nylon in a finger-trap suture pattern. Avoid placing excessive external tension on the tube. The tube is occluded (use a 3 ml syringe placed into the tube end) and bandaged to the dorsal aspect of the patient for easy access for intermittent drainage multiple times daily. Gravity flow into a sterile collection system can also be used. The wound at the tube exit site is cleaned daily. The procedure should be accomplished in about 15 minutes in an attempt to minimize patient morbidity.

If the bile is not septic and the patient is eating or being fed through a tube (esophagostomy, gastrostomy), collected bile can be returned to the patient in gelatin capsules or directly into the tube to support digestion of dietary fats if prolonged drainage is anticipated.[7,16,20] In cases of temporary bile duct obstruction, biliary tract patency can be determined with cholangiography by injecting radiographic contrast media (**Conray® 400**) through the tube and into the gallbladder, taking a radiograph immediately after injection. If biliary patency is confirmed, the patient is sedated and the tube removed by firm traction five or more days postoperative without concern for bile leakage into the abdomen.[7,16] If at the time of tube placement the surgeon anticipates tube removal without further definitive biliary tract surgery, a balloon-tipped catheter (Foley catheter, Tyco Healthcare/Kendall, Mansfield, MA) is preferred since it can be deflated and more easily removed by traction than a mushroom-tipped catheter. The omentum forms a fibrous tract around the tube that collapses and seals off the gallbladder stoma after the tube is extracted. The cutaneous stoma is cleaned daily and allowed to heal by second intention.

After stabilization of a patient requiring definitive biliary surgery, the tube is removed under direct visualization following a second celiotomy. Tube cholecystostomy does not hinder subsequent cholecystectomy or biliary diversion using the gallbladder for a cholecystoenterostomy. In either procedure the tube should be cut several cm distal to the pursestring suture site to extract it externally from the body wall. The tube stump can be used to apply traction while the surgeon dissects the gallbladder from its hepatic fossa.

Choledochal Tube Stenting

Use of a choledochal tube stent has been previously described in individual case reports in the veterinary literature and in experimental studies however only recently has its use in a series of dogs with clinical biliary tract obstruction been reported, including long-term outcome.[7,21] Indications include short-term stenting for reversible disease processes (acute pancreatitis with temporary obstruction), internal support after primary repair of bile duct trauma, palliation of bile duct obstructing malignancy, and drainage of an obstructed bile duct prior to definitive surgical management in the severely compromised patient.[21] We prefer tube cholecystostomy over choledochal tube stenting for temporary decompression of biliary obstruction in the severely compromised patient because tube cholecystostomy is a more rapid surgical technique that does not require an enterotomy. Advantages of choledochal tube stenting include decompression for temporary obstructive diseases (pancreatic inflammation, edema, or abscesses) without altering the normal anatomic features of the biliary tract, support for primary repair of a bile duct tear, and possibly preventing stricture during the early phases of healing (controversial).[7,21]

An antimesenteric duodenotomy is made 3 to 6 cm distal (aborad) to the pylorus over the major duodenal papilla. A red rubber catheter (Feeding tube, Tyco Healthcare/Kendall, Mansfield, MA) is used because of its availability in a variety of sizes to accommodate variable diameters of a bile duct opening.[21] An appropriate diameter catheter is selected and passed retrograde from the bile duct opening at the major duodenal papilla. The biliary tract is flushed with a balanced electrolyte solution or sterile saline (0.9% NaCl) solution. If patency can be established, either by flushing through the stent only or by concurrent removal of choledocholiths/cholecystoliths through a choledochotomy, cholecystotomy or cholecystectomy, the stent is left with its tip midway in the free portion of the bile duct. The remaining tube is cut to leave 3 to 5 cm of stent extending through the major duodenal papilla and into the duodenal lumen. The stent is secured in place by passing a monofilament absorbable suture through the stent wall and through the submucosa of the duodenal wall just distal (aborad) to the major duodenal papilla and tying the suture routinely.[21] A monofilament nonabsorbable suture material should be used when a stent is placed for palliation of malignancy. Because of likelihood for stent occlusion to occur postoperatively, removal of the tip of the red rubber catheter while preserving the side openings should be considered even though bile can be expected to flow freely around the stent and into the duodenum.[21] The duodenotomy is closed routinely. The stent can be expected to pass through the feces months later or it can be electively removed by endoscopic retrieval 3 to 6 months later after clinical and biochemical evidence of biliary tract obstruction has resolved.

An alternate placement of a red rubber catheter stent is by direct introduction through the body wall and duodenum and through the major duodenal papilla into the bile duct. A large bore needle is passed from within the abdominal cavity through the right body wall at a point equidistant between the tip of the last rib and ventral midline. The tip of an appropriate size red rubber catheter is passed from outside into the needle lumen and into

the abdomen. The needle is removed from the body wall and catheter and it is next passed from the lumen of the duodenum 5 to 10 centimeters distal (aborad) to the major duodenal papilla (at a point in the descending duodenum that can be easily approximated to the right body wall) through the bowel wall on the antimesenteric surface of the duodenum. The tip of the red rubber catheter is again passed through the needle lumen and into the duodenal lumen. The needle is withdrawn and the catheter is passed into the bile duct through the major duodenal papilla to the midpoint in the free portion of the bile duct proximal to the level of obstruction or tear. The duodenotomy is closed routinely. The descending duodenum is sutured to the right body wall to fix the points of tube entry and prevent potential leakage. The red rubber feeding tube (Tyco Healthcare/Kendall, Mansfield, MA) is fixed to the skin by a finger-trap suture pattern with 3/0 nylon suture material. Bile can be drained passively from the tube externally or aspirated intermittently and returned to the animal through feeding as described above, if appropriate. Once serum bilirubin concentrations return to a normal level, a cholangiogram is performed by injecting contrast material (**Conray 400®**) through the stent and into the biliary system. If contrast can be seen flowing around the stent and into the duodenum, then the tube can be removed by cutting the fingertrap suture and placing gentle traction on the catheter.

Choledochal stenting may provide a less invasive and less time-consuming option for palliation of malignancies, compared with rerouting procedures.[21] Duodenobiliary reflux with subsequent cholangiohepatitis does not seem to be a consequence of stenting.[21]

Cholecystotomy

Cholecystotomy has limited indications in biliary surgery (removal of inspissated bile or biliary sludge, gelatinous bile, cholecystoliths/choledocholiths, and possibly to cannulate the bile duct to confirm its patency).[7,16] A bile sample for culture analysis can be obtained as an attempt is made to aspirate bile (20 to 35 ml syringe, 14- or 16-ga needle) before cholecystotomy is performed.[7] The bile duct is difficult to catheterize through a cholecystotomy because of the acute angle formed by the cystic duct as it joins the bile duct. An angiographic flexible-tipped guidewire is usually necessary to first pass around the sharp angle, followed by catheter passage over the guidewire to explore and flush the bile duct and its branches from this approach.[16] Diseases of the gallbladder are usually best managed by cholecystectomy and not just evacuation of gallbladder contents (stones, mucocoele, and sludge) although stones can be successfully removed via cholecystotomy.[7] It is imperative to insure that the bile duct is patent and a biopsy of the gallbladder wall is taken before a cholecystotomy is closed.[7] Closure is best achieved by using small-gauge monofilament absorbable sutures in a simple interrupted or continuous, inverting suture pattern (Lembert or Cushing). A two-layer closure is not necessary or recommended.[7] The primary indication for a controlled surgical opening of the gallbladder is in preparation for tube cholecystostomy or cholecystoenterostomy.

Cholecystectomy

Gallbladder removal is the treatment of choice for diseases of the gallbladder.[7] Secondary changes of inflammation, fibrosis or necrosis of the gallbladder wall are common. Removing the gallbladder eliminates a potential source of disease and a reservoir for subsequent stone formation.[7] An intact distended gallbladder is more easily dissected from its hepatic fossa than a flaccid one and stay sutures or tissue clamp become useful in manipulating the structure (Figure 21-6).[16] With gallbladder necrosis and/or rupture, cholecystectomy becomes more difficult to perform because stay sutures are no longer useful.

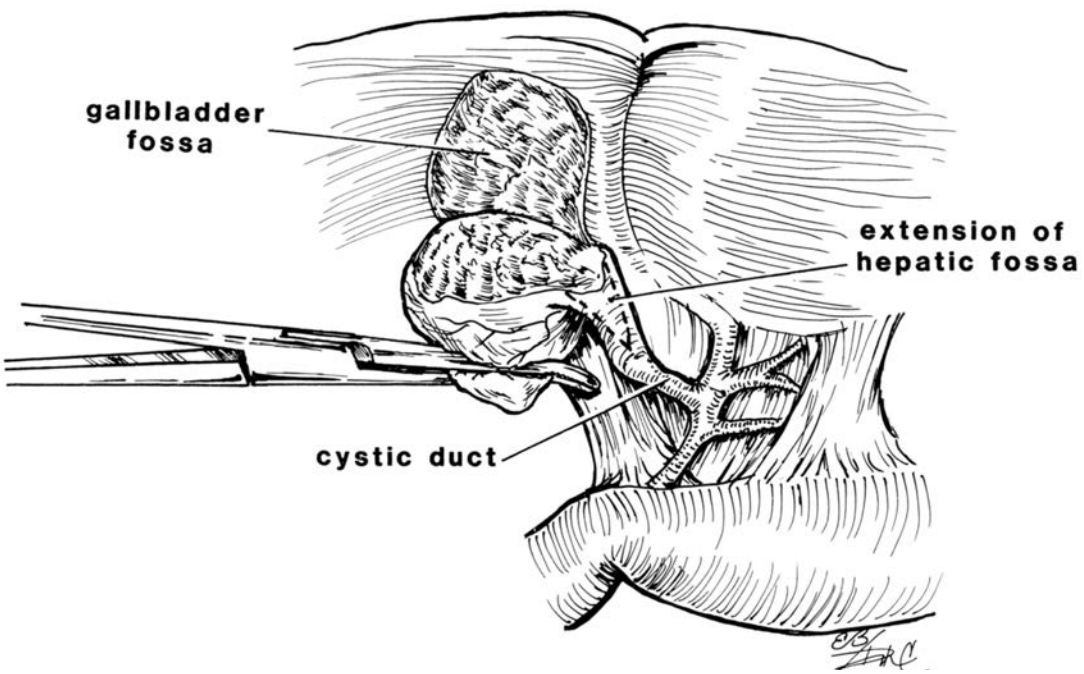


Figure 21-6. Tissue clamp is placed on the fundus of the gallbladder, and dissection from fundus to neck begins. (Redrawn from Nora PF, ed. Operative surgery. Philadelphia: Lea & Febiger, 1972.)

Omental, liver lobe, and diaphragmatic adhesions often require dissection to expose the gallbladder.[7] Traumatic rupture of the gallbladder is uncommon, and by the time of diagnosis, omental adhesions have usually formed so that primary closure is a less likely consideration, necessitating cholecystectomy.[7]

The gallbladder is covered by a layer of visceral peritoneum over its free (abdominal) surface that is confluent with the liver surface (tunica serosa or Glisson's capsule). This layer requires sharp dissection along the complete margin of the gallbladder and hepatic fossa. Some surgeons inject fluid beneath this layer to make it more distinct and to improve ease of dissection (Figure 21-7).[7,16] Once this layer of peritoneal reflection is partially disrupted, the gallbladder can be sequentially removed from its intimate attachment with hepatic parenchyma in the hepatic fossa, either by precise blunt scissor dissection or by more crude but rapid finger dissection. As this separation progresses, the peritoneal reflection can be continued sharply until the gallbladder is completely freed from its hepatic fossa, down to the junction of the cystic duct and the bile duct. With precise dissection, the hepatic fossa is minimally disturbed so that hemorrhage from a raw liver surface is minimal. With finger dissection, increased hepatic hemorrhage can be expected.[7] Because hemorrhage is not usually a major concern, blunt finger dissection of the gallbladder from the liver after peritoneal incision is a rapid method of mobilizing the gallbladder.[7] Any hepatic hemorrhage is controlled with pressure by packing with a moist laparotomy sponge.[7] In the normal dog, the cystic artery can be identified and ligated or coagulated directly. In clinical obstructive disease this structure can be ligated or coagulated when it is encountered. After gallbladder dissection is complete, the cystic duct can be cross-clamped and severed between the clamps (Figure 21-8). Our preference is to place a single clamp midway on the cystic duct to prevent spillage of gallbladder contents while leaving a sufficient stump (5 to 10 mm) attached to the bile duct to manipulate with Debakey tissue forceps for cannulation with an appropriate size catheter (5- to 8-Fr red rubber feeding tube, Tyco Healthcare/Kendall, Mansfield, MA). Once patency of the bile duct is confirmed by flushing and passing a catheter through the bile duct, a circumferential ligature is placed on the stump with 3/0 monofilament absorbable suture material or a hemoclip is applied. Double ligation or transfixation is not necessary when an adequate cystic duct stump is preserved although either can be employed, based on a surgeons' discretion. With a very short stump or with friable tissue, transfixation becomes more important to avoid suture slippage or tissue tearing and subsequent bile leakage. Because bile is soluble in saline or balanced electrolyte solutions, any spillage not contained by laparotomy sponges during the cholecystectomy can be removed during abdominal lavage. Sponges are removed from the hepatic fossa at completion of the procedure. Omentum can be placed in contact with the raw liver surface if leakage is a concern.

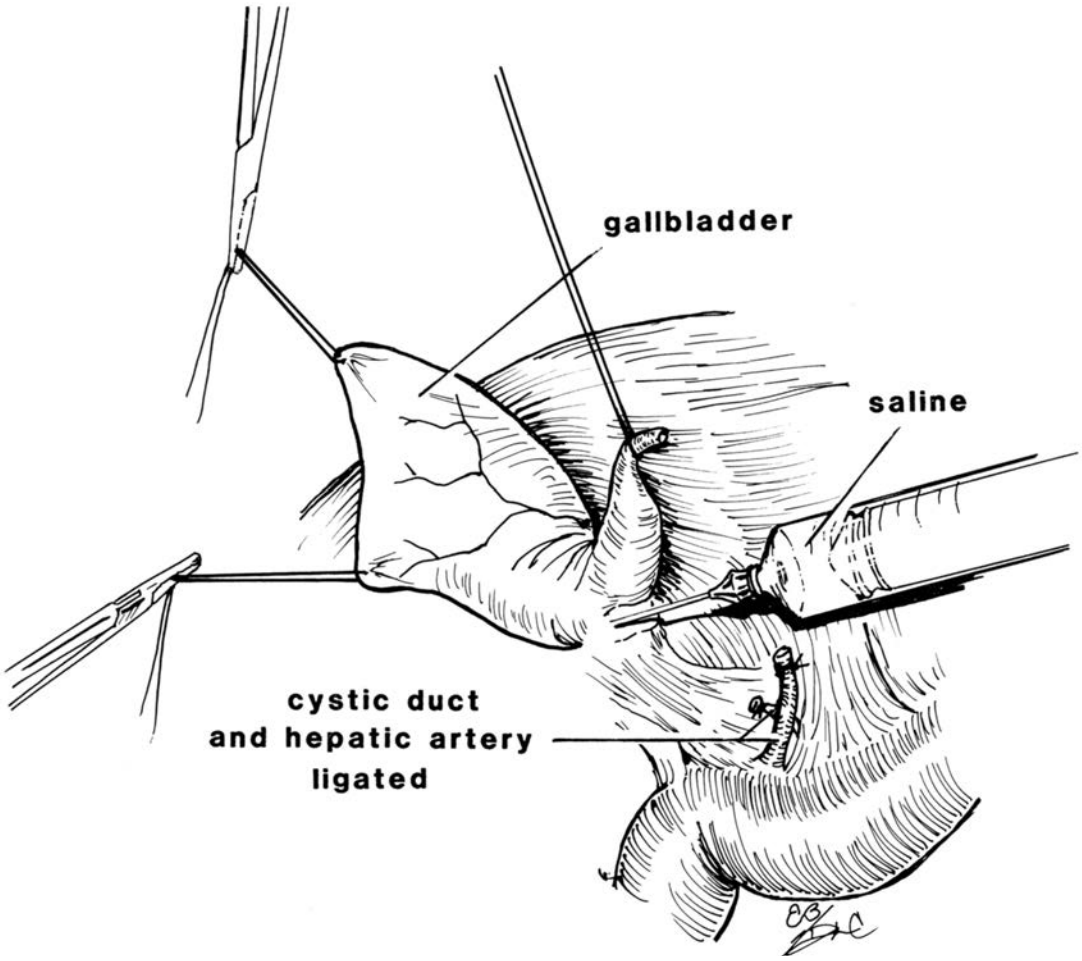


Figure 21-7. Saline solution injected subserosally, where the gallbladder adheres to the liver, aids in dissection during cholecystectomy. (Redrawn from Nora PF, ed. Operative surgery. Philadelphia: Lea & Febiger, 1972.)

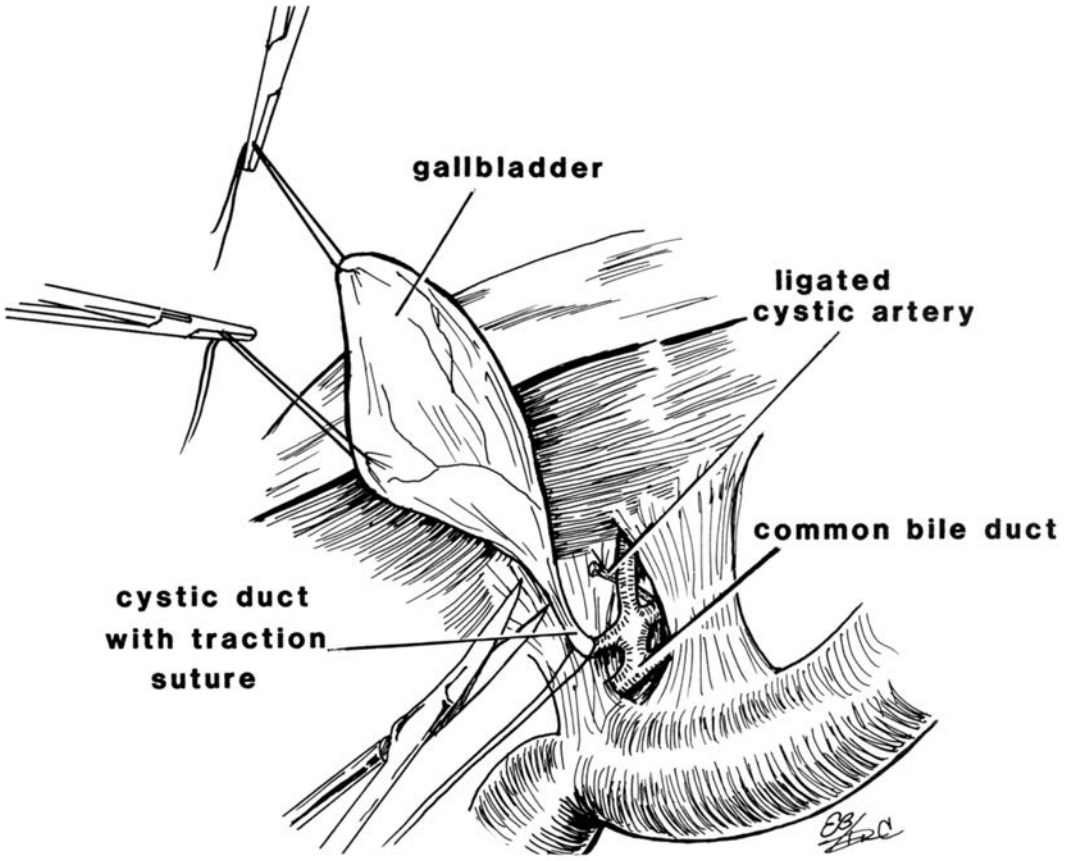


Figure 21-8. Sharp and blunt dissection isolates the cystic duct with traction sutures; the cystic artery is doubly ligated and transected between ligatures. (Redrawn from Nora PF, ed. Operative surgery. Philadelphia: Lea & Febiger, 1972.)

Drainage of the area is unnecessary. The bile duct will dilate 2 to 3 times its normal diameter and remain dilated after cholecystectomy.[7] Cholecystectomy performed by beginning the dissection at the cystic duct has been described.[16]

Choledochotomy

The normal bile duct in dogs and cats is usually too small (2.5 mm in diameter[15]) to consider an elective choledochotomy because of risk of either stricture and/or leakage after closure. However, in cases of bile duct obstruction in the distal free portion or in the intramural portion, dilation can result in a duct of sufficient size to make choledochotomy practical if needed to remove an intraluminal obstruction such as a choledocholith.[7] Biliary flushing and tube exploration in both directions is achieved through the choledochotomy.

Solitary choledocholiths located in the free portion of the bile duct can occasionally be removed via a linear choledochotomy directly over the stone. Bile duct patency is confirmed using a catheter inserted through the choledochotomy site with flushing of the bile duct in both directions. Primary closure with small-gauge (5/0 or 6/0) monofilament absorbable suture in a simple interrupted or continuous pattern is used to close the incision. A continuous cruciate pattern is leak proof when the bile duct is of sufficient diameter and thickness to employ the suture pattern.

Traumatic tears of the bile duct may be amenable to primary repair followed by placement of a stent tube[21] or a cholecystoenterostomy can be performed after ligation of the bile duct proximal to the tear. Primary closure of a choledochotomy or laceration by application of collagen biomaterial (fibrin-glued, sutured collagen patch) has been described; fibrin sealant alone was not reported to be effective.[7]

The bile duct is used in humans to bypass distal benign obstructions, usually stones, by creating a choledochoenterostomy (duodenal or jejunal). The procedure is described as a viable option in dogs and cats (Figure 21-9) when the duct is of sufficient size and the obstruction is distal.[16] There is little indication for this procedure electively in dogs and cats. Choledochoduodenostomy is not recommended unless the gallbladder must be removed, the bile duct is dilated to at least 1 cm in diameter, and a stoma of at least 2.5 cm can be created.[7]

Sphincterotomy/Sphincteroplasty

When the intramural portion of the bile duct contains an intraluminal obstruction (choledocholith), antimesenteric duodenotomy is used to access the major duodenal papilla where a blade of a blunt-tipped iris scissors or 60° Potts scissors can be introduced across the sphincter of Oddi to incise the intramural bile duct and duodenal mucosa sufficiently to remove the obstruction.[7] Because of its small size, creation of a sphincteroplasty (suturing bile duct mucosa to duodenal mucosa; (Figure 21-10) to permanently enlarge the opening of the intramural bile duct is not usually practical in the dog or cat. Following a sphincterotomy, the biliary system is catheterized and flushed but no further manipu-

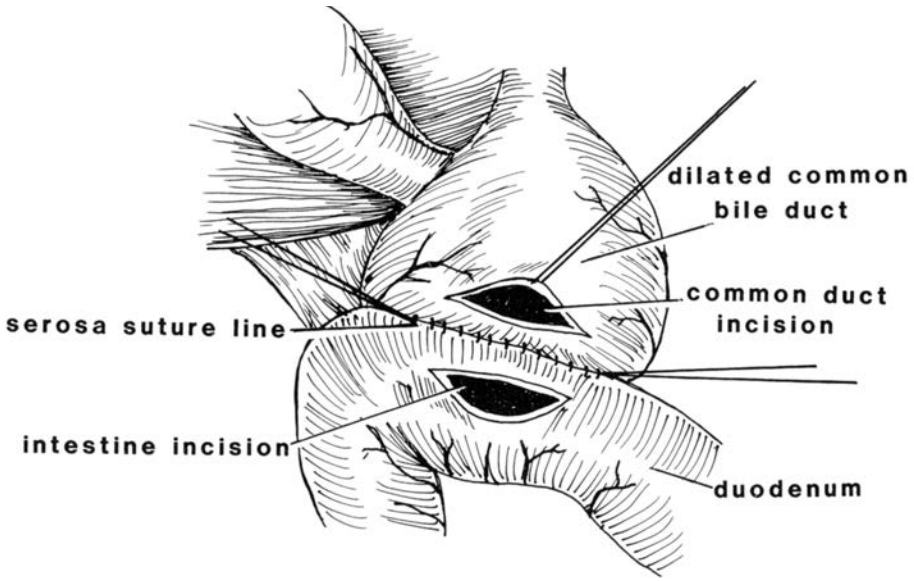


Figure 21-9. The dilated common bile duct is united by a simple interrupted serosal suture line to the intestine, and a gallbladder incision and enterotomy are made close to the serosal suture line. (Redrawn from Nora PF, ed. Operative surgery. Philadelphia: Lea & Febiger, 1972.)

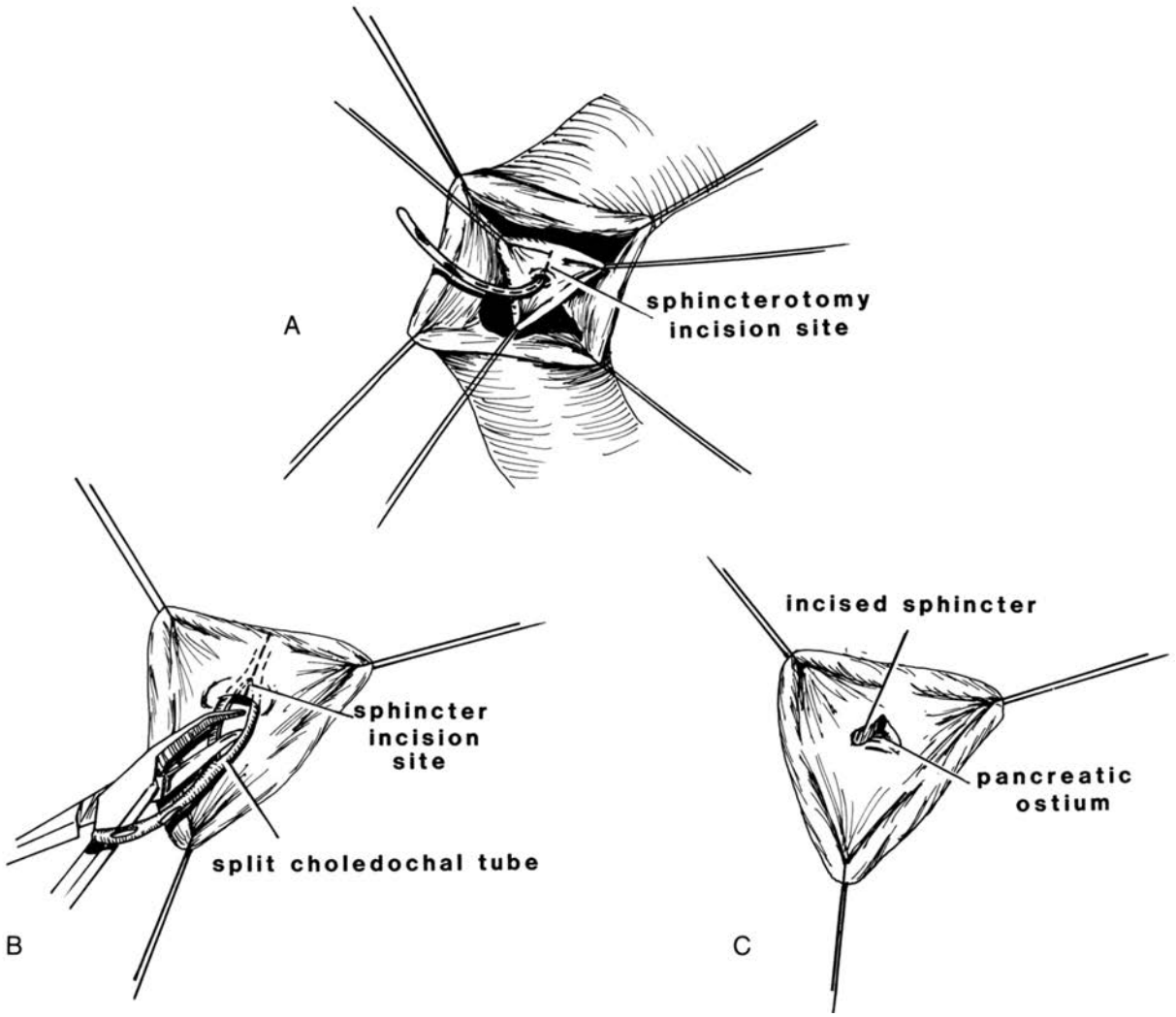


Figure 21-10. A. The duodenal incision is maintained open with four traction sutures. Three additional traction sutures elevate the bile duct hillock containing a choledochal tube in the bile duct orifice. Dashed lines on the hillock and tube indicate incision lines. **B.** The choledochal tube is split and retracted into the common bile duct. Mosquito forceps spread the split tube in and out of the common duct. Sphincterotomy can be easily performed along the split tube (dashed line). **C.** Sphincterotomy is complete. The ventral pancreatic duct may be present within the common bile duct hillock.

lation of the intramural bile duct is required. The duodenotomy is closed routinely with 3/0 monofilament absorbable suture in a simple continuous pattern that captures the submucosal layer of the bowel wall. The major pancreatic duct empties into the duodenal hillock with the bile duct in approximately 50% of dogs and in nearly all cats yet iatrogenic pancreatic insufficiency has not been reported.[16]

Rarely, a pancreatic abscess[22] or carcinoma of the intramural bile duct or major duodenal papilla can cause biliary obstruction. Drainage and stent management of a pancreatic abscess has been described in a dog.[21] Duodenal resection and anastomosis with biliary diversion using a cholecystoenterostomy is required for definitive treatment of a neoplasm in this location. The first author (RAM) has seen one case of obstruction caused by a solitary tumor of the major duodenal papilla. A stent could be considered for palliative management of neoplastic obstruction of the intramural portion of the bile duct if it can be introduced into the bile duct successfully.[21]

Biliary-enteric Anastomosis for Bile Flow Diversion

Rerouting the flow of bile is necessary when its normal course is disrupted, either by traumatic rupture or benign or malignant obstruction. Obstruction of the distal part of the free portion of the bile duct that cannot be relieved by other means becomes the most common reason to reroute bile through an anastomosis surgically created between the gallbladder and duodenum or jejunum. Occasionally, traumatic rupture of the bile duct by avulsion of its free portion from its intramural junction or a tear in its free portion occurs and is managed by bile flow diversion. Normally, the anatomic arrangement of smooth muscle layers around the intramural portion of the bile duct and around its terminal opening at the major duodenal papilla prevents reflux of duodenal contents into the biliary system.[15] However, reflux of intestinal contents (chyme and bacteria) into the biliary system occurs when the gallbladder is anastomosed to the small bowel. While long-term hepatic enzyme values (SAP, SGPT) and histological changes reflect subclinical reflux cholangitis, clinical signs of cholecystitis/cholangiohepatitis (fever, vomiting, anorexia, depression, abdominal pain and icterus) do not occur as long as the anastomosis remains sufficiently patent for ingress of contents to egress with the flow of bile.

Cholecystoduodenostomy is the most common bile flow diversion procedure used in veterinary medicine.[7,16] Cholecystojejunostomy has been reported in dogs and cats as a viable technique for bile flow diversion but postoperative complications are more common. Increased alkaline phosphatase and alanine aminotransferase hepatic enzymes and subclinical periportal inflammation and fibrosis result following biliary enteric anastomosis in normal and clinical dogs but these changes may already exist with bile duct obstruction in most clinical patients. Serum hepatic enzyme levels remain elevated for at least 6 months after cholecystoduodenostomy but may return to normal within 1 to 2 years.[7]

Cholecystoduodenostomy

The gallbladder is dissected from its hepatic fossa down to the junction of the cystic duct and the bile duct, as for cholecystectomy. Partial dissection of the gallbladder from the hepatic fossa has been described to minimize trauma to the cystic artery nourishing the gallbladder and to prevent cystic duct torsion.[7,16] Decreased tension on the anastomosis is achieved by complete dissection of the gallbladder from the hepatic fossa without loss of its viability. Use of two full-thickness stay sutures, one in the fundus and the other in the neck on the free surface, prevent iatrogenic gallbladder torsion. These retraction sutures are then used to stabilize the gallbladder for anastomosis to the antimesenteric border of the duodenum at its most tension-free location, typically 3 to 6 cm distal to the pylorus, depending on patient size (Figure 21-11). Similarly, two full-thickness stay sutures are placed in antimesenteric surfaces of the duodenum to stabilize this portion of small intestine. Doyen intestinal forceps can be used across the gastric antrum and distal to the right limb of the pancreas after the descending duodenum has been manually "milked" to empty lumen contents in an aborad direction to prevent leakage of fluid into the abdomen following duodenotomy. This step is usually not necessary. Packing clean, moist laparotomy pads dorsal to the gallbladder and duodenum also helps contain any bile or gastrointestinal fluid spillage in the region of the anastomosis.

The gallbladder is opened sharply from its fundus toward its neck for 4 cm or to the level of the neck in smaller gall bladders in order to create a stoma that will remain patent after it contracts up to 50% as it heals.[7] An incision of this length permits the maximum stoma size in small patients and an adequate stoma size in all patients. Using 3/0 monofilament absorbable suture on a tapered needle, a U-suture is placed between the proximal (orad) apex of the duodenotomy and the opposing apex at the neck of the cholecystotomy. A second U-suture is placed at the distal (aborad) apices of each structure. A single square knot is used to secure each U-suture to avoid a "daisy chain" effect created by multiple knots that potentially could leave enough space to allow for anastomosis leakage. The needle and suture of the proximally placed U-suture are brought back through the gallbladder wall and into its lumen immediately adjacent to the U-suture knot. A continuous suture pattern is employed to appose the dorsal (deep) margins of the stoma in a distal direction toward the second U-suture. When the suture line reaches the distal apices and U-suture, the needle and suture are brought through the gallbladder wall adjacent to that U-suture knot and the suture is tied securely to the free tag of that U-suture. At this point, the deep margin of the stoma is complete as a single-layer, simple continuous suture anastomosis that should be leak-proof if suture bites are placed appropriately (2 to 3 mm apart). The needle limb of the distal U-suture is now used to place a full-thickness simple continuous suture line through the ventral (superficial) margins of the gallbladder and duodenum, ending this suture pattern by tying to the free limb of the first U-suture on the external surface of the completed anastomosis. The deep stoma margin is inverted since it was created by suturing from within the lumen of the stoma whereas the superficial margin with be everted since it was created by suturing from the external surface of the stoma. The surgeon can digitally palpate

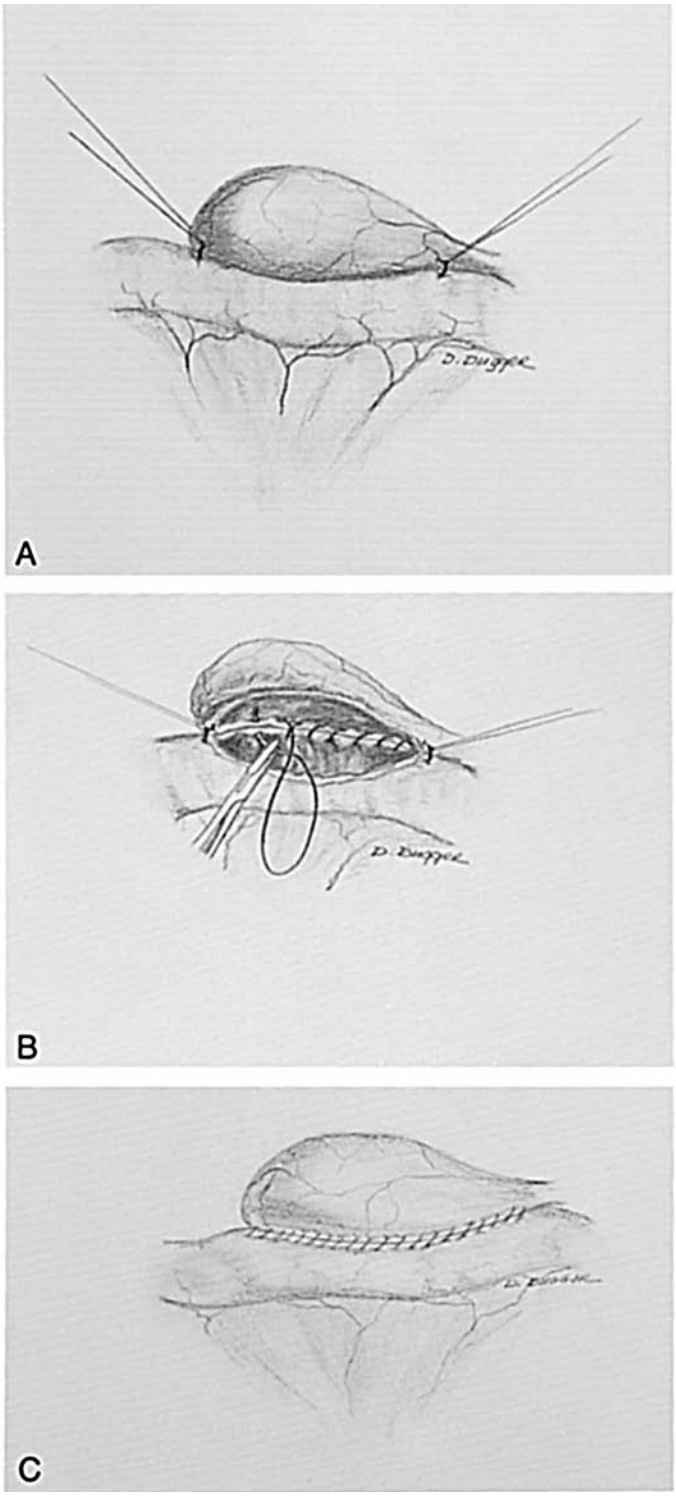


Figure 21-11. A. The gallbladder is approximated to the duodenum with one or two stay sutures. One stay suture should be placed close to the cystic duct to allow a 2.5 to 4 cm incision in the gallbladder. **B.** The gallbladder mucosa is sutured to the duodenal mucosa using a simple continuous pattern. **C.** The serosal surfaces surrounding the anastomosis are approximated with a simple continuous or Lembert pattern.

the stoma through the walls of the gallbladder and duodenum to assess the opening created. The anastomosis is lavaged locally, followed by complete abdominal lavage prior to body wall closure.

Cholecystojejunostomy

This technique is employed when a surgeon either elects to perform the procedure or circumstances (gastric, duodenal, pancreatic, or biliary masses) require its performance. When bile is diverted from the proximal duodenum, normal physiology of gastric acid production and fat digestion is altered. Bile is required in the proximal duodenum to activate duodenal mechanisms responsible for inhibition of gastric acid secretion. Excessive gastric acid production can lead to peptic ulceration of the pyloric antrum and/or, more commonly, the proximal duodenum.[7] Fat digestion is also disrupted since bile salts enhance both the hydrolysis and absorption of fats. Weight loss can result. No long-term reports exist on outcomes of cholecystojejunostomy in a series of dogs or cats to recommend the procedure.

Two techniques can be employed. A loop cholecystojejunostomy between the gallbladder and proximal jejunum is the simpler technique to perform. Noncrushing intestinal forceps (pediatric Doyen) should be applied proximal and distal to the selected jejunotomy site to minimize intestinal fluid spillage. Without dissecting the gallbladder from its hepatic fossa, a cholecystotomy is created in the free portion of the gallbladder from its fundus toward the neck and a loop of proximal jejunum is brought into proximity. An antimesenteric jejunotomy of equal length to the cholecystotomy is created and the two structures are anastomosed in a side-to-side fashion, using a continuous suture pattern with U-sutures as described for cholecystoduodenostomy. Stoma size should be either 4 cm in length or as long as the cholecystotomy will accommodate in patients too small to achieve this length. Reflux of jejunal contents will occur.

An alternate technique requires construction of an isoperistaltic antireflux limb of jejunum 40 to 50 cm long, according to the Roux-en-Y principle. The proximal jejunum is divided transversely, and the distal (aborad) segment is advanced to the gallbladder and anastomosed end to end with the gallbladder fundus. The proximal (orad) jejunal segment is anastomosed in an end-to-side manner 40 to 50 cm distal (aborad) in the distal (aborad) jejunal segment. This distance, considered necessary to prevent reflux of chyme into the gallbladder, is greater than half the length of the jejunoileum in all cats and most small dogs. A short bowel syndrome (maldigestion due to lack of small intestinal mucosal surface area) or stagnant bowel syndrome (overgrowth of bacteria in refluxed intestinal contents that stagnate in the limb) could result. This technique has only been reported in dogs experimentally where reflux occurred in all dogs having only a 15 cm Roux-en-Y jejunal limb.[7]

References

1. Dyce KM, Sack WO, Wensing CJG: *In* Dyce KM, ed.: *Textbook of Veterinary Anatomy.* 2nd ed. Philadelphia: WB Saunders, 1996, p

2. Evans HE, deLahunta A: *Millers' Guide to the Dissection of the Dog.*

4th ed. Philadelphia: WB Saunders, 1996.

3. Weiss DJ, Blauvelt M, Aird B: Cytologic evaluation of inflammation in canine liver aspirates. Vet Clin Pathol 30:193, 2001.

4. Roth L: Comparison of liver cytology and biopsy diagnoses in dogs and cats: 56 cases. Vet Clin Pathol 30:35, 2001.

5. Wang KY, et al: Accuracy of ultrasound-guided fine-needle aspiration of the liver and cytologic findings in dogs and cats: 97 cases (1990-2000). J Am Vet Med Assoc 224:75, 2004.

6. Bjorling DE: Partial hepatectomy and hepatic biopsy. *In* Bojrab MJ, ed.: *Current Techniques in Small Animal Surgery.* Philadelphia: Williams & Wilkins, 1998, p 287

7. Martin RA, Lanz OI, Tobias KM: Liver and biliary system. *In* Slatter D, ed.: *Textbook of Small Animal Surgery.* Philadelphia: WB Saunders, 2003, p 708.

8. Bigge LA, Brown DJ, Penninck DG: Correlation between coagulation profile findings and bleeding complications after ultrasound-guided biopsies: 434 cases (1993-1996). J Am Anim Hosp Assoc 37:228, 2001.

9. Cole TL, et al: Diagnostic comparison of needle and wedge biopsy specimens of the liver in dogs and cats. J Am Vet Med Assoc 220:1483, 2002.

10. Farrar ET, Washabau RJ, Saunders HM: Hepatic abscesses in dogs: 14 cases (1982-1994). J Am Vet Med Assoc 208:243, 1996.

11. Schwartz SG, et al: Liver lobe torsion in dogs: 13 cases (1995-2004). J Am Vet Med Assoc 229:242, 2006.

12. Bjorling DE, Prasse KW, Holmes RA: Partial hepatectomy in dogs. Compend Contin Educ Pract Vet 7:257, 1985.

13. Lewis DD, et al: Hepatic lobectomy in the dog. A comparison of stapling and ligation techniques. Vet Surg 19:221, 1990.

14. Lewis DD, Ellison GW, Bellah JR: Partial hepatectomy using stapling instruments. J Am Anim Hosp Assoc 23:597, 1987.

15. Evans HE, Christensen GC: *Miller's Anatomy of the Dog.* 2nd ed. Philadelphia: WB Saunders, 1979, 499.

16. Breznock EM: Surgical procedures of the hepatobiliary system. *In* Bojrab MJ, Ellison GW, Slocum B, eds.: *Current Techniques in Small Animal Surgery,* 4th ed. Williams & Wilkins, Baltimore, 1997, p 298

17. Lawrence D: Percutaneous biliary drainage (cholecystostomy). *In* Bojrab MJ, Ellison GW, Slocum B (eds): *Current Techniques in Small Animal Surgery,* 4th ed. Baltimore: Williams & Wilkins, 1997, p 398

18. Church EM, Matthiesen DT: Surgical treatment of 23 dogs with necrotizing cholecystitis. J Am Anim Hosp Assoc 24:305, 1988.

19. Martin RA: Biliary obstruction/stones. *In* Bojrab MJ, ed.: *Disease Mechanisms in Small Animal Surgery.* Philadelphia: Lea & Febiger, 1992, p 306

20. Martin RA, MacCoy DM, Harvey HJ: Surgical management of extrahepatic biliary tract disease: A report of eleven cases. J Am Anim Hosp Assoc 22:301, 1986.

21. Mayhew PD, Richardson RW, Mehler SJ, et al: Choledochal tube stenting for decompression of the extrahepatic portion of the biliary tract in dogs. J Am Vet Med Assoc 228:1209, 2006.

22. Matthiesen DT, Rosin E: Common bile duct obstruction secondary to chronic fibrosing pancreatitis: Treatment by use of cholecystoduodenostomy in the dog. J Am Vet Med Assoc 189:1443, 1986.

23. Herman BA, Brawer RS, Murtaugh RJ, et al: Therapeutic percutaneous ultrasound-guided cholecystocentesis in three dogs with extrahepatic biliary obstruction and pancreatitis. J Am Vet Med Assoc 227: 1782, 2005.

Congenital Portosystemic Shunts in Dogs and Cats

Karen M. Tobias

Introduction

Portosystemic shunts (PSS) are abnormal vessels that divert blood from the abdominal viscera to the heart, bypassing the hepatic sinusoids and carrying intestinal absorption products directly to the systemic circulation.[1] Portosystemic shunts can occur as congenital anomalies, or may develop secondary to liver disease and portal hypertension. Congenital PSS usually occur as single large vessels, while acquired shunts are numerous and often small in size. Common types of single congenital portovascular anomalies include intrahepatic portocaval shunts, such as patent ductus venosus, and extrahepatic portocaval or portal-azygos shunts. Shunts may connect the portal vein with the caudal vena cava directly, or may originate from a portal tributary, such as the left gastric vein, and terminate on a caval tributary, such as a phrenic or hepatic vein. In a small percentage of dogs, the prehepatic portal vein is also congenitally absent.[1,2]

Signalment, History, and Clinical Signs

Congenital intrahepatic and extrahepatic PSS are usually diagnosed in immature animals. No sex predilection is evident. Intrahepatic PSS are found primarily in large breed dogs such as Irish Wolfhounds, Bernese Mountain dogs, Old English sheepdogs, Golden and Labrador Retrievers, and Samoyeds, and in medium-sized breeds such as Australian shepherds and Australian Cattle dogs.[1,3] Extrahepatic PSS occur primarily in small breed dogs such as Yorkshire terrier, Maltese, pug, Schnauzer, Cairn terrier, Shih Tzu, and dachshund.[3] In cats, PSS are most often extrahepatic. Congenital shunts are hereditary in Irish Wolfhounds, Yorkshire Terriers, Cairn Terriers, and several other breeds.[3-6]

Clinical signs associated with portosystemic shunts commonly involve the nervous system, gastrointestinal tract, and urinary tract.[1] General clinical signs include poor growth rate, weight loss, fever, and anesthetic or tranquilizer intolerance. Neurologic dysfunction is seen in most animals with PSS and includes lethargy and depression, ataxia, behavioral changes, and blindness (especially cats).[1,7,8] Animals with severe hepatic encephalopathy may develop head pressing, circling, dementia, stupor, muscle tremors, motor abnormalities, focal and generalized seizures, or coma. Hepatic encephalopathy may be precipitated by drugs (i.e.diuretics or sedatives), protein overload, hypokalemia, alkalosis, transfusion of stored red cells, hypoxia, hypovolemia, gastrointestinal hemorrhage, infection, and constipation.[1,9,10] Gastrointestinal clinical abnormalities in animals with PSS include anorexia, vomiting, and diarrhea. Some dogs have no apparent clinical signs or are presented only with signs of cystitis or urinary tract obstruction. Seizures and hypersalivation are the most common clinical sign in cats, and some have unusual copper colored irises.[7,8]

Diagnostic Tests

The most common abnormality found on hemograms of animals with PSS is microcytosis.[1,11] Up to half of dogs with congenital PSS have prolonged PTTs;[12] however, this does not usually result in clinically significant hemorrhage. Biochemical abnormalities in dogs with PSS include decreases in blood urea nitrogen, protein, albumin, glucose, and cholesterol; and increases in serum alanine aminotransferase and alkaline phosphatase.[1] An increase in alkaline phosphatase is most likely from bone growth, since cholestasis is not usually a problem in animals with PSS. Cats with PSS often have increased liver enzymes but may have normal albumin and cholesterol concentrations.[7,8] Urine abnormalities may include low urine specific gravity and ammonium biurate crystalluria, and inflammatory urine sediment in animals with cystitis or urolithiasis.

Animals with portosystemic shunting will have decreased protein C activity and increases in fasting and 2-hour postprandial bile acids and in ammonia after an ammonia challenge (ammonia tolerance test). These tests are not specific for shunting, since they can occur with many liver diseases.

Hepatic histologic changes in animals with PSS include generalized congestion of central veins and sinusoids, lobular collapse, bile duct proliferation, hypoplasia of intrahepatic portal tributaries, proliferation of small vessels and lymphatics, diffuse fatty infiltration, hepatocellular atrophy, and cytoplasmic vacuolization.[1,11,13] These pathologic changes are often termed "hepatic microvascular dysplasia" and can also be seen in dogs with congenital portal vein hypoplasia (without macroscopic shunting) or noncirrhotic portal hypertension. Pathologic changes may be present in the central nervous system, especially in encephalopathic animals with shunts.

On plain radiographs, microhepatica and renomegaly may be present. Urate calculi normally are radiolucent but occasionally will be seen in the renal pelvis, ureter, or bladder on survey films when combined with struvite or other radioopaque material. Portosystemic shunts may be definitive diagnosed with angiography, ultrasonography, scintigraphy, computed tomography, or magnetic resonance angiography.[1] Mesenteric portography provides excellent visualization of the portal system but usually requires an abdominal incision. Water-soluble,sterile, iodinated contrast medium is injected into a catheterized jejunal or splenic vein (Figure 21-12), and one or more radiographs are taken during completion of the injection. Sensitivity of the test is greatest when performed with the animal in left lateral recumbancy.[14]

Differential Diagnoses

Single congenital portosystemic shunts must be differentiated from multiple acquired shunts secondary to portal hypertension, and from congenital portal vein hypoplasia (PVH); previously known as hepatic microvascular dysplasia or MVD). Congenital portal hypoplasia signifies a disorganization of the liver's microscopic architecture that is similar to that of dogs with single congenital shunts.[11,13] Congenital portal hypoplasia has been reported primarily in small breed dogs such as the Yorkshire terrier, Cairn terrier, Maltese, Cocker spaniel, and papillon. Dogs

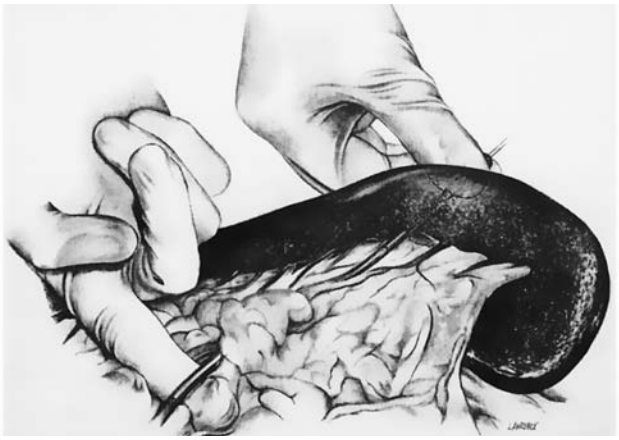


Figure 21-12. A transplenic through-the-needle catheter has been placed through the parenchyma and into splenic vein. The catheter may be used for portography or portal pressure measurements. (From Schultz KS, Marin RA, Henderson RA. Transsplenic portal catheterization: surgical technique and use in two dogs with portosystemic shunts. Vet Surg 1993;22:365)

with PVH display biochemical, hematologic, and clinical changes consistent with portosystemic shunting but lack a macroscopic portosystemic shunt. Therefore, in dogs with PVH, portograms and scintigrams are normal. Signs of PVH are managed with a protein restricted diet. Lactulose is added if clinical signs are not controlled with diet alone. Some clinicians may administer nutriceuticals (milk thistle, denosyl) to improve hepatic function.

Medical Management of PSS

Medical management of animals with PSS includes correction of fluid, electrolyte, and glucose imbalances and prevention of hepatic encephalopathy by controlling precipitating factors.[1] Dietary protein is restricted (protein content 18-22% in dogs; 30-35% in cats) to reduce substrates for ammonia formation by colonic bacteria, and any sources of gastrointestinal bleeding must be treated. Antibiotics that are effective against urease producing bacteria, such as neomycin or metronidazole, can be administered to decrease intestinal bacterial populations. Enemas and cathartics may be used to reduce colonic bacteria and substrates and are especially important in animals with hepatic encephalopathy. Lactulose is administered to reduce ammonia absorption and production. Cystitis is treated with an appropriate antibiotic based on urine culture and sensitivity; response may be poor if uroliths are present. Urate uroliths may respond to low protein diets; renal calculi have reportedly dissolved after shunt ligation.

With proper medical management, weight and quality of life stabilize or improve with treatment in most animals. In one study,[15] one third of dogs did well with medical management as the sole method of treatment, with many living to 7 years of age or older. Duration of survival with medical management alone was correlated to age at initial onset of clinical signs and with BUN concentration: dogs with extrahepatic PSS that were older at presentation or had a higher BUN lived longer. Over half of dogs treated with medical management alone were euthanized, usually within 10 months of diagnosis, because of uncontrollable neurologic signs and, in some cases, progressive hepatic fibrosis

and subsequent portal hypertension.[15] In another study[16] long term survival rate was 88% for dogs that underwent surgical treatment and 51% for dogs that were managed medically. In that study, age was not correlated with length of survival.[16] To the author's knowledge, no studies have evaluated survival of cats treated with only medical management. Of 4 cats managed medically by the author, 3 died or were euthanized less than 3 years after diagnosis because of neurologic disease or recurrent urinary tract obstruction. For animals with congenital PSS, particularly those that are symptomatic, surgery is considered the treatment of choice; however, surgery should be delayed until the animals are clinically stable.

Surgical Management

Most patients are premedicated with an opioid and a sedative. Low dose acepromazine (0.1 to 0.25 mg total dose) can be used for sedation before or after surgery since it does not increase the risk of seizures in these patients.[1] Animals can be induced with intravenous propofol or by mask induction with isoflurane or sevoflurane in oxygen.

Definitive diagnosis of extrahepatic PSS can usually be made during exploratory laparotomy if the veterinarian is thoroughly familiar with the vascular anatomy of the abdomen.[17,18] In a normal dog, there are no large vessels entering the caudal vena cava between the renal and hepatic veins. Many extrahepatic PSS terminate on the caudal vena cava cranial to the renal veins at the level of the epiploic foramen. The caudal vena cava will appear dilated and contain turbulent flow at the level of the shunt terminus. Portocaval shunts entering near the epiploic foramen may be difficult to see if the terminus of the PSS is obscured by an overlying artery, liver lobe, or the pancreas. Occasionally, portocaval shunts will traverse along the lesser curvature of the stomach and the ventral surface of the distal esophagus before joining the left phrenic vein. Portoazygos shunts traverse the diaphragm at the level of the crura or aortic hiatus and are obscured by overlying viscera.[17] To improve detection of and access to these shunts, it may be necessary to open the omental bursa (Figure 21-13) by tearing a hole in the superficial, ventral leaf of the greater omentum and retracting the stomach cranially and intestines caudally. Any vein of significant size that visibly penetrates the diaphragm at its lumbar attachments is likely to be a portoazygos shunt. Shunts that traverse the diaphragm through the esophageal hiatus may be easier to approach outside of the omental bursa by retracting the liver and stomach to the dog's right so that the cardia and esophagus are visible. Thorough exploration is warranted in all dogs with single congenital PSS because of the possibility, though rare, of a second shunt.

Intrahepatic PSS are more difficult to detect and treat. Experienced surgeons will note enlargement of the portal vein branch to, or hepatic vein draining, the lobe containing the shunt.[18] The liver lobe containing the intrahepatic shunt may have a visible, aneurysmal dilation of the shunt near the diaphragmatic surface of the parenchyma or may be palpably softer than the other lobes. When the shunt is a patent ductus venosus, it can occasionally be seen as it traverses between the left lateral and medial lobes. Because intrahepatic shunts are difficult to find and treat, preoperative dual phase contrast computed tomography is recommended in all large breed dogs and any other dog in which an intrahepatic shunt is suspected. Intrahepatic shunts can be occluded with interventional techniques (placement of a caval stent, followed by coils within the shunt); facilities that perform this procedure will utilize fluoroscopic and computed tomographic imaging as part of their diagnostic and therapeutic planning.

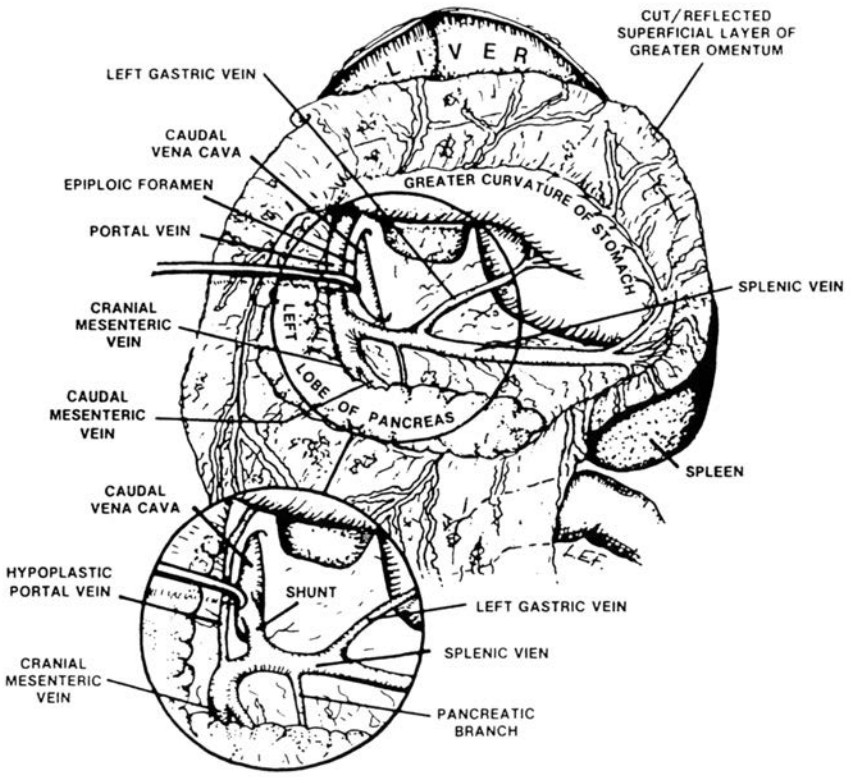


Figure 21-13. Ventral view into the omental bursa. Note the normal topographic relationships between the splenic, left gastric, and portal vein and compare with a typical single extrahepatic portocaval shunt diagram (inset). (From Martin RA. Identification and surgical management of portosystemic shunts in the dog and cat. Semin Vet Med Surg (Small Anim) 1987;2:304).

When a shunt is not found, the surgeon should obtain a liver biopsy to rule out other hepatic diseases such as PVH and perform intraoperative mesenteric or splenic portography to definitively rule out a PSS.

Porsostystemic Shunt Occlusion

Once the PSS is identified and presence of a prehepatic portal vein is verified, shunt occlusion can be attempted. It is critical to attenuate the shunt as close to its insertion site as possible so that all tributaries of the shunt are upstream from the occlusion. Portocaval shunts should be occluded at their terminus on the caudal vena cava. Portoazygos shunts can be occluded on the abdominal side of the diaphragm. Thorough examination is warranted before ligature placement as portoazygos and portophrenic shunts frequently have small branches from gastric veins that enter the PSS just before it traverses the diaphragm. The diaphragm may be opened if more exposure is needed.

Shunts can be occluded with suture or constricting devices. Most surgeons prefer to use devices that result in gradual occlusion of the shunt (e.g. ameroid constrictors or cellophane bands) or that are less invasive than open abdominal surgery (e.g., coiling of intrahepatic shunts). Suture attenuation is occasionally necessary when occlusive devices are not available. It is critical for veterinarians undertaking shunt ligation to understand that over half of animals with congenital shunts will die if the shunt is acutely ligated; therefore, partial ligation is necessary in most animals that undergo suture attenuation. If suture is to be used to ligate the shunt, then a small opening is made through the fascia around the shunt by dissecting adjacent to the PSS at its terminus. Silk suture (2-0) is frequently used in dogs because of ease of handling and knot security; however, a nonabsorbable monofilament suture is recommended in cats. The shunt should be temporarily occluded for 5 to 10 minutes while the surgeon evaluates the viscera for evidence of portal hypertension, including pallor or cyanosis of the intestines, increased intestinal peristalsis, cyanosis or edema of the pancreas, and increased mesenteric vascular pulsations.[19] Additionally, the surgeon can measure portal and central venous pressures.[18,20] To measure portal pressure, a catheter is placed directly into a jejunal vein or through the splenic parenchyma and into a splenic vein (See Figure 21-13).[21] The catheter is secured in place with gut suture and is attached to an extension set, 3-way stopcock, and syringe. A water manometer is attached to the 3-way stopcock, which is rested on the inguinal region of the patient to provide consistent readings during portal pressure measurements.

Recommendations for postligation pressures are to limit the maximum portal pressure to 17 to 24 cm H_2O, maximal change in portal pressure to 9 to 10 cm H_2O, and maximal decrease in central venous pressure to 1 cm H_2O.[1,17,18,20] Partial ligation should be performed if evidence of portal hypertension is noticed during surgery. Objective pressure measurements should not be used as the sole criteria for degree of shunt attenuation, since blood pressures can vary with depth of anesthesia, hydration status, phase of respiration, degree of splanchnic compliance, and other systemic factors. To perform partial ligation, choose a cylinder (a piece of tubing, steel pin, or rod) that is the approximate diameter that you wish to achieve during shunt occlusion.[22] Place the cylinder next to the shunt and wrap the ligature around the shunt and the cylinder. Tie the ligature and remove the cylinder, then recheck portal pressures and evaluate the color of the viscera.

Abrupt occlusion and partial ligation of PSS have been associated with serious postoperative complications, including perioperative death in 14 to 22%, seizures in 7.5 to 11%, recurrence of clinical signs in 40 to 41%, and development of multiple PSS in 7%.[1,17,22,23] Therefore, many surgeons prefer gradual, complete shunt ligation with devices such as ameroid constrictors, cellophane bands, or hydraulic occluders.[1,24-27] An ameroid constrictor (Research Instruments N.W., INC, Lebanon Oregon, 97355; researchinstrumentsnw.com) is an inner ring of casein that is surrounded by a stainless steel sheath. Casein is a hygroscopic substance that swells as it slowly absorbs body fluid; the stainless steel sheath forces the casein to swell inwardly, partially compressing the shunt. Ameroid constrictors cause shunt occlusion over 2-3 weeks by direct pressure and by stimulation of a fibrous tissue reaction. Ameroid constrictors are gas sterilized and therefore should not be used until 12 to 24 hours after sterilization to allow residual ethylene oxide to be released from the casein.

Ameroid constrictors with a 5 mm internal diameter are most frequently used for extrahepatic PSS ligation. The choice of ameroid constrictor size for PSS occlusion is based on shunt diameter; therefore, the surgeon should have a selection of sizes available at each surgery. To avoid postoperative portal hypertension, choose a constrictor that does not compress the shunt vessel during initial placement.[1,17] In cases where larger constrictors are not available, portal pressures can be measured during partial shunt occlusion and viscera can be evaluated subjectively for signs of portal hypertension to determine whether a smaller constrictor could be used.

Before constrictor placement, the "key", a small column of stainless steel that completes the constrictor ring, is removed from the ameroid constrictor and set aside. The ameroid constrictor is held securely by a pair of Allis tissue forceps, which prevent rotation of the casein inside of the stainless steel ring. Dissection of the supporting fascia around the PSS should be kept to a minimum when placing an ameroid constrictor to prevent postoperative movement of the ring and acute obstruction of the shunt (Figure 21-14). Once an opening has been made through the fascia around the PSS, the shunt is flattened by elevating it with open right angle forceps or two silk sutures. The constrictor ring is slipped over the shunt and, with a hemostat, the key is replaced within the constrictor to complete the circle (Figure 21-15). Anti-inflammatory doses of steroids should not be administered for 1 month after ameroid constrictor placement since they reduce the amount of tissue reaction and may prevent shunt closure. Complication and mortality rates after ameroid constrictor occlusion of extrahepatic PSS were 10% and 7%, respectively, in one study.[25] Excellent outcomes were seen in 80% to 85% of patients, although persistent shunting on scintigraphy was seen on recheck scintigraphy in 17 to 21% of animals in earlier studies.[1,17,24,25] Causes of persistent shunting include development of multiple acquired shunts, presence of a second



Figure 21-14. The fascia around the shunt is dissected as close to its terminus as possible, and the open constrictor is slipped over the flattened vessel.

shunt, inadequate fibrosis of the original shunt, or inappropriate location of the constrictor. Multiple acquired shunts are less common when shunt diameter is smaller than the constrictor ring internal diameter at the time of surgical placement.

Gas sterilized strips of cellophane have been used to provide partial occlusion of shunts in dogs.[26] Because the strips are flexible, they are easier to place around intrahepatic shunts than ameroid constrictors. The strips are wrapped once around the shunt and an adjacent stainless steel pin, and the ends of the band are held together with 4 alternating 11.5 mm surgical clips. Portal pressures are measured for several minutes after banding, and the viscera are evaluated for subjective signs of portal hypertension. Originally, animals required placement of bands with a final internal diameter of < 3 mm in diameter in animals to induce complete shunt closure.[26] In more recent studies, however, PSS closure occurred after bands were placed without intraoperative shunt attenuation.[27] Inflammation caused by the cellophane results in complete occlusion of most shunts in dogs in less than 4 to 6 weeks.[24,26] Mortality rates are 6% to 9% after cellophane banding, and persistent hepatic dysfunction was evident on bloodwork in 16% of animals.[26,27]

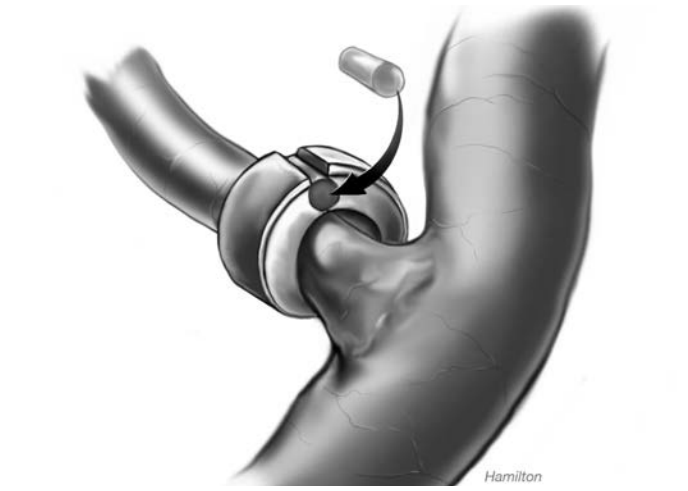


Figure 21-15. After application of the ameroid constrictor to the portosystemic shunt, the ring is locked with a cylindrical key to prevent dislodgement. The ameroid gradual swells, compressing the shunt, which subsequently closes by fibrosis or thrombosis.

Hydraulic occluders have been used for gradual extravascular occlusion of intrahepatic portosystemic shunts.[24,28] The silicone and polyester cuff of the occluder is placed around the shunt, and the attached access port is inserted under the skin. The cuff is gradually inflated postoperatively by intermittent injections of a solution into the subcutaneous port until the shunt is closed.

Blood flow through intrahepatic PSS may be reduced by occluding the portal vein branches leading to, or hepatic veins draining, the shunt using the above described extravascular techniques.[1,18] Alternatively, the shunt can be approached intravascularly during inflow occlusion. Most surgeons prefer minimally invasive extravascular techniques when possible to reduce the risk of complications.

Minimally invasive techniques for shunt occlusion are showing great promise for treatment of intrahepatic PSS. Thrombogenic coils have been placed via catheter access into the shunt to gradually obstruct PSS.[24,29,30] Coil migration is prevented by placement of a caval wall stent.[24] Under fluoroscopic guidance, a catheter is inserted through the mesh wall of the stent and into the shunt, and coils are placed via the catheter until portal pressure increases. Initially, complication rates were high with this technique; however, complication rates have been reduced to < 5% since initiating lifelong antacid therapy in dogs undergoing this procedure.[29]

Postoperative Management

After surgery, animals are monitored closely for seizures, hypothermia, hypoglycemia, and signs of portal hypertension, including shock, pain, and abdominal distension.[1,9] Most animals will need analgesics; opioids are used most frequently. Carprofen and meloxicam have been used safely in dogs with extrahepatic shunts but, in rare instances, may precipitate gastrointestinal ulcerations. Antacid therapy is recommended in all dogs with intrahepatic shunts. Sedation with a low dose (0.1 to 0.25 mg total dose) of acepromazine or dexmedetomidine 1-3 mcg/kg IV may be necessary if dogs are vocalizing or abdominal pressing, since these activities will increase portal pressure. Dogs with ameroid constrictor occlusion usually experience minimal discomfort.

A protein restricted diet and lactulose are continued after surgery until liver function improves. Frequently the animals can be gradually weaned off of the lactulose 4 to 6 weeks after the surgery. Bile acids and albumin are evaluated 3, 6, and 12 months after the surgery or until liver function is improved. Protein in the diet can be gradually increased once bile acids are improved. In dogs with mildly elevated bile acids and normal albumin, it may be necessary to monitor clinical response to diet change to determine whether dietary protein content can be gradually increased, since many dogs with PSS also have PVH and, therefore, will always have mildly increased bile acids.

Treatment of postoperative portal hypertension includes intravenous fluid administration for hypovolemic shock, systemic antibiotics, and immediate surgery to remove the constrictor

or ligature.[1,9] Factors that may increase portal pressure postoperatively include excessive intraoperative fluid administration, increased systemic blood pressure from anesthetic recovery, and increased intra-abdominal pressure from bandages, pain, or vocalization.

Between 0 and 18% of small breed dogs develop seizures after shunt ligation.[1,25,26,30,31,32] The etiology is unknown, and affected animals usually do not respond to fluids, dextrose, or enemas. Seizures are treated with an IV bolus of diazepam to effect or propofol to induce anesthesia and blood glucose is measured and corrected if low. The patient is started on intravenous levetiracetam and switched to an oral form once the animal is able to swallow. If the animal continues to seizure, the animal is placed on a continuous intravenous infusion of propofol to maintain light anesthesia and treated with IV mannitol and phenobarbital. Levetiracetam is continued, and intensive nursing care is provided. Propofol is discontinued after 12 hours; sedation with dexmedetomidine or acepromazine may be required during propofol recovery. If seizures occur after anesthetic recovery, the CRI is reinstated for another 12 hours. Prognosis is poor for animals with postoperative seizures, and those that survive usually continue to have neurologic problems.

Animals with persistently elevated bile acids should be re-evaluated by ultrasound, scintigraphy, or portography. Persistent shunting is usually from development of multiple acquired shunts but can occur with lack of closure of the shunt within the constricting device, or because of presence of a second shunt. If no shunting is detected, a liver biopsy is performed to determine the underlying pathology.

Prognosis

The prognosis for successful surgical treatment is best for dogs with extrahepatic shunts, for animals that undergo complete suture ligation or gradual occlusion with ameroid constrictors or cellophane bands, and for those animals that are presented with urinary tract signs and no hepatic encephalopathy.[1,25,33-35] Mortality rates after surgery are higher in animals with low albumin, high white blood cell counts, seizures, or intrahepatic shunts and in those that undergo acute partial shunt ligation.[1,25,26]

Half of dogs that undergo partial shunt ligation with suture develop clinical signs of portosystemic shunting within 2 years after ligation.[34] Some of these animals will respond to further ligation, while others have developed multiple acquired shunts or cannot tolerate further PSS occlusion. Clinical signs in these patients are controlled with lactulose and a protein restricted diet.

Cats commonly develop neurologic signs after surgery and may require continued treatment with phenobarbital. The prognosis is variable depending on the severity of preoperative clinical signs. After ameroid constrictor placement, acute complications occur in 25% to 75% of cats and excellent long term outcome is seen in 33% to 77%.[7,8] The mortality rate was 20% and recurrence of hepatic encephalopathy was noted in 30% to 40% of cats after acute suture ligation.[22]

References

1. Berent A, Tobias KM: Hepatic Vascular Anomalies. In Tobias KM, Johnston S: Veterinary Surgery: Small Animal. St. Louis IL, Elsevier, 2011, pp1624-1658.

2. Hunt GB, Bellenger CR, Borg R, et al. Congenital interruption of the portal vein and caudal vena cava in dogs: six case reports and a review of the literature. Vet Surg 1998;3:203-215.

3. Tobias KM, Rohrbach BW. Proportional Diagnosis of Congenital Portosystemic Shunts in Dogs Accessed by Veterinary Teaching Hospitals: 1980-2002. J Am Vet Med Assoc 2003;223:1636-1639.

4. Tobias KM. Determination of heredity of single congenital portosystemic shunts in Yorkshire terriers. J Am Anim Hosp Assoc 2003;39:385-389.

5. van Straten G, Leegwater PAJ, de Vries M, et al. Inherited congenital extrahepatic portosystemic shunts in Cairn terriers. J Vet Intern Med 2005;19:321-324.

6. Ubbink GJ, van de Broek J, Meyer HP, et al. Prediction of inherited portosystemic shunts in Irish Wolfhounds on the basis of pedigree analysis. Am J Vet Res 1998;59:1553-1556.

7. Lipscomb VJ, Jones HJ, Brockman DJ: Complications and long-term outcomes of the ligation of congenital portosystemic shunts in 49 cats. Vet Rec 2007;160:465-470.

8. Kyles AE, Hardie EM, Mehl M, et al. Evaluation of ameroid ring constrictors for the management of single extrahepatic portosystemic shunts in cats: 23 cases (1996-2001). J Am Vet Med Assoc 2002;220:1341-1347.

9. Holt D. Critical care management of the portosystemic shunt patient. Compend Contin Educ Pract Vet 1994;16:879…892.

10. Maddison JE. Hepatic encephalopathy. Current concepts of the pathogenesis. J Vet Int Med 1992 ;6:341-353.

11. Allen L, Stobie D, Mauldlin, et al. Clinicopathologic features of dogs with hepatic microvascular dysplasia with and without portosystemic shunts; 42 cases (1991-1996). J Am Vet Med Assoc 1999;214:218-220.

12. Niles JD, Williams JM, Cripps PJ. Hemostatic profiles in 39 dogs with congenital portosystemic shunts. 2001;30:97-104.

13. Phillips L, Tappe J, Lyman R, et al. Hepatic microvascular dysplasia in dogs. Progr Vet Neurol 1996;3:88-96.

14. Scrivani PV, Yeager AE, Dykes NL, et al. Influence of patient positioning on sensitivity of mesenteric portography for detecting an anomalous portosystemic blood vessel in dogs: 34 cases (1997-2000). J Am Vet Med Assoc 2001;219:1251-1253.

15. Watson PJ, ME Herrtage. Medical management of congenital portosystemic shunts in 27 dogs–a retrospective study. J Small Anim Pract 1998;39:62-68.

16. Greenhalgh SN, Dunning MD, McKinley TJ, et al: Comparison of survival after surgical or medical treatment in dogs with a congenital portosystemic shunt. J Am Vet Med Assoc 236:1215, 2010.

17. Tobias KMS, Seguin B, Johnston G. Surgical approaches to single extrahepatic portosystemic shunts. Compend Contin Educ Pract Vet 1998;20:593-601.

18. Tobias KMS, Rawlings CA. Surgical techniques for extravascular occlusion of intrahepatic shunts. Compend Contin Educ Pract Vet 1996;18:745-755.

19. Mathew K, Grofton N. Congenital extrahepatic portosystemic shunt occlusion in the dog: gross observation during surgical correction. J Am Anim Hosp Assoc 1988;24:387-394.

20. Swalec KM, Smeak DD. Partial versus complete attenuation of single portosystemic shunts. Vet Surg 1990;19:406-411.

21. Schulz KS, Martin RA, Henderson RA. Transplenic portal catheter-

ization. Surgical technique and use in two dogs with portosystemic shunts. Vet Surg 1993;22:363-369.

22. Wolscrijn CF, Mahapokai W, Rothuizen J, et al. Gauged attenuation of congenital portosystemic shunts: Results in 160 dogs and 15 cats. Vet Quart 2000;22:94-98.

23. Kummeling A, van Sluijs FJ, Rothuizen J. Prognostic implications of the degree of shunt narrowing and of the portal vein diameter in dogs with congenital portosystemic shunts. Vet Surg 2004;33:17-24.

24. Sereda CW, Adin CA. Methods of gradual vascular occlusion and their applications in treatment of congenital portosystemic shunts in dogs: a review. Vet Surg 2005;34:83-91.

25. Mehl ML, Kyles AE, Hardie EM, et al. Evaluation of ameroid ring constrictors for treatment for single extrahepatic portosystemic shunts in dogs: 168 cases (1995-2001).

26. Hunt GB, Kummeling A, Tisdall PLC, et al. Outcomes of cellophane banding for congenital portosystemic shunts in 106 dogs and 5 cats. Vet Surg 2004;33:25-31.

27. Frankel D, Seim H, MacPhail C, et al. Evaluation of cellophane banding with and without intraoperative attenuation for treatment of congenital extraheptaic portosystemic shunts in dogs. J Am Vet med Assoc 2006;228:1355-1360.

28. Adin CA, Sereda CW, Thompson MS, et al. Outcome associated with use of a percutaneously controlled hydraulic occluder for treatment of dogs with intrahepatic portosystemic shunts. J Am Vet Med Assoc 2006;229:1749-1755.

29. Weisse C, Berent AC, Todd K, et al. Endovascular evaluation and treatment of intrahepatic portosystemic shunts in dogs: 100 cases (2001-2011). J Am Vet Med Assoc 2014;244:78-94.

30. Fryer KJ, Levine JM, Peycke LE, et al: Incidence of postoperative seizures with and without levetiracetam pretreatment in dogs undergoing portosystemic shutn attenuation. J Vet Intern Med.

31. Tisdall PLC, Hunt GB, Youmans KR, et al. Neurological dysfunction in dogs following attenuation of congenital extrahepatic portosystemic shunts. J Small Anim Pract 2000;41:539-546.

32. Heldmann E, Holt DE, Brockman DJ, et al. Use of propofol to manage seizure activity after surgical treatment of portosystemic shunts. J Small Anim Pract 1999;40:590-594.

33. Harvey J, Erb HN. Complete ligation of extrahepatic congenital portosystemic shunts in nonencephalopathic dogs. Vet Surg 1998;27:413-416.

34. Hottinger HA, Walshaw R. Long-term results of complete and partial ligation of congenital portosystemic shunts in dogs. Vet Surg 1995;24:331-336.

35. Murphy ST, Ellison GW, Long M, et al. A comparison of the ameroid constrictor versus ligation in the surgical management of single extrahepatic portosystemic shunts. J Am Anim Hosp Assoc 2001;37:390-396.

Cellophane Banding of Portosystemic Shunts

Geraldine B. Hunt

Background

Most congenital portosystemic shunts cannot be completely ligated at the time of surgery because of the risk of inducing life-threatening portal hypertension. Placement of devices to produce gradual progressive occlusion is now considered by most surgeons to be the treatment of choice. A variety of methods of gradual occlusion have been evaluated clinically and experimentally, including cellophane bands,[1-3] ameroid constrictors,[4-9] thrombogenic coils[2,10] and hydraulic occluders.[11]

Cellophane is a transparent flexible cellulose sheeting widely used in the packaging industry. It creates a foreign body reaction when implanted into the body of dogs. When placed around a blood vessel, cellophane promotes gradual progressive occlusion of the vessel by direct pressure of the developing fibrous tissue. Cellophane has been used for vessel occlusion in experimental animals for many years[12] and had a role in human surgery at one stage, as a means of supporting vascular aneurysms and as a non-permeable barrier to discourage adhesions around joints.[13] Cellophane was first reported for attenuation of a congenital portosystemic shunt in a dog in 1990[14] and its use has been reported subsequently in larger case series.[1,3] Studies by Youmans and Hunt showed progressive reduction in diameter of the femoral vein from 5 mm to 2 mm in dogs after application of cellophane bands.[2] For this reason, cellophane band diameters of no more than 3 mm are usually applied to the target vessel. However, a previous report,[15] anecdotal observations and the author's own experiences indicate that larger bands are capable of promoting complete vessel occlusion in some animals.

Equipment

Cellophane is acquired in sheet form from a stationer or paper company. It should be strong enough to withstand handling, but not sufficiently thick to cause kinking of the fragile shunt vessel. Recent work has shown that the clear films reported for portosystemic shunt attenuation are not always cellophane.[18] Nevertheless, polypropylene and polyethylene have yielded similar results, possibly due to the irritant effect of chemicals used during processing. Prior to implantation, the surgeon should check which particular clear film they are using. Cellophane strips should be cut parallel to the fiber orientation to preserve its breaking strength. Cellophane should be sterilized by autoclave, as this best preserves its strength once the band becomes wet with saline or body fluids. The best method of sterilization for synthetic polymers has yet to be determined. Gauging devices of various diameters are fashioned from surgical pins or connecting bars, bent at right angles and with their ends filed to a blunt tip if necessary. In most cases, a range between 2 mm and 1 cm is satisfactory. Medium-sized titanium surgical ligating clips are used to secure the cellophane band around the shunt. A water manometer is used to monitor changes in portal pressure during cellophane application in dogs weighing more than 10 kg. Right angled dissecting forceps (Debakey bile duct forceps) and Adson tissue foceps assist mobilization of the shunt and passage of materials around it.

Surgical Technique

Surgery is performed through a ventral midline celiotomy incision. The incision extends ventral to the xiphoid process of the sternum and the linea alba is divided to expose the xiphoid at the level of its cranial connection to the pectoral muscles. Care is taken when dividing the falciform ligament as shunts have occasionally been encountered in this location.

Initially, the abdominal viscera is retracted to the right using the mesocolon and the paravertebral gutter and left kidney are examined to rule out the presence of multiple acquired shunts that result from portal hypertension. The crura of the diaphragm is examined to determine whether a portoazygous shunt is present.

The abdominal viscera is then retracted to the left using the mesoduodenum and the caudal vena cava examined for the presence of abnormal veins emptying into it. The cava should be visualized from its origin at the confluence of the common iliac veins to the area cranially where it deviates to pass dorsad to the liver. The right and left renal veins, gonadal veins and phrenicoabdominal veins should be the only vessels entering the caudal vena cava within the cranial abdominal cavity. Any vessel terminating in the vena cava cranial to the phrenicoabdominal veins is abnormal. Dilation and obvious turbulence visualized through the thin wall of the cava may be indicative of an abnormal vessel. However, turbulence can occur as a normal finding at the point of entry of the renal veins in some animals. The caudal vena cava should be inspected as it crosses the liver to ensure that it does not continue forward as the azygous vein.

Particular attention is directed to the area of the epiploic foramen. The epiploic foramen is dorsal to the duodenum and is created by the fold of tissue containing the hepatic artery and portal vein ventrally and bounded by the vena cava dorsally. A small, flat-bladed retractor is placed dorsal to the hepatic artery into the foramen and elevated to visualize the left side of the vena cava. Extrahepatic portosystemic shunts are commonly detected entering the vena cava in this location.

The hepatic portal vein should be examined as it courses adjacent and ventral to the hepatic artery to arborize at the porta hepatis of the liver. Portal vein branches can be identified that supply the right lateral, right medial and left liver lobes. Dilation of one of these branches may indicate the presence of an intrahepatic shunt. *Dilatation of all portal vessels simultaneously may signify portal hypertension, rather than increased portal flow.*

If a shunt has not been identified within the epiploic foramen, the abdominal viscera are returned to their normal position and an opening created in the ventral leaf of the omentum to visualize the omental bursa. The stomach is retracted cranially to inspect the left gastric, splenic and pancreaticoduodenal veins. Dilation of one of these vessels usually indicates the presence of an extrahepatic shunt. Identify the portal branch giving rise to the dilated vessel and follow it to its point of entry into the systemic circulation.

If it is not possible to confidently identify an extrahepatic shunt, consider the likelihood of an intrahepatic shunt, or microvascular dysplasia. If a portoazygous shunt is suspected, the crura of the diaphragm may be divided to allow visualization of the caudal mediastinum.

Once the shunt has been identified, the viscera should be retracted so as to provide maximum access for dissection and attenuation of the vessel. Exposure of the shunt varies according to specific shunt anatomy but in most cases, portocaval shunt dissection is easiest when performed through the epiploic foramen. For portoazygous shunts, dissection is usually easiest from a left approach with the viscera retracted to the right. Attenuation of any shunt should take place as close as possible to the systemic vascular system so as to ensure that small portal branches do not enter distal to the attenuation point.

Determining Cellophane Band Diameter

The shunt vessel should be dissected free from surrounding fat and connective tissue. A suture of 2-0 or 0 polypropylene is passed around the vessel to facilitate further attenuation at a later date should the cellophane band not promote complete shunt occlusion. Baseline physiologic parameters are measured including heart rate, direct or indirect systolic arterial pressure and central venous pressure. The color of the pancreas and intestines, and intestinal motility are assessed prior to placement of the cellophane band. In dogs heavier than 10 kg, and those with intrahepatic shunts, a jejunal vein is catheterized to permit measurement of portal pressure using a water manometer during band placement and tightening.

The polypropylene suture is tightened so as to occlude the shunt completely and measurement of the previously described physiologic parameters repeated. Elevation of the heart rate by more than 20 beats per minute, a fall in systolic arterial pressure of more than 10 mm Hg, a fall in central venous pressure of more than 1 mm Hg, or a rise in portal pressure of more than 10 cm H_20 (to a maximum of 20 cm H_20) all signify inability to completely occlude the shunt.

Congestion and cyanosis of the pancreas and intestines, and a substantial increase in intestinal motility are also considered indications of unacceptable portal hypertension.

In animals weighing 10 kg or less, cellophane bands between 2 and 3 mm diameter are usually placed around the shunt. A 3 mm band is placed if the shunt is not amenable to total occlusion. If mild to moderate changes in baseline hemodynamic parameters and intestinal color and motility are observed, a 2.5 mm band is placed. If no change is observed, a 2 mm band is applied. In dogs weighing 10 kg or more, the band diameter is dictated by changes in portal pressure, as for other forms of attenuation. Cellophane bands between 2 and 3 mm diameter result in substantial shunt attenuation, however, life-threatening portal hypertension necessitating removal of the cellophane band has only been seen in one small dog (a Bichon Frise in which a small thrombus embolized to the attenuation site 3 days after surgery). Wider cellophane bands may also cause complete eventual occlusion, but this has not been proven in an experimental setting.

Preparation and Placement of the Cellophane Band

Following identification and mobilization of the shunt, a strip of cellophane 1.2 cm wide and about 15 cm long is folded lengthwise to produce a 3-layered band 4 mm in width and 15 cm in length. The end of the cellophane is cut obliquely to facilitate passage around the shunt.

The cellophane band is passed gently around the shunt, incorporating as little perivascular tissue as possible (Figure 21-16A). The cellophane is easily torn when wet, so manipulation of the band should be minimized once it is in place around the vessel.

The surgeon should hold both ends of the band between thumb and forefinger and insert a stainless steel pin of appropriate diameter inside the band, next to the shunt vessel (Figure 21-16B). Hemostatic clips are then applied while the cellophane band is held tight around both the pin and the shunt (Figure 21-16C). Recent work has shown that the resistance to tensile forces of the clip-cellophane configuration increases when multiple clips are alternately applied from opposing directions.[19] In practice, the forces applied to the cellophane band following implantation are low, and placement of two clips with opposing orientations should be sufficient. This results in creation of a cellophane band of the required diameter. The stainless steel pin is withdrawn, allowing the shunt to expand inside the cellophane band to the predetermined diameter (Figure 21-16D). One of the original research studies[4] showed that the diameter tended not

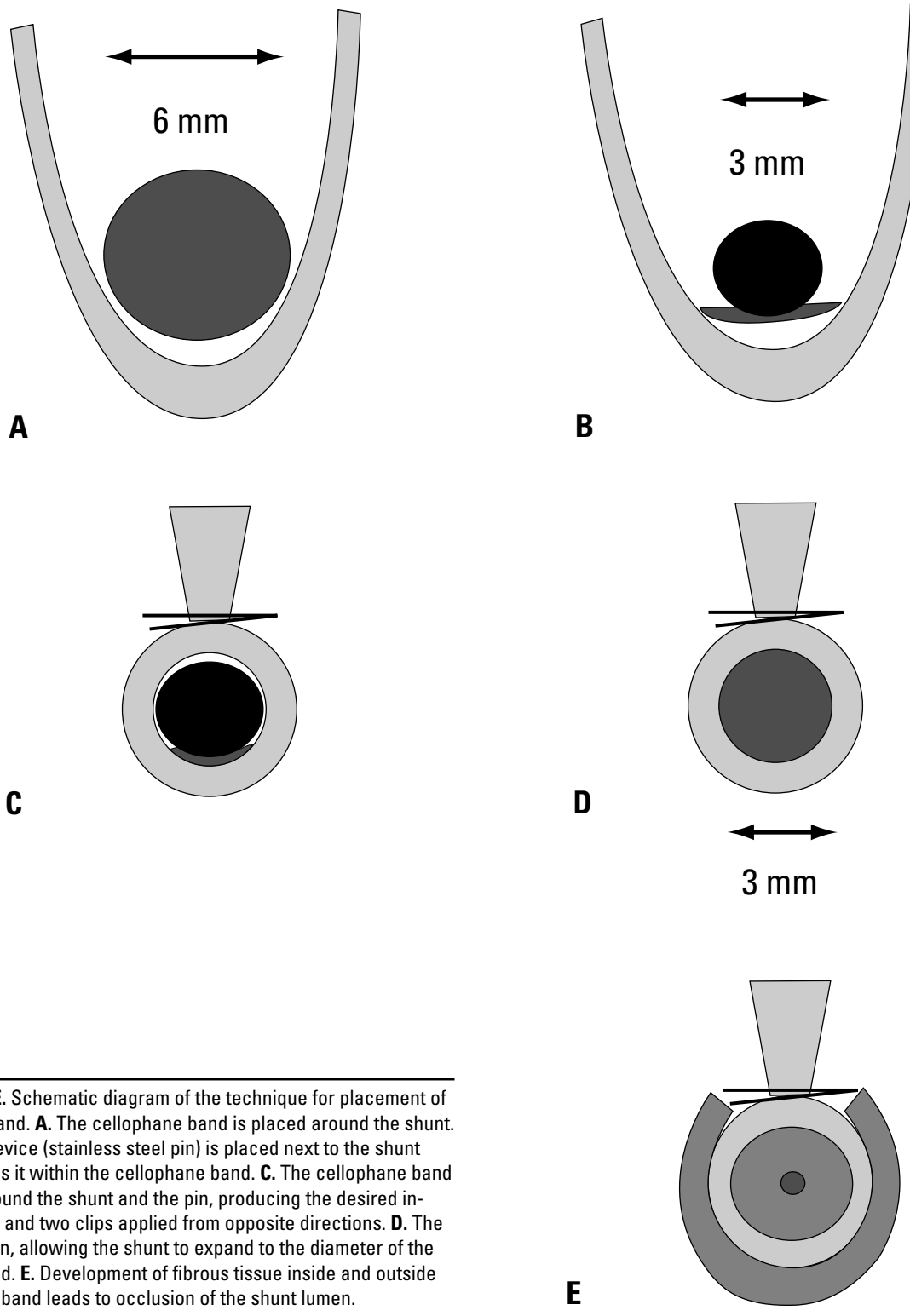


Figure 21-16A-E. Schematic diagram of the technique for placement of a cellophane band. **A.** The cellophane band is placed around the shunt. **B.** A gauging device (stainless steel pin) is placed next to the shunt and compresses it within the cellophane band. **C.** The cellophane band is tightened around the shunt and the pin, producing the desired internal diameter and two clips applied from opposite directions. **D.** The pin is withdrawn, allowing the shunt to expand to the diameter of the cellophane band. **E.** Development of fibrous tissue inside and outside the cellophane band leads to occlusion of the shunt lumen.

to decrease by more than 3 mm following cellophane band application, and hence it is recommended that this diameter not be exceeded in smaller patients. However, other researchers[6] have shown that placement of loose bands that do not constrict the shunt may be preferable in larger patients. It should be noted, however, that the clear film used in these other reports was not cellophane, and may therefore behave differently to cellophane in clinical patients.

Haemodynamic measurements are repeated and the intestine and pancreas inspected to ensure that safe portal pressures have not been exceeded. The ends of the cellophane are cut, so as to leave 1 mm protruding beyond the surgical clip. The cellophane band is gently rotated to ensure it does not kink the shunt or adjacent vessels. The polypropylene suture is tied loosely and cut to leave 4 cm ends. This enables identification of the shunt if subsequent surgery is required due to persistent signs of hepatic dysfunction or portosystemic shunting. The polypropylene suture may be pulled tight during later surgery to check whether the original shunt is closed or patent, thus avoiding the necessity of dissecting through fibrous tissue. The polypropylene suture may be tightened if necessary without having to disturb the shunt itself. The need for a second surgery is rare following cellophane banding of portosystemic shunts.

Postoperative Care

The abdomen is lavaged with warm saline and the celiotomy wound closed routinely. Animals are monitored intensively for the first 72 hours after surgery, which is considered the high risk period for seizures and portal hypertension. A broad spectrum antibiotic is administered perioperatively. Phenobarbital is given as a premedication 30 minutes before surgery (10 mg/kg intramuscularly) and continued for 72 hours postoperatively (2 to 5 mg/kg twice daily by injection or *per os*). If the animal experienced generalized motor seizures before surgery, phenobarbital is continued for approximately four weeks postoperatively and the dose then tapered. Animals are maintained on a commercially available restricted protein diet (Hills L/D) for the first 4 weeks after surgery. No other medical management is used unless animals show signs of hepatic encephalopathy (rare). If the patient is clinically normal four weeks after surgery, the owners are instructed to gradually return them to the original diet they were eating before they experienced clinical signs. If the patient shows signs of hepatic encephalopathy, medical management with restricted protein diet, lactulose syrup (0.5 ml/kg twice daily) and antibiotics is resumed. Analysis of liver function using ammonia tolerance testing, serum bile acid determination or scintigraphy is recommended two months after surgical attenuation of the shunt. Follow up of patients demonstrating continued liver dysfunction should include some form of imaging (ideally contrast-enhanced computer tomography) to differentiate the cause of persistent shunting and determine the best management plan.

Summary

Results of cellophane banding have been reported by several authors.[5-8] The mortality rate is up to 5.5%, largely resulting from portal hypertension and post ligation neurological dysfunction. Liver function returned to normal postoperatively in 85% of dogs and 60% of cats. Reasons for continued liver dysfunction include failure of the shunt to close, inappropriate placement of the cellophane band, and development of acquired shunts.[7,9] This was similar to reported results for a series of 127 dogs that underwent placement of ameroid constrictors in dogs[7] and cats.[10,11] The survival rate and resolution of hepatic dysfunction were lower in dogs with intrahepatic shunts versus those with extrahepatic shunts. Follow up of an additional 33 dogs subsequent to the cases reported above[3] confirms the low mortality rate (1 dog, 3%). This dog (a Bichon Frise) was the only animal that experienced post ligation neurological disorder and was euthanized as a result of uncontrollable seizures that commenced 70 hours after shunt attenuation. No instances of life-threatening portal hypertension were encountered. Cellophane banding continues to yield poorer results in cats than in dogs, for reasons that are not entirely clear.[8]

References

1. Harari J, Lincoln J, Alexander J, et al. Lateral thoracotomy and cellophane banding of a congenital portoazygous shunt in a dog. J Sm Anim Pract 31: 571, 1990.

2. Connery NA, McAllister H, Skelly C, Pawson P, Bellenger CR: Cellophane banding of congenital intrahepatic portosystemic shunts in two Irish wolfhounds. Journal of Sm Anim Pract 43: 345-349, 2002.

3. Youmans KR, Hunt GB: Cellophane banding for the gradual attenuation of single extrahepatic portosystemic shunts in eleven dogs. Aust Vet J 76: 1998.

4. Youmans KR, Hunt GB: Experimental evaluation of four methods of progressive venous attenuation in dogs. Vet Surg 28: 531, 1999.

5. Hunt GB, Kummeling A, Tisdall PLC, et al.: Outcomes of cellophane banding for congenital portosystemic shunts in 106 dogs and 5 cats. Vet Surg 33: 25, 2004.

6. Frankel D, Seim H, Macphail C, et al: Evaluation of cellophane banding with and without intraoperative attenuation for treatment of congenital extrahepatic portosystemic shunts in dogs. J Am Vet Med Assoc 228: 1355, 2006.

7. Landon BP, Abraham LA, Charles JA: Use of transcolonic portal scintigraphy to evaluate efficacy of cellophane banding of congenital extrahepatic shunts in 16 dogs. Aust Vet J 86: 169, 2008.

8. Cabassu J, Seim HB III, MacPhail C, et al: Outcomes of cats undergoing surgical attenuation of congenital extrahepatic portosystemic shunts through cellophane banding: 9 cases (2000-2007). J Am Vet Med Assoc 238: 89, 2011.

9. Nelson NC, Neslon LL: Anatomy of extrahepatic portosystemic shunts in dogs as determined by computed tomography angiography. Vet Rad Ultrasound, 52, 498, 2011.

10. Vogt J, Krahwinkel DJ, Bright RM, et al.: Gradual occlusion of extrahepatic portosystemic shunts in dogs and cats using the ameroid constrictor. Vet Surg 25: 495, 1996.

11. Havig M TK: Outcome of ameroid constrictor occlusion of single extrahepatic portosystemic shunts in cats: 12 cases (1993-2000). J Am Vet Med Assoc 220: 337, 2002.

12. Kyles AE HE, Mehl M, Gregory CR: Evaluation of ameroid ring constrictors for the management of single extrahepatic portosystemic shunts in cats: 23 cases (1996-2001). J Am Vet Med Assoc 220: 1341, 2002.

13. Mehl ML , Kyles AE, Hardie EM, ety al: Evaluation of ameroid ring constrictors for treatment of single extrahepatic portosystemic shunts in dogs: 168 cases (1995-2001). J Amer Vet Med Assoc 226, 2020-2030, 2002.

14. Falls EL, Milovancev M, Hunt GB et al: Long term outcome after

surgical ameroid ring constrictor placement for treatment of single extrahepatic portosystemic shunts in dogs. Vet Surg 42: 951, 2013.

15. Leveille R JS, Birchard SJ: Transvenous coil embolization of portosystemic shunt in dogs. Vet Radiol Ultrasound 44: 32, 2003.

16. Sereda CW, Adin CA, Ginn PE, Farese JP: Evaluation of a percutaneously controlled hydraulic occluder in a rat model of gradual venous occlusion. Vet Surg 34: 35, 2005.

17. Stone PW MR: A method for experimental production of gradual occlusion of the portal vein. Proc Soc Exp Biol Med 72: 255, 1949.

18. Harley GH BL: Cellophane in surgery. Am J Surg 68: 229, 1945.

19. Smith RR, Hunt GB, Garcia-Nolen TC, et al: Spectroscopic and mechanical evaluation of thin film commonly used for banding congenital portosystemic shunts in dogs. Vet Surg 42 (4), 478-87, 2013.

20. McAlinden AB, Buckley CT, Kirby BM. Biomechanical evaluation of different numbers, sizes, and placement configurations of ligaclips required to secure cellophane bands. Vet Surg 39: 59, 2010.

Pancreatic Surgery

Elizabeth Hardie

Introduction

In general, surgeons prefer to avoid the pancreas, because manipulation may incite inflammation and pancreatitis. The blood supply of the pancreas is intimately connected to that of the duodenum, which makes pancreatic resection technically challenging. However, there are some indications for surgery on the pancreas.[1,2] Pancreatic biopsy is used to confirm pancreatic disease. Nodule removal or partial pancreatectomy is used to treat insulinoma, other endocrine tumors, and pancreatic carcinoma. Complete pancreatectomy has been used mainly as a research surgery to create diabetic models, but may be performed in animals with intractable chronic pancreatitis. Acute pancreatitis is not treated surgically, but may require placement of a jejunostomy tube for enteral feeding. The intimate relationship of the pancreatic duct and the bile duct as they enter the duodenum means that inflammation or scarring of pancreatic tissue may compress the bile duct, and stenting or diversion of the biliary tract may be needed in animals with pancreatitis. The pancreas can develop cysts or abscesses, and drainage or resection may be needed to resolve clinical signs related to these fluid accumulations.

Pancreatic Anatomy

The pancreas is a bilobed organ that sits in the angle between the duodenum and the greater curvature of the stomach. The portion of the gland lying along the duodenum is termed the right lobe, while the portion lying adjacent to the stomach is the left lobe. The portion where the two lobes join is the body. The right lobe lies within the duodenal mesentery. The more distal aspect of the right lobe can be separated from the duodenum, but the gland is tightly adherent to the duodenum in the region of the body. The left lobe lies within the dorsal sheet of the greater omentum. Accessory pancreatic tissue may occur in the region of the gall bladder or mesentery in the dog.[3]

Exocrine secretions from pancreatic tissue are carried by ducts that run along the center of each pancreatic lobe (Figure 21-17).

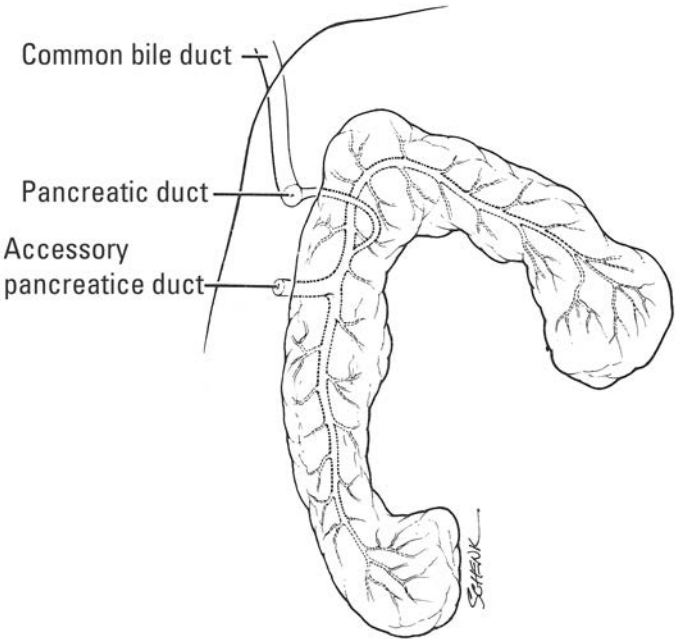


Figure 21-17. The pancreatic excretory ducts.

There is significant anatomic variation between individuals and between species in the number and location of the principal pancreatic ducts that carry pancreatic secretions to the duodenum.[1,3] In most dogs, there are two ducts entering the duodenum. The pancreatic duct is in the body of the pancreas and enters the duodenum, along with the bile duct, at the major duodenal papilla. The second duct, the accessory pancreatic duct, is further distal in the right pancreatic lobe and enters the duodenum at the minor duodenal papilla. In most dogs, the accessory pancreatic duct is the larger duct and drains both lobes of the pancreas, while the pancreatic duct is small and only carries a small amount of secretions. Variations include the presence of three ducts (two opening at the minor papilla and one at the major papilla) and completely separate ducts for the right and left lobes. In the cat, the pancreatic duct is the larger duct, joining the bile duct and entering the duodenum at the major duodenal papilla. Eighty percent of cats do not have an accessory pancreatic duct or a minor duodenal papilla. Ferrets are similar to cats, but the accessory pancreatic duct is present more often.[4] Pancreatic bladders, which are dilations off the pancreatic duct, have been reported in cats.[3]

The blood supply to the right lobe of the pancreas comes from the cranial and caudal pancreaticoduodenal arteries, which anastomose in the right lobe (Figure 21-18). The cranial pancreaticoduodenal artery is a branch of the gastroduodenal artery, while the caudal pancreaticoduodenal artery is a branch of the cranial mesenteric artery. The left lobe of the pancreas is supplied by the splenic artery and small branches off the hepatic artery. Venous blood drains to the portal vein through the pancreaticoduodenal veins and the splenic vein. Lymphatic drainage goes to the pancreaticoduodenal, hepatic, jejunal and splenic lymph nodes.[3]

Pancreatic Biopsy

Pancreatic biopsy is performed to diagnose or confirm pancreatic disease.[1,5] Chronic low-grade pancreatitis must be differentiated

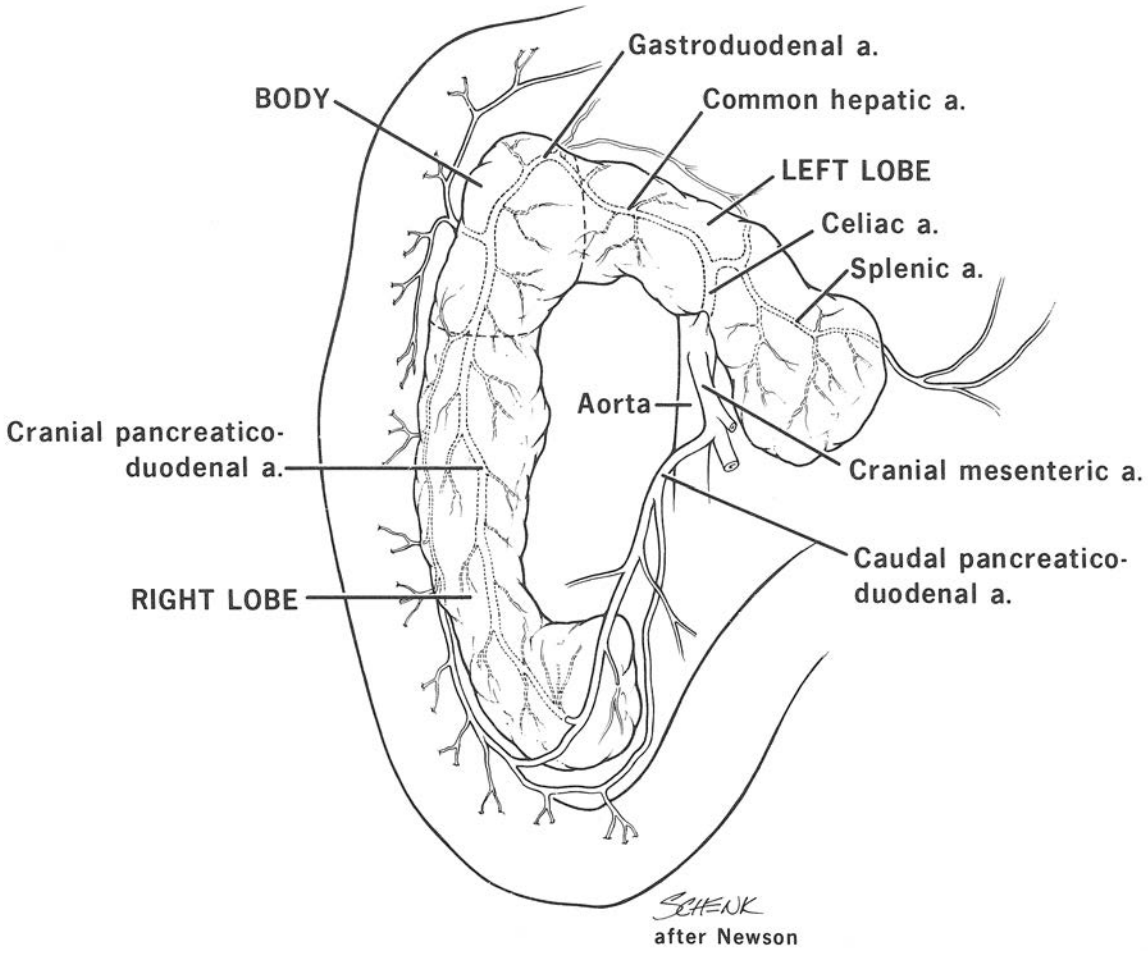


Figure 21-18. The pancreatic arterial supply.[5]

from other causes of chronic gastrointestinal disease. Chronic pancreatitis may only be apparent microscopically and may be multifocal rather than diffuse, requiring several small biopsies to confirm or deny a diagnosis.[6] In animals with macroscopic disease of the pancreas, biopsy is used to differentiate between diseases such as chronic pancreatitis, pancreatic carcinoma, and pythiosis. Leiomyosarcoma of the duodenal wall may invade the pancreas through the shared blood supply.

If the biopsy is being obtained from a grossly normal pancreas, it is usually taken at the distal aspect of the right lobe of the pancreas because of the ease of exposure and low risk of inciting pancreatitis. If the biopsy is obtained laparoscopically, a small piece of tissue is removed using cup biopsy forceps.[7] If needed, hemorrhage is controlled with gentle pressure or a piece of Gelfoam. When the biopsy is taken as part of an exploratory laparotomy, an encircling ligature of a monofilament suture is placed around a portion of the distal lobe. The ligature is tightened and the tissue is removed. If multiple small samples of pancreatic tissue are needed, hemostatic clips can be used to occlude the vessels supplying the tissue which is then excised distal to the clip. The mutilobular nature of pancreatic tissue makes this a relatively easy procedure, but small delicate instruments and magnification are helpful when isolating a lobule. The major ducts and vessels should be avoided, thus biopsies are most safely taken at the edges of the gland opposite the duodenum and the stomach. The mesentery or omentum overlying the portion of the pancreas to be biopsied must be incised to expose the tissue.

Partial Pancreatectomy and Nodule Removal

Partial pancreatectomy is most commonly used to treat insulin secreting beta cell tumor (insulinoma), but there is confusion in the veterinary literature over the term partial pancreatectomy.[2,8] The term has been used to describe neoplastic nodule removal (enucleation), nodule removal with removal of a border of normal pancreatic tissue, and removal of most of one lobe of the pancreas. The term should probably be reserved for removal of most of one lobe. In general, pancreatic neoplastic nodules should be removed with a border of normal tissue, which is most easily accomplished by removing the nodule and the lobe of the pancreas distal to the nodule. In ferrets, it has been shown that animals with beta-cell tumors treated with partial pancreatectomy survive longer than animals treated with enucleation.[8] Enucleation should be reserved for animals with nodules in the body of the pancreas. If the nodule in the body is large or is in a difficult location, it may be preferable to biopsy the nodule using a needle biopsy technique and forego nodule removal in favor of medical therapy (frequent feeding, corticosteroids, diazoxide, octreotide, streptozocin).[2,9,10] The risk of pancreatitis is higher when extensive or prolonged dissection of the body is performed.

The technique for partial pancreatectomy differs for the two

lobes of the pancreas. For the right lobe, dissection is begun at the distal aspect of the lobe, where the pancreaticoduodenal vessels are most easily visualized. The mesentery is incised and the distal pancreas is grasped. The dissection proceeds towards the pylorus, and care is taken to protect the pancreaticoduodenal vessels. Hemoclips or bipolar cautery are used to control bleeding from small branches of the pancreaticoduodenal vessels entering the pancreas. The pancreas becomes more tightly associated with the duodenum as the dissection proceeds proximally, making isolation of the pancreaticoduodenal vessels more difficult. Blunt dissection using moistened cotton swabs or fine hemostats is used to separate the lobules from the vessels (Figure 21-19). In the dog, the right lobe can only be removed to the level of the accessory pancreatic duct, while in the ferret or the cat, the lobe can be removed to the level of the pancreatic duct. Once the desired portion of the pancreas is dissected free from its attachments, one of several techniques may be used to occlude the ducts. An encircling ligature can be placed around the organ, a stapling device can be used to compress the tissue, or fine hemostats can be used to bluntly remove glandular tissue from the vessels and ducts, which are then individually occluded with vascular clips or ligated. The distal portion of the gland is then removed. Any complete rent in the mesentery created by removal of the gland is directly repaired or is covered with an omental patch.

To gain exposure to the left lobe, the ventral leaf of the omentum is opened. The distal portion of the lobe is grasped and the relationship of the pancreas to the splenic and left gastroepiploic vessels is identified. The pancreatic arteries supplying the distal left lobe are branches off the splenic artery. The venous drainage of the left lobe of the pancreas is through two branches that enter the splenic vein. The various pancreatic vascular branches are occluded with vascular clips or ligated, while preserving the splenic vessels. If there is doubt about the integrity of the splenic vessels, splenectomy is performed. As the dissection proceeds towards the body, the branches of the hepatic artery that supply the pancreas must be ligated. Care is taken to preserve the celiac, left gastric, hepatic and gastroduodenal arteries. Once the vasculature is clipped or ligated, the pancreatic tissue is removed in a similar fashion to the right lobe.

Nodule removal is performed by bluntly dissecting the nodule from the surrounding tissue using cotton swabs or a fine hemostat. Hemorrhage from small vessels may be controlled using pressure or small vascular clips. Care is taken to preserve the major intestinal and pancreatic vessels and ducts. Ideally, a border of normal pancreatic tissue should be removed with the nodule.

If multiple pancreatic nodules are found, it may be necessary to use a combination of techniques to remove the nodules. If no nodules are found, intraoperative ultrasound may aid in identification. In dogs, injection of methylene blue has been used to help identify nodules, but the technique carries the risk of causing acute renal failure and is falling out of favor. Finally, if no nodules can be identified , pancreatic biopsy should be performed to rule out diffuse pancreatic beta cell tumor, a condition that occurs in < 5% of dogs with insulinoma.[2]

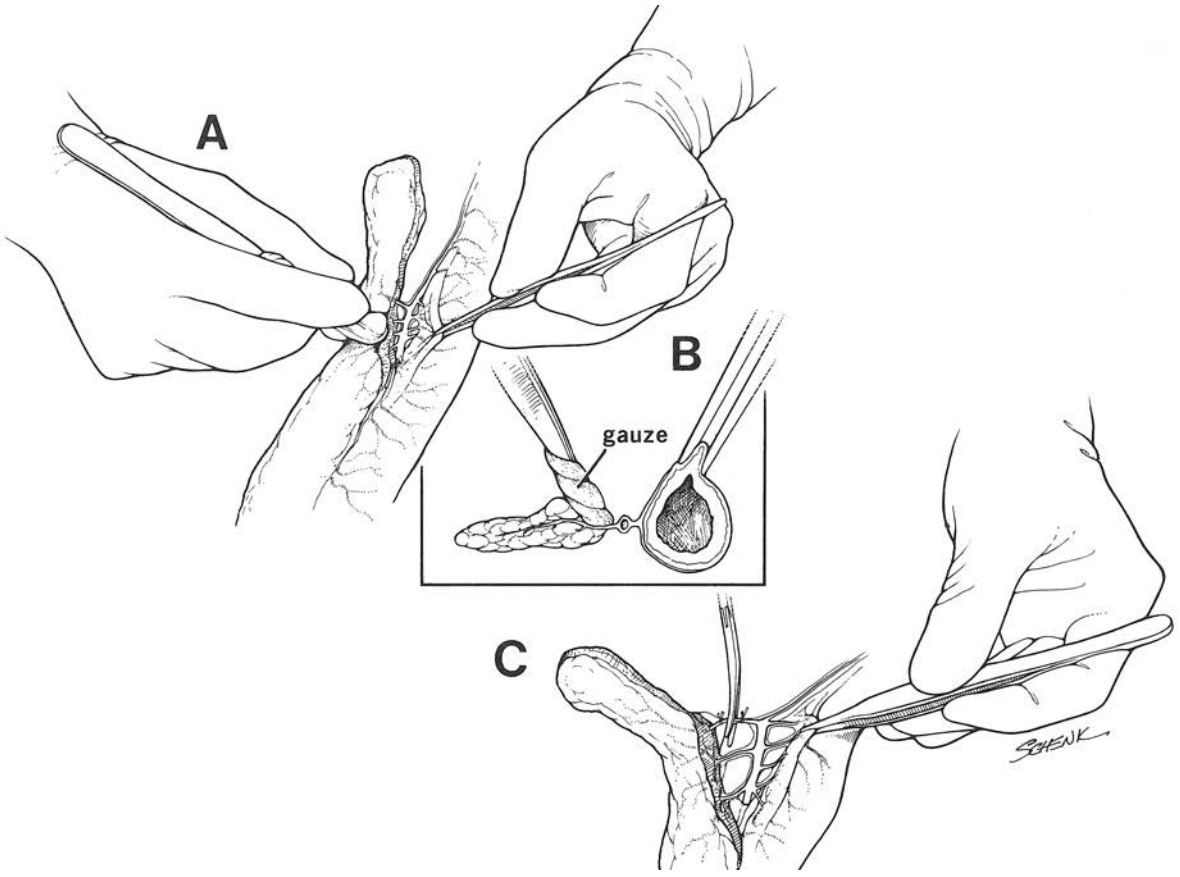


Figure 21-19. Pancreatectomy technique: separation of the pancreas from the duodenum.[5]

Most animals with insulinoma have microscopic or gross metastatic lesions present at the time of initial diagnosis. Metastasis is seen most commonly in regional lymph nodes and the liver. Since metastases are functional tumors it is important to identify and remove as many of the lesions as possible. It would be ideal if metatstatic lesions were identified before surgery, but surgical exploration is currently the most accurate method for identifying these lesions. Ultrasound, computed tomography and single photon emission computed tomography have all been used to identify primary and metastatic lesions, but no technique is superior to surgery.[11] The pancreaticoduodenal, hepatic, jejunal and splenic lymph nodes are carefully examined for enlargement. Precise, careful dissection using fine vascular instruments and magnification is often needed to remove an enlarged lymph node while preserving the vasculature to the intestines. Nodules within the liver can be removed with partial hepatectomy. If removal of the metastatic lesions is likely to endanger the life of the animal, it may be preferable to treat with medical therapy.

Pancreatic tumors other than insulinomas are rare. Endocrine tumors include gastrinomas, glucagonomas and other neuroendocrine cell tumors. Surgical treatment of these tumors is similar to that of insulinoma. Pancreatic carcinomas are often extensive at the time of diagnosis and are highly metastatic. Partial pancreatectomy can provide a period of remission from clinical signs if the primary tumor is localized to one lobe.[12]

Complete Pancreatectomy

Complete pancreatectomy is a formidable procedure and is rarely indicated. Removal of the entire pancreas produces an animal that is diabetic and has pancreatic exocrine insufficiency. Management of these patients requires an intelligent, dedicated owner, who can follow a detailed feeding, medication and glucose monitoring regime. The technique is similar to the technique for partial pancreatectomy, except that the dissection is carried around the body of the pancreas. The dissection is most commonly performed from the left to the right side. The pancreatic branches from the hepatic and gastroduodenal arteries are ligated. Blunt dissection is used to expose and preserve the pancreaticoduodenal vessels and the branches entering the pancreas are clipped or ligated. The pancreatic ducts are transected without ligation. After removal of the pancreas, the rent in the duodenal mesentery is closed.

Surgical Treatment of Pancreatitis

A recent consensus conference on the treatment of acute pancreatitis in people confirmed that surgical treatment of acute pancreatitis is not indicated unless confirmed bacterial abscess formation is present.[13] Studies in dogs have shown that animals treated with early enteral feeding rather than intravenous feeding during pancreatitis have reduced plasma endotoxin levels, decreased bacterial translocation to the portal and systemic blood, and improved measures of bowel wall health.[14] Jejunal feeding tubes can be placed during celiotomy or using minimally invasive surgery techniques. Acute pancreatitis can also lead to obstruction of the bile duct secondary to inflammation. Temporary choledochal stenting (See Hepatobiliary Surgery) is used to maintain biliary tract patency.[15] Animals with chronic pancreatitis can have obstruction of the bile duct secondary to scar formation and may need to be treated with a biliary diversion procedure.

Surgical Treatment of Pancreatic Cysts and Abscesses

Cystic fluid accumulations and abscesses can occur in pancreatic tissue, mainly in association with pancreatitis. Sterile abscesses may be the result of tissue necrosis. When a pancreatic fluid accumulation is observed on ultrasonic examination, needle aspiration is used to identify the fluid and may also be used to drain the accumulation. Cysts and sterile abscesses are not usually treated surgically, unless they are causing obstruction. Infected abscesses require surgical debridement and drainage.

The pancreatic region is carefully explored and the fluid accumulation is located. The wall of the cyst or abscess is removed. The region is flushed and debrided, if indicated. If available, omentum can be placed in the cavity to aid in drainage.[16] A silicone closed suction wound drain or a sump drain is placed to further drain the region.

Perioperative Care

Glucose control is an important part of perioperative management of an insulinoma patient. At the time of food withdrawal, an intravenous infusion of a balanced electrolyte solution containing 2.5-5% dextrose is begun. Infusion is continued through surgery and into the postoperative period. Large doses of dextrose may cause an exaggerated insulin response and should be avoided. After surgery, glucose must be monitored closely because hyperglycemia (8-35% of canine patients) and hypoglycemia (15-26% of canine patients) have been reported. The goal is to maintain a blood glucose between 40-200 mg/dL. If hyperglycemia persists after 48-72 hrs, insulin therapy may be needed.[2]

Animals should be kept well hydrated to help prevent the development of pancreatitis. Oral feeding may be delayed for 24-72 hours after surgery, depending on the extent of pancreatic manipulation. When food is reintroduced, small bland meals are fed. The animal is monitored closely for the development of nausea, vomiting, cranial abdominal pain or systemic inflammatory syndrome. Postoperative pancreatitis has been reported in 10-43% of canine patients undergoing nodule removal or partial pancreatectomy.[2] It is rare in ferrets.[8] If extensive dissection in the body of the pancreas is performed, a jejeunostomy tube should be placed prophylactically to allow early enteral feeding after surgery. Placement of a closed silicone abdominal drain in the region of the pancreas at the conclusion of surgery allows for rapid diagnosis of postoperative pancreatitis and aids in the management of abdominal effusion associated with pancreatitis.

References

1. Cornell KF, J. Surgery of the exocrine pancreas In: Slatter D, ed. *Textbook of Small Animal Surgery, third edition.* Philadelphia, PA: W.B. Saunders, 2003;p 752.

2. Kyles A. Endocrine Pancreas In: Slatter D, ed. *Textbook of Small Animal Surgery, third edition.* Philadelphia, PA: W. B. Saunders, 2003; p1724.

3. Miller ME CG, Evans HE. *Anatomy of the Dog.* Philadelphia: W. B. Saunders, 1964. p. 706.

4. Poddar S. Gross and microscopic anatomy of the biliary tract of the ferret. *Acta Anat (Basel)*;97:121, 1977.

5. Caywood D. Surgery of the Pancreas In: Bojrab M, ed. *Current Techniques in Small Animal Surgery 2nd edition.* Philadelphia: Lea & Febiger, 1983; p 232.

6. Newman S, Steiner J, Woosley K, et al. Localization of pancreatic inflammation and necrosis in dogs. *J Vet Intern Med* 18:488, 2004.

7. Harmoinen J, Saari S, Rinkinen M, et al. Evaluation of pancreatic forceps biopsy by laparoscopy in healthy beagles. *Vet Ther*;3:31, 2002.

8. Weiss CA, Williams BH, Scott MV. Insulinoma in the ferret: clinical findings and treatment comparison of 66 cases. *J Am Anim Hosp Assoc*;34:471, 1998.

9. Moore AS, Nelson RW, Henry CJ, et al. Streptozocin for treatment of pancreatic islet cell tumors in dogs: 17 cases (1989-1999). *J Am Vet Med Assoc*;221:811, 2002.

10. Robben JH, van den Brom WE, Mol JA, et al. Effect of octreotide on plasma concentrations of glucose, insulin, glucagon, growth hormone, and cortisol in healthy dogs and dogs with insulinoma. *Res Vet Sci* 2005, in press.

11. Robben JH, Pollak YW, Kirpensteijn J, et al. Comparison of ultrasonography, computed tomography, and single-photon emission computed tomography for the detection and localization of canine insulinoma. *J Vet Intern Med*;19:15, 2005.

12. Tasker S, Griffon DJ, Nuttall TJ, et al. Resolution of paraneoplastic alopecia following surgical removal of a pancreatic carcinoma in a cat. *J Small Anim Pract*;40:16, 1999.

13. Nathens AB, Curtis JR, Beale RJ, et al. Management of the critically ill patient with severe acute pancreatitis. *Crit Care Med*;32:2524, 2004.

14. Qin HL, Su ZD, Gao Q, et al. Early intrajejunal nutrition: bacterial translocation and gut barrier function of severe acute pancreatitis in dogs. *Hepatobiliary Pancreat Dis Int*;1:150, 2002.

15. Mayhew PD RR, Mehler SJ, Holt DE, Weisse. Choledochal tube stenting for decompression of extrahepatic biliary obstruction in dogs. *Proceedings of the American College of Veterinary Surgeons Veterinary Symposium* 2004:14.

16. Jerram RM, Warman CG, Davies ES, et al. Successful treatment of a pancreatic pseudocyst by omentalisation in a dog. *N Z Vet J* 2004;52:197, 2004.

Surgery of Pancreatic Neoplasia

James M. Fingeroth

Introduction

Many veterinarians are reluctant to touch, palpate, or operate on the pancreas because of concern for inducing pancreatitis. Leakage and activation of pancreatic enzymes caused by pancreatic trauma or surgery is possible and caution is indicated but it should not inhibit pancreatic manipulation in an appropriate manner when indicated. Pancreatic palpation, biopsy, and resection can all be performed safely, and proper post-operative patient management will minimize complications postoperatively.

Pancreatic examination should be part of every routine exploratory celiotomy. The right limb of the pancreas is easily visualized by identification and elevation of the descending duodenum toward the ventral midline from right to left during ventral midline celiotomy. The left limb can then be identified by tracing the right limb towards the angle (body), and retraction of the spleen. It can be helpful to perforate the greater omentum to better visualize and palpate the left limb of the pancreas as it courses dorsally along the greater curvature of the stomach. In the area of the angle and left limb of the pancreas the surgeon should also examine the regional lymph nodes since these may be affected by metastasis in cases of pancreatic neoplasia (Figure 21-20).

Because of the lobulated nature of the pancreatic parenchyma, and the tendency for the organ to sometimes fold on itself, examination of the pancreas should be both *visual* and *tactile* (See Figure 21-20). The latter requires the surgeon to gently palpate the organ between his or her fingers along its entire course. Small, but potentially significant lesions (e.g., islet cell tumors) may be missed if the pancreas is not palpated in addition to visual inspection.

On occasion the pancreas will be explored because a large mass has been identified on pre-operative imaging, or because of medically unresponsive pancreatitis. Surgeons should be familiar with the appearance of such lesions as pancreatic pseudocysts and abscesses when examining the pancreas at the operating table. Surgeons should especially be aware that inflammatory disease of the pancreas may appear aggressive and invasive. The organ may be diffusely enlarged, irregular, have varying color, and appear to invade into surrounding omental fat. This appearance may suggest a gross diagnosis of "extensive and unresectable malignant neoplasia", and may even prompt the surgeon to recommend immediate euthanasia. However, it is not uncommon for biopsies of aggressive appearing pancreatic lesions to reveal no evidence of neoplasia, and instead necrotizing/hemorrhagic inflammation along with local steatitis, adhesions, and fat saponification. While the diagnosis of necrotizing/hemorrhagic pancreatitis may prove to be a serious and potentially fatal diagnosis, it may still be manageable with appropriate therapy. The surgeon should not conclude that neoplasia is the diagnosis on the basis of appearance alone.

Similarly, it is common to see multifocal or diffuse small white spots in the pancreas, during exploratory celiotomy especially in older animals. These are usually not neoplastic or of any clinical significance. They usually represent areas of fibrosis. However, I have seen cases of lymphoma affecting the pancreas (albeit there are usually lesions beyond the pancreas as well in such cases), so any doubt or concern should be resolved with pancreatic biopsy.

Surgical Anatomy

The pancreas is coarsely lobulated with color that varies between a creamy white, to pink, to occasionally brownish-red (dependent on the amount of blood in the organ).[1] The right limb is molded to the duodenum with which it shares its blood supply (cranial and caudal pancreaticoduodenal artery; caudal pancreaticoduodenal vein). The "tightness" of this fit between the pancreas and duodenum varies from patient to patient. In some animals there is quite a bit of mesenteric tissue between

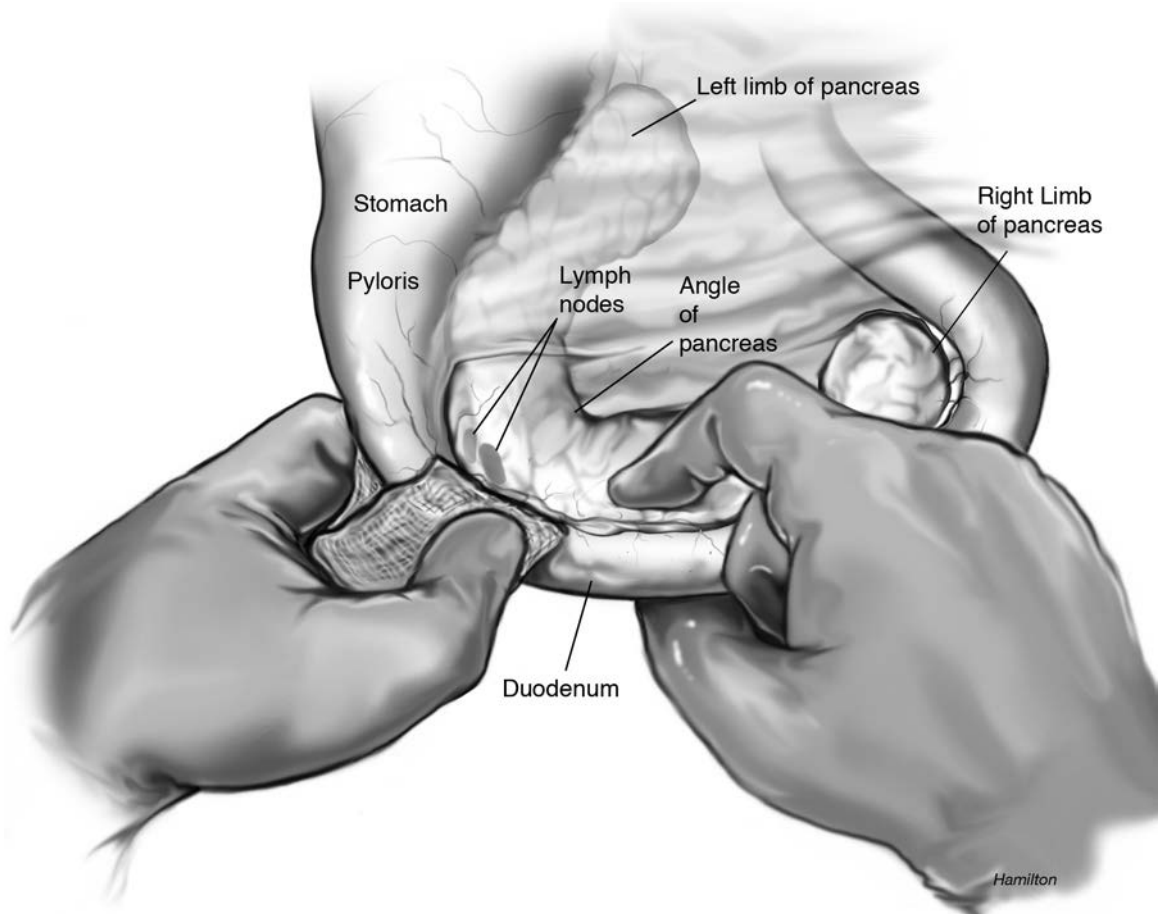


Figure 21-20. Pertinent anatomy for exploration of the pancreas. Arrows depict the right limb, left limb, angle, and approximate location of the pyloric lymph nodes. The pancreas may be gently palpated as shown to detect small masses that may be otherwise visually obscured. The entire organ should be examined, including the left limb which is located in the omental tissues caudal to the stomach and cranial to the spleen. Note the relationship between the right limb and the duodenum, including their shared blood supply.

the two organs, but even then they usually become more closely apposed at the cranial aspect of the right limb near the angle. The arteries course longitudinally between the two organs and are almost completely obscured by pancreatic parenchyma on both sides. The cranial and caudal pancreaticoduodenal arteries (the former a branch of the celiac via the hepatic; the latter a branch from the cranial mesenteric) anastomose within the organ. The left limb of the pancreas is contained within the deep leaf of the greater omentum. Its main blood supply is from the pancreatic branches of the splenic and hepatic arteries (branches of the celiac), with some contribution by the gastroduodenal artery. Thus, the blood supply to the left limb is more segmental than the right. The left and right limbs are joined at a V-shaped angle called the body. This portion of the pancreas resides caudal to the pylorus and antral region of the stomach, and is where the exocrine ducts of the pancreas enter into the duodenum.

The location of the right limb of the pancreas brings it into proximity with other abdominal structures including the right body wall/flank, sublumbar fat containing the right ureter and kidney, the caudate process of the liver, the ascending colon and cecum, and loops of jejunum. The left limb may be in contact with the caudate process of the liver, the portal vein, caudal vena cava, aorta, left adrenal gland, transverse colon, and cranial pole of the left kidney.[2] These relationships may have implications for the surgeon when examining or operating on the pancreas.

The pancreas has lymphatics that drain into the mesenteric, hepatic, and splenic lymph nodes, and these nodes (along with the pyloric nodes) should be examined for metastatic disease when pancreatic neoplasia is suspected. The pancreas receives some sympathetic innervation from the nerves that emerge from the celiac plexus, while parasympathetic nerve fibers from the vagus course to the gland with the celiac and cranial mesenteric vessels. Venous drainage from the pancreas (caudal pancreaticoduodenal vein from the right limb and splenic vein from the left) empties into the portal vein.

The exocrine ducts were named based on the description in humans (pancreatic vs. accessory pancreatic) and this leads to some confusion. Although variation in ductal anatomy has been well described in dogs, the vast majority of dogs have most of their pancreatic exocrine flow into the duodenum via the *accessory duct* and the *minor duodenal papilla*. Since, with few exceptions, the left and right ducts anastomose within the body, the accessory duct carries secretion from both limbs. The smaller (in dogs) pancreatic duct enters the duodenum at the major papilla directly, or by opening into the bile duct as it joins the intestine. In **cats**, the ducts from left and right join to empty almost exclusively via the pancreatic duct into the bile duct at the major duodenal papilla.[3]

Indications for Pancreatic Surgery

Exocrine Pancreatic Disease

The pancreas may be explored because of a clinical diagnosis of exocrine pancreatic insufficiency (EPI). Dogs with EPI are expected to have a significantly reduced volume of pancreatic parenchyma compared with normal individuals. A confirmatory biopsy may be performed as described below. Assuming the entire organ is diffusely affected, the easiest and safest location to biopsy is the distal aspect of the right limb. Dogs with EPI, especially German shepherds, have a reported higher risk for mesenteric volvulus, and may also be at higher risk for gastric volvulus.[4] Therefore, a dog with suspected EPI should have a prophylactic gastropexy performed as part of the surgical procedure (See Chapter 19).

Pancreatitis is treated with intense medical management and is rarely an indication for exploration of the pancreas surgically. However, if imaging studies suggest the presence of an *abscess* or *pseudocyst* then there may be benefit to surgical intervention. The goal should be to obtain appropriate samples for histopathology and culture, and to establish drainage. Drainage techniques will be dependent on the location, size, and mobility of any cavitary lesion identified. Marsupialization is probably the least practical or desirable technique. Drainage tubes may be chosen, and of these a fenestrated silastic drain attached to a closed-suction type device exited through the body wall would be best. Another excellent option to consider is omentalization. This has been described for use with a variety of intra-abdominal abscesses and involves placing a pedicle of vascularized omentum into and/or through the abscess or cystic cavity and securing it with sutures. The omentum brings a blood supply as well as lymphaticovenous drainage to the site of disease.[5-12]

Pancreatitis may be associated causally with or as a result of **biliary disease**.[13,14] Because of the close anatomic association of the pancreatic and accessory pancreatic ducts with the bile duct in the proximal duodenum it is possible for disease in one system to spread to the other. Sludging of bile with extrahepatic biliary obstruction has been reported in dogs with previous episodes of acute pancreatitis.[13,14] Similarly, but less commonly, a primary cholangitis/cholangiohepatitis might result in spread of micro-organisms from the biliary tree into the pancreatic ducts, inducing pancreatitis. Thus, whenever examining the pancreas in instances of exocrine disease the surgeon should also evaluate the biliary tree and liver.

Exocrine tumors of the pancreas (pancreatic adenocarcinoma) are infrequently diagnosed in the canine and feline. Clinical signs of vomiting and anorexia are non-specific, however cats may develop a cutaneous syndrome that includes lameness due to foot pad ulceration and sloughing.[15-17] Clinical signs of exocrine pancreatic neoplasia may be due to the mass effect on neighboring organs if the tumor is large enough, or due to the effects of metastatic disease and/or carcinomatosis. Dogs with pancreatic adenocarcinoma usually do not have signs of either EPI or of pancreatitis. Surgical resection may be attempted depending on the extent of disease, but the prognosis is usually grim. Malignant pancreatic tumors are aggressive cancers and the absence of specific clinical signs usually results in a delay in diagnosis until late in the biological course of disease.

Endocrine Pancreatic Disease

The most common endocrine disease of the pancreas is diabetes mellitus. This disease is usually not an indication for pancreatic surgery. There are important considerations with respect to properly managing diabetic patients undergoing anesthesia and surgery for other disease processes that are addressed elsewhere.[18]

The most common indication for pancreatic surgery due to endocrine disease is the suspicion that the patient has a functional endocrine tumor. Several types of endocrine pancreatic neoplasia have been documented in small animals. The endocrine functions of the pancreas are located in the islet cells (of Langerhans), which are distributed randomly throughout all portions of the pancreas. These mostly neural crest-derived APUD (*A*mine *P*recursor *U*ptake and *D*ecarboxylation) cells migrate into the pancreas during embryonic development. This migration can be imperfect, and as a result functional neuroendocrine cells normally associated with the pancreatic islets may be located in extra-pancreatic locations, including the gastric wall, duodenum, and elsewhere. This in turn implies that functional "pancreatic" tumors may arise ectopically, and this must be borne in mind when exploring a patient's abdomen for a suspected endocrine tumor, especially if a primary lesion is not found in the pancreas itself.

Endocrine pancreatic neoplasia is usually named based on the predominant hormone produced by the tumor. The most common of these tumors is the insulinoma, derived chiefly from a clone of neoplastic beta cells in an islet. In older veterinary literature and in the parlance of the human literature a distinction is made between "insulinoma" (a benign proliferation of beta cells) and "functional islet cell adenocarcinoma" (the malignant variety most commonly diagnosed in dogs). However, in current veterinary clinical and pathology literature the two terms tend to be used interchangeably, so that the term "insulinoma" can describe either benign or malignant neoplasia. Other reported neuroendocrine tumors include gastrinomas (Zollinger-Ellison syndrome) arising mostly from non-pancreatic sites, but occasionally in the pancreas (putatively from delta cells), glucagonomas (alpha cells), non-specific polypeptidinomas, and somatostatinomas (delta cells). In dogs these tumors are usually malignant, and spread to local lymph nodes (Stage II disease) or liver (Stage III disease) is commonly found at the time of initial surgery. The implications for prognosis (disease-free interval and survival time) have been reported as has the use of adjuvant medical therapy.[18-23] This discussion will be limited to patient management during surgery and the immediate postoperative period. The reader is directed elsewhere for a review of criteria for confirming the diagnosis of specific endocrine tumors of the pancreas.[18]

Pancreatic Biopsy and Partial Pancreatectomy

Incisions into the pancreas have the potential for inducing pancreatitis as a consequence of enzymatic leakage and activation of zymogens. Even gentle tissue handling may cause enzymatic

activation. The safest course of action, in my opinion, is to assume that some leakage has occurred. I recommend withholding food and water for a minimum of 36 hours after pancreatic incision. Serum enzymes such as lipase and amylase may be monitored as desired, but these enzymes are notoriously insensitive and non-specific markers for acute pancreatitis. A better indication of when to resume oral intake is the clinical appearance of the patient, including such signs as rectal temperature and emesis. If the patient has not vomited for 36 hours or more, there is no fever, and there is no unusual abdominal tenderness on palpation, oral consumption of small amounts of water, followed by small amounts of bland food every few hours can be attempted, with a gradual return to normal alimentation. Oral consumption should be discontinued or delayed if the animal has signs suggestive of pancreatitis. If extensive pancreatic manipulation is required a **jejunostomy feeding** tube should be placed at the time of surgery (See Chapter 6). The jejunostomy tube will permit feeding the animal without stimulation of pancreatic exocrine secretion.

A generous cranial ventral midline incision is made to expose the cranial abdomen. Exposure of the pancreas is facilitated by appropriate use of retractors and moistened laparotomy pads. Self-retaining retractors such as Balfours placed on the abdominal wall and a surgical assistant using malleable ribbon retractors to retract viscera are beneficial for exposure. Warmed irrigation solution is indicated for local lavage after pancreatic surgery is completed, and suction is helpful to aspirate blood and lavage fluid.

When lesions are confined to the caudal aspect of the right limb of the pancreas, or a random biopsy is intended, the easiest method is excision of the caudal aspect of the right pancreatic limb. This can be performed with sutures, surgical stapling equipment, or the use of a hemostatic sealing device (eg. Liga Sure™). For those animals with a small pancreas it may be suitable to mass ligate the isolated portion with suture (suture-fracture technique) after dissection of the pancreas from the mesoduodenum. I recommend the use of 2-0 or 3-0 monofilament non-absorbable suture such as polypropylene. Alternatively, the duodenal serosa can be gently grasped and dissected off the pancreatic lobules; the lobules are then separated (sterile cotton swabs are useful) from the midline of the gland to expose the vessels and ducts. The vasculature and ducts can then be ligated with suture (3-0 or 4-0) or hemostatic clips and the pancreas resected distal to the ligations. Thoracoabdominal staplers are effective for single-stage ligation and resection. In most dogs the TA-30 size will be suitable, and small vascular staple cartridges (V3) are most effective (Figure 21-21) Stapling can also be performed by laparoscopy. Although the suture-fracture and stapling techniques induce some parenchymal crushing as the suture is tightened or staples are fired, no differences in complication rates have been found.[24] Ligation of a pancreatic duct does not induce pancreatitis but will induce acinar atrophy in any residual pancreas distal to the ligation.

If biopsy or excision of a lesion nearer the body or in the left limb is required, surgical options include partial pancreatectomy as described above (for the left side this requires dissection of the deep leaf of the omentum for exposure), enucleation of the mass, or incisional or needle biopsy. The latter may be performed with a Tru-cut device or other biopsy needle such as Vim-Silverman needle. Enucleation refers to a local dissection of pancreatic lobules while leaving the pancreas distal to the biopsy site intact. Lobules of parenchyma are teased away from the tissue to be removed using fine hemostats and sterile cotton swabs. Hemostasis can be achieved with gentle direct pressure, fine suture (4-0 or 5-0) or fine-tipped bipolar electrocautery. However, if extensive damage to the ducts or vessels is required (depending on the size and location of the lesion), partial pancreatectomy is considered and is preferred rather than enucleation. Incisional biopsy is performed using a #15 scalpel blade to take a small wedge of tissue and a single absorbable suture is used to close the defect.

When pancreatic disease is identified during surgery, the surgeon must determine whether and how to employ the above techniques for successful excision if possible. The most difficult anatomic location to excise a lesion is in the body of the pancreas since there is a risk of disrupting both the pancreatic and accessory pancreatic ducts. There are techniques for attempting to directly anastomose the remaining pancreas and duct to the intestine, but this is technically difficult and rarely performed in veterinary clinical cases.[25] In this situation, or in other situations that might call for total pancreatectomy (such as lesions causing complete obstruction to exocrine flow already, as might be seen with chronic pancreatitis or neoplasia), the surgeon must give careful consideration to the merits of attempting to resect all disease relative to the impact on the animal's (and client's) quality of life following surgery.

Total Pancreatectomy

There are no indications for total removal of the pancreas in dogs other than in the research laboratory. The clinical diagnosis where total pancreatectomy might be indicated is extensive pancreatic neoplasia, but it would be unlikely to have disease confined to the pancreas in such a case. The presence of local infiltration and distant metastasis make such surgical treatment a short term palliative procedure at best. Because of the shared blood supply between duodenum and pancreas, total pancreatectomy will require duodenectomy, splenectomy, and biliary diversion. As a result of surgery the patient will be diabetic and have EPI post-operatively. To my knowledge, there are, at present, no reports of total pancreatectomy for treatment of naturally-occurring disease in dogs or cats.

Surgical Technique for Treating Pancreatic Endocrine Neoplasia

The most common indication for pancreatic exploration and partial pancreatectomy is the suspicion of a functional beta-cell tumor (insulinoma). In most cases the veterinarian should have make a diagnosis of insulinoma by demonstrating that the patient has persistent hypoglycemia not due to laboratory error, and a high level of serum insulin when the serum glucose is well below normal ranges. These findings are not exclusive to insulinoma however. There may be other causes for hyperinsulinism such as hepatic disease (usually neoplasia) that disrupts normal

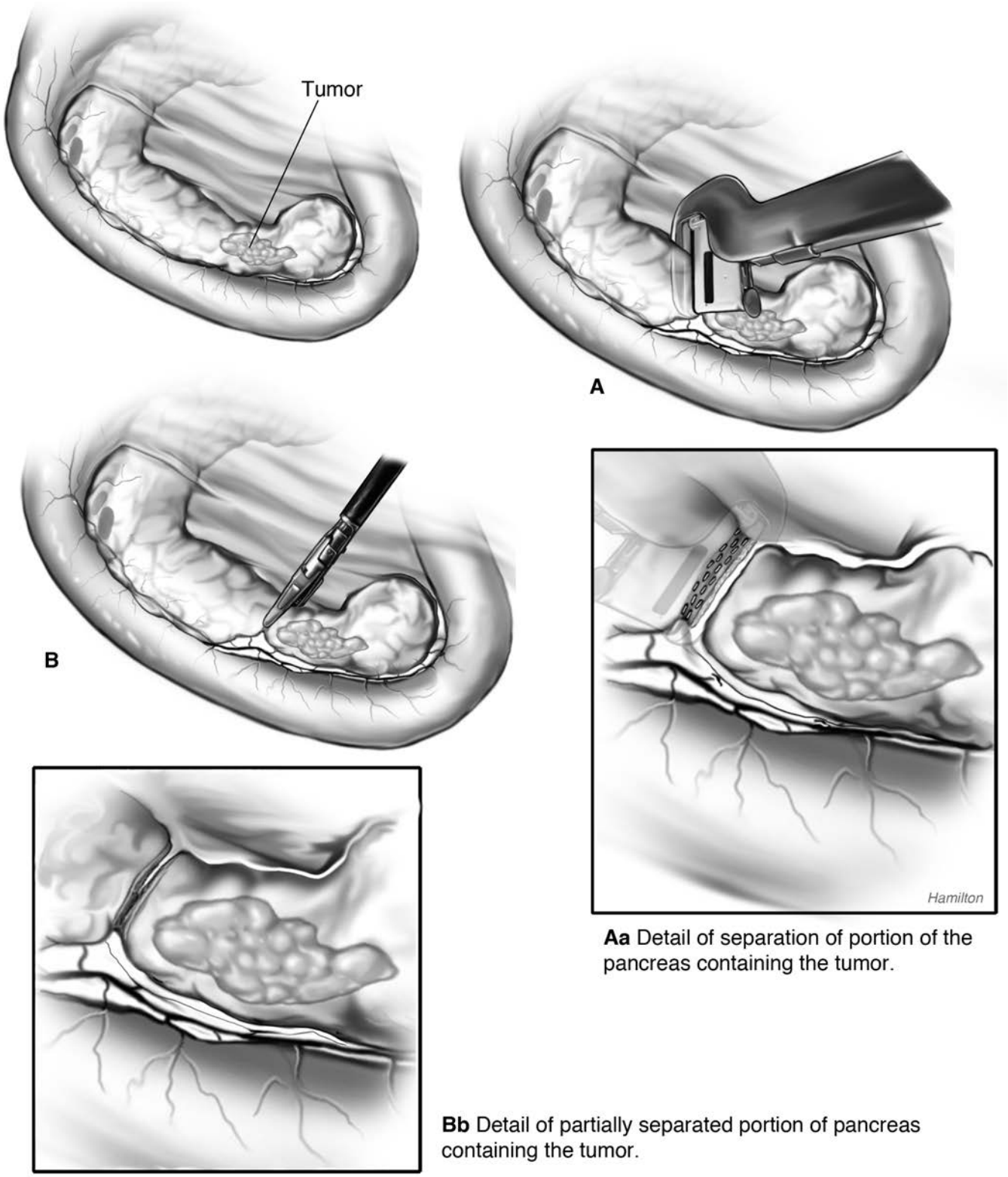


Figure 21-21. Partial pancreatectomy. Depending on patient size, it may be possible to mass ligate the distal aspect of the pancreas for excision of a tumor. For most patients, however, surgical tools designed for achieving hemostasis without inducing pancreatic injury that might activate zymogens (and cause pancreatitis) are preferred. Two of these instruments are depicted here. **A.** is application of a thoracoabdominal *(TA)* stapling device. For most patients a 30 mm instrument is appropriate, and a cartridge with small vascular staples in a triple staggered row achieves both hemostasis and closure of the ducts. *(Aa)* The specimen distal to the stapler, containing the tumor, is then sharply incised using the stapler as a cutting guide, and the specimen is removed. Alternatively, a vessel sealing device may be used as depicted in **B.** The jaws of the instrument are closed around the pancreas and the instrument activated to seal the vessels and ducts. An audible feedback is provided by the instrument to alert the surgeon whether successful sealing has occurred. *(Bb)* The device contains a cutting blade that then divides the tissues contained in the jaws, and the instrument is then advanced sequentially until the entire specimen has been dissected and can be removed. With the vessel sealing device, a portion of the pancreas distal to the area containing the tumor may be preserved. However, the ducts may not be patent and acinar atrophy might result.

insulin degradative metabolism and which may also consume glucose prodigiously. Appropriate imaging studies (ultrasound, computed tomography, magnetic resonance imaging) should be able to distinguish those patients with a primary hepatic lesion. With the possible exception of CT or MRI, however, imaging studies (particularly ultrasound) are often *not* able to confirm the presence of a primary insulinoma in the pancreas. Thus, in most cases animals undergo celiotomy for diagnostic confirmation as well as for disease staging and treatment.

The goal of pre-operative and intra-operative patient management should be to stabilize the blood glucose in an acceptable range, ideally in the low normal range if possible. Anesthetized patients and those with a history of hypoglycemia-induced seizures are particularly vulnerable to the effects of neuroglycopenia which can cause cortical laminar necrosis and permanent brain damage. To some degree, the central nervous system (CNS) has adaptive mechanisms that permit function even at low levels of blood glucose, but the neurons are at a threshold and are intolerant of any further (especially sudden) decrease in glucose levels. Achieving and keeping blood glucose normalized and stabilized is challenging since insulinomas, although not responsive to normal negative feedback mechanisms, may still have intact *positive* feedback. Administering exogenous dextrose especially in high concentrations may stimulate further secretion of insulin. This may fail to raise the blood glucose level by stimulating excess insulin secretion and may cause wide variations in glucose levels. These variations, especially sudden decreases in glucose may induce more severe signs of CNS dysfunction than persistently low blood glucose, at least in conscious patients. The use of 10% to 20% glucose solutions is indicated for management of patients with persistent hypoglycemia. Hypertonic dextrose solutions are best adminstereed through a jugular catheter. A second peripheral catheter can be used for blood sampling and monitoring. In addition to dextrose, other techniques for raising and stabilizing blood glucose include constant rate infusions of glucagon,[26] administration of corticosteroids, beta-blockers, and specific drugs that inhibit secretion of insulin from beta cells such as diazoxide.[18-23] Blood glucose should be monitored regularly during anesthesia and modifications in treatment made as necessary to stabilize levels in the appropriate range.

Anesthetic protocols, other than for glucose homeostasis, are routine and at the discretion of the surgeon or anesthesiologist. I administer prophylactic antibiotics, typically cefazolin (22mg/kg IV, q2h) starting at induction, and pre-emptive use of analgesics should be standard. Drugs that cause blood pooling in the spleen (barbiturates, phenothiazines, certain opioids) should be avoided since retraction of an enlarged spleen may make surgical visualization and manipulation of the left limb of the pancreas more difficult.

Exploratory surgery of the pancreas for an insulinoma is preceded by complete abdominal exploration to identify related or unrelated disease. Special attention and examination for metastasis is focused on the liver and local lymph nodes. I usually reserve examination of the pancreas for last so as to not miss other lesions. The entire pancreas should be exposed, then examined visually and thoroughly palpated. Most islet cell tumors will appear as discrete, raised, firm, lobulated nodules. They range from light brown to almost violet in color. Size can range from a few millimeters in diameter to several centimeters. There is no proven site predilection within the pancreas and tumors have been reported with equal distribution in both limbs and the body of the organ. There is also no correlation between the severity/refractoriness of pre-operative hypoglycemia and the size of the primary tumor. Tumors are usually solitary but the entire pancreas should be examined to ensure that no additional tumors are present. Once the tumor is identified the surgeon will need to determine which of the techniques for partial pancreatectomy is appropriate. In all cases, whether there are gross lesions or not, one or more regional lymph nodes should be resected and at least one liver biopsy obtained for staging purposes. Partial pancreatectomy is desirable when possible since recurrence rates may be lower with this technique compared to enucleation of the mass. All apparent neoplastic tissue including metastatic disease is resected when possible. Persisitent hypoglycemia may result if gross neoplastic disease cannot be resected.[27] The local area should be lavaged with warm saline to remove bacterial contamination or pancreatic enzymes that might have leaked, and the abdominal incision closed routinely.

In rare instances, examination of the pancreas will fail to identify the tumor. This could be the consequence of missing a tumor that's present (eg., a small tumor enveloped within surrounding exocrine parenchyma), an ectopic (extra-pancreatic) tumor, or a misdiagnosis. The first two are most likely. In this case, it can be helpful to utilize *intra-operative vital staining with methylene blue, USP*. Methylene blue concentrates in specific endocrine cells, notably pancreatic islet cells and parathyroid chief cells. The degree of cellular uptake (and therefore intensity of tissue staining) is correlated with the degree of function (secretion) of these cells. Thus islet cell tumors and parathyroid gland tumors will selectively stain more intensively than normal cells.[28,29]

Methylene blue, USP (**MB**) is provided in 10 ml ampules as a 1% solution. It is approved for *in vivo*, intravenous administration. **IT IS NOT THE SAME AS** *NEW* **METHYLENE BLUE** (NMB)**!** The latter is a laboratory reagent, and other than for the unfortunate similarity in common names, the two products are entirely different chemically. If you choose to use this technique be certain you use the correct product. *Do **not** use New* Methylene Blue!

The recommended protocol is to calculate a dose of 3mg/kg methylene blue and dissolve this quantity in 250 to 500 ml of 0.9% saline. This fluid can then be infused intravenously at a maintenance fluid rate of 10ml/kg/hr. Visualization of tissue staining will usually occur 15 to 20 minutes after starting the infusion, with the pancreas taking on a dusky pale blue hue. An islet cell tumor will stain a more intense blue or purplish color. Once the tumor is visualized the MB infusion can be discontinued.[28,29]

In addition to identifying an occult primary tumor or ectopic disease MB infusion can help determine if a lesion seen beyond the pancreas is a metastatic nodule, and help determine if it should be resected.[30]

Using MB infusion routinely during pancreatic exploration for endocrine tumors is not recommended because of potential negative effects. The patient may develop a pseudocyanosis that has the potential for interfering with monitoring of patient oxygenation during anesthesia. More significantly, MB can induce a Heinz-body anemia that will cause the hematocrit to decrease 1 to 2 days after MB administration. In experimental cases and limited clinical use the anemia has not required transfusion however the potential exists, especially if the patient has sustained acute blood loss from the operation. There have been reports of acute renal failure after MB infusion. I am not convinced this was a toxic effect of MB as the reported cases did not provide adequate descriptions of either the pre-operative renal status or of the use of intra-operative fluid therapy. However, caution dictates that this potentially serious adverse effect should be considered especially if the animal has preexisting renal disease. Finally, MB is excreted in the urine. This will make the urine green, and has the potential of staining flooring surfaces that urine may come in contact with.[28]

After the primary insulinoma has been resected the surgeon can expect a rapid rise in blood glucose levels. Fluid therapy should be modified as glucose levels change. In most dogs, the blood glucose will return to and remain in the normal range after administration of dextrose and other pro-glycemic agents has been stopped. However, in some instances the dog will become hyperglycemic and have at least a transient diabetes mellitus. This is largely explained by down-regulation of receptors on the normal beta cells. Persistent hyperglycemia may require exogenous insulin for treatment. Less commonly, but especially if incompletely excised metastatic disease in lymph nodes or liver is present, hypoglycemia may persist after removal of the primary tumor. Further surgical resection of gross disease is possible however most animals are managed with combinations of euglycemic agents such as corticosteroids, diazoxide, and dietary modification. Because almost all insulinomas in dogs are malignant, metastatic disease, even if not grossly apparent at the time of surgery, is likely to develop. Development of metastatic disease may result in illness caused by the effects of the tumor in the organ involved, or more likely, due to the recurrence of hyperinsulinism and resultant hypoglycemia. In some cases a second (or more) operation can be used to effectively debulk metastatic disease and prolong the disease-free interval and survival time.

In addition to medical therapy that specifically promotes euglycemia, cytotoxic chemotherapy can be used as adjunctive treatment. The current drug of choice is streptozotocin. This drug acts specifically to cause death of islet cells, but is also extremely nephrotoxic. Historically, the drug was not used clinically because of its nephrotoxic effects which were reported to be lethal. Interestingly, this conclusion was reached based on a report of *four* dogs in the literature. More recently, streptozotocin has been used with success in treating islet cell tumors when administered with an intensive diuresis protocol.[31]

Other Pancreatic Islet Cell Tumors

Less common than insulinoma are the other islet cell tumors of the pancreas. The principles of surgical exploration, disease staging, and partial pancreatectomy are similar to that described for insulinomas. Management of the medical syndrome induced by the specific hormome excess is dictated by the effects of that syndrome. *Gastrinomas* are usually associated with the *Zollinger-Ellison syndrome*. These tumors produce hypergastrinemia that cause pyloric mucosal hypertrophy and possible gastric outflow obstruction. Gastrin also acts synergistically with histamine and acetylcholine to increase production of hydrochloric acid by parietal cells in the stomach, this may cause gastric ulceration. Antacids such as proton-pump inhibitors, as well as H2-receptor antagonists are part of the medical management for this neuroendocrine tumor. Definitive therapy is removal of the primary tumor, however gastrinomas may be occult, ectopic, or diffuse, making identification and complete removal difficult. Although gastrin is produced by fetal islet cells (some gastrinomas have a primary pancreatic location), in adults most gastrin is derived from extra-pancreatic sites. One of the treatments for this disease is to remove the target for gastrin, ie, to perform a partial gastrectomy with gastroduodenostomy (Bilroth I) or gastrojejunostomy (Bilroth II).

Too few glucagonomas, VIPomas, pancreatic polypeptidomas or somatostatinomas have been reported in animals to reach meaningful conclusions about their biological behavior or treatment, but the principles with respect to pancreatic surgery should be similar. Glucagonomas in dogs have been associated with superficial necrolytic dermatitis and diabetes mellitus, but these conditions can arise independently of a glucagonoma, and need not occur in confirmed cases of glucagonoma.[32-34]

References

1. Nickel R, Schummer A, Seiferle E, Sack WO: The Viscera of the Domestic Mammals. Berlin, Verlag Paul Parey, 1973, p119-122.

2. DeHoff W, Archibald J: Pancreas. In: Archibald J (ed) Canine Surgery, 2nd. Santa Barbara, American Veterinary Publications, 1974, p827-842.

3. Nielsen SW, Bishop EJ: The duct system of the canine pancreas. Am J Vet Res 15:266, 1954.

4. Westermarck E, Rimmaila-Parnanen E: Mesenteric torsion in dogs with exocrine pancreatic insufficiency: 21 cases (1978-1987). J Am Vet Med Assoc 195:1404-1406, 1989.

5. Whittemore JC, Campbell VL: Canine and feline pancreatitis. Compend Contin Ed Pract Vet 27:766-776, 2005.

6. Salisbury SK, Lantz GC, Nelson RW, et al: Pancreatic abscess in dogs: Six cases (1978-1986) J Am Vet Med Assoc 193:1104-1108, 1988.

7. Bailiff NL, Norris CR, Seguin B, et al: Pancreatolitihiasis and pancreatic pseudobladder associated with pancreatitis in a cat. J Am Anim Hosp Assoc 40:69-74, 2004.

8. Coleman M, Robson M: Pancreatic masses following pancreatitis: Pancreatic psedocysts, necrosis, and abscesses. Compend Contin Ed Vet Med 27:147-154, 2005.

9. Bray JP, White RAS, Williams JM: Partial resection and omentalization: A new technique for management of prostatic retention cysts in dogs. Vet Surg 26:202-209, 1997.

10. Campbell BG: Omentalization of a non-resectable uterine stump abscess in a dog. J Am Vet Med Assoc 224:1799-1803, 2004.

11. Johnson MD, Mann FA: Treatment for pancreatic abscesses via omentalization with abdominal closure versus open peritoneal drainage in dogs: 15 cases (1994-2004) J Am Vet Med Assoc 228: 397-402, 2006.

12. Hosgood G: The omentum – the forgotten organ. Physiology and potential surgical applications in dogs and cats. Compend Contin Educ

Pract Vet 12:45-50, 1990.

13. Matthiesen DT, Rosen E: Common bile duct obstruction secondary to chronic fibrosing pancreatitis J Am Vet Med Assoc 189:1443, 1986.

14. Neer TM: A review of disorders of the gallbladder and extrahepatic biliary tract in the dog and cat. J Vet Int Med 6:186-192, 1992.

15. Pascal-Tenorio A, Olivry T, Gross TL, et al: Case report: paraneoplastic alopecia associated with internal malignancies in the cat. Vet Derm 8:47-52, 1997.

16. Brooks DG, Campbell KL, Dennis JS, et al: Pancreatic paraneoplastic alopecia in three cats. J Am Anim Hosp Assoc 30:557-563, 1994.

17. Seaman RL: Exocrine pancreatic neoplasia in the cat: A case series. J Am Anim Hosp Assoc 40:238-245, 2004.

18. Fingeroth JM: Endocrine Pancreatic Disease In: Bojrab MJ (ed). Disease Mechanisms in Small Animal Surgery, 2nd ed. Philadelphia, Lea and Febiger, 1993, p589-607.

19. Caywood DD, Klausner JS, O'Leary TP, et al: Pancreatic insulin-secreting neoplasms: Clinical, diagnostic, and prognostic features in 73 dogs. J Am Anim Hosp Assoc 24:577-584, 1987.

20. Leifer CE, Peterson ME, Matus RE: Insulin-secreting tumor: diagnosis and medical and surgical management ion 55 dogs. J Am Vet Med Assoc 188:60-64, 1986.

21. Steiner JM, Bruyette DS: Canine insulinoma. Compend Contin Educ Pract Vet 18:13-16, 1996.

22. Trifonidou MA, Kirpensteijn J, Robben JH: A retrospective evaluation of 51 dogs with insulinoma. Vet Quarterly 20:S114-115, 1998.

23. Tobin RL, Nelson RW, Lucroy MD, et al: Outcome of surgical versus medical treatment of dogs with beta cell neoplasia: 39 cases (1990-1997). J Am Vet Med Assoc 215:226-230, 1999.

24. Allen SW, Cornelius LM, Mahaffey EA: A comparison of two methods of partial pancreatectomy in the dog. Vet Surg 18:274-278, 1989.

25. Markowitz J, Archibald J, Downie HG: Experimental surgery. Baltimore, Willams and Wikeins, 1964, p236-252.

26. Fischer JR, Smith SA, Harkin KR: Glucagon constant-rate infusion: A novel strategy for the management of hyperinsulinemic-hypoglycemic crisis in the dog. J Am Anim Hosp Assoc 36:27-32, 2000.

27. Melhaff-Schunk, C: Surgery of the pancreas. In: Bojrab MJ (ed) Current Techniques in Small Animal Surgery, 3rd ed. Philadelphia, Lea and Febiger, 1990, p304-308.

28. Fingeroth JM, Smeak DD, Jacobs RM: Intravenous methylene blue infusion for intraoperative identification of parathyroid gland and pancreatic islet-cell tumors in dogs. Part I: Experimental determination of dose-related staining efficacy and toxicity. J Am Anim Hosp Assoc 24: 165-173, 1988.

29. Fingeroth JM, Smeak DD: Intravenous methylene blue infusion for intraoperative identification of pancreatic islet-cell tumors in dogs. Part II: Clinical trials and results in four dogs. J Am Anim Hosp Assoc 24:175-182, 1988.

30. Smeak DD, Fingeroth JM, Bilbrey SA: Intravenous methylene blue as a specific stain for primary and metastatic insulinoma in a dog. J Am Anim Hosp Assoc 24:478-480, 1988.

31. Moore AS, Nelson RW, Henry CJ, et al: Streptozotocin for treatment of pancreatic islet cell tumors in dogs: 17 cases (1989-1999) J Am Vet Med Assoc 221:811-818, 2002.

32. Gross TL, O'Brien TD, Davies AP, et al: Glucagon-producing pancreatic endocrine tumors in two dogs with superficial necrolytic dermatitis. J Am Vet Med Assoc 197:1619-1622, 1990.

33. Langer NB, Jergens AE, Miles KG: Canine glucagonoma. Compend Contin Educ Pract Vet 25:56-63, 2003.

34. Feldman EC, Nelson RW: The Endocrine Pancreas. In: Feldman EC, Nelson RW: Canine and Feline Endocrinology and Reproduction, 2nd ed. Philadelphia, WB Saunders, 1996. pp. 450-452.

Chapter 22

Diaphragm

Traumatic Diaphragmatic Hernia

Jamie R. Bellah

Introduction

In small animals, diaphragmatic injury may occur by direct or indirect trauma.[1,2] Indirect injury to the diaphragm is the most common cause of diaphragmatic hernia and originates from blunt trauma to the abdominal cavity.[1] Pleuroperitoneal pressure gradients vary from 7 to 20 cm H_2O during quiet inspiration and can increase to over 100 cm H_2O during maximal inspiration.[3] Blunt trauma results in a sudden increase in abdominal pressure, and if it is concomitant with an open glottis, the resultant pleuroperitoneal pressure gradient increases dramatically and domes and tears the diaphragm.[1,2] Prolapse of abdominal viscera is expected to occur simultaneously with the tear. Direct injury to the diaphragm is rare, but it may be inflicted by gunshot, bite, or stab wounds.[4,5] Iatrogenic injury to the diaphragm may occur by inappropriate abdominal incision cranial to the xiphoid process or inappropriate placement of a chest drain.[5]

Loss of continuity of the diaphragm does not necessarily result in severe respiratory distress.[6] The cause of respiratory impairment associated with diaphragmatic hernia is multifactorial.[6] Hypovolemic shock, chest wall trauma, pleural fluid or air, pulmonary contusions, and cardiac dysfunction all contribute to hypoventilation.[6] Rib fractures and an associated flail chest cause mechanical dysfunction. Pulmonary compliance is decreased by pleural fluid, by the presence of abdominal organs in the thorax, or by pneumothorax. Pulmonary hemorrhage, edema, and atelectasis reduce total lung capacity, vital capacity, and functional residual capacity. Myocardial contusion may decrease cardiac output and in conjunction with impaired ventilation, may result in tissue hypoxia. Pain resulting from chest and abdominal contusion and accompanying injuries causes voluntary restriction of motion (thoracic excursion).[6]

Diagnosis

Thoracic injury occurs in 39% of small animals with musculoskeletal trauma, and 2% have diaphragmatic hernia.[7] Therefore, animals examined for blunt traumatic injury must be evaluated for diaphragmatic injury. The average length of time between traumatic injury and the diagnosis of diaphragmatic hernia is several weeks, but it ranges from hours to 6 years.[8,10] Young male dogs have the highest incidence of diaphragmatic hernia.[8,10] Clinical signs of diaphragmatic hernia vary from no overt signs to severe respiratory compromise and shock.[8,11,13] Dyspnea is the most common clinical sign and relates multifactorily to the presence of shock, chest *wall* dysfunction, the presence of air, fluid, or viscera in the pleural space, decreased pulmonary compliance, edema, and cardiovascular dysfunction.[8,11,13] Cardiac

arrhythmias are present in 12% of small animals with diaphragmatic hernia.[8] Other common clinical signs include muffled heart and lung sounds, thoracic borborygmi, a strong apex beat ausculted on one side of the chest because of shifting of the apex to one side, and an asymmetric decreased caudoventral resonance when the thoracic cavity is percussed.[5] A "tucked up" abdomen is a rare finding.[5,14]

Lateral radiographs of the thorax show an incomplete diaphragmatic silhouette in 97% of animals with a diaphragm tear.[15] In 61% of these animals, airfilled small intestinal loops are identified on the thoracic side of the diaphragm.[15] Hydrothorax, which may be pleural effusion or hemothorax depending on the chronicity of the hernia, may be identified and may obscure the diaphragm. Repeated radiography after thoracocentesis is advisable, but it may not show a diaphragmatic hernia definitively.[15] Ultrasonographic evaluation is useful to identify abdominal viscera on the thoracic side of the diaphragm, especially in the presence of pleural fluid because it enhances sonographic evaluation.[16] Ultrasound can show abdominal organs, can differentiate organs such as the spleen or liver from pleural fluid, and can sometimes demonstrate the defect in the diaphragm.[16] Cytologic evaluation of pleural fluid in patients with acute hernias usually reveals hemorrhage, whereas in a chronic diaphragmatic hernia, a modified serosanguinous transudate is identified.[5]

Alternative techniques to attempt to confirm the presence or absence of a diaphragmatic hernia include barium administration (1.0 mL 1kg) to verify herniation of a portion of the gastrointestinal tract, pneumoperitoneography, and positive contrast peritoneography (using 1 to 2 mL/kg of an aqueous tri iodidinated contrast agent).[17,18] These techniques are done only if, in the clinician's judgment, the patient can tolerate the stress of such a procedure and if plain radiographs and ultrasonography are nondiagnostic.[15] Moreover, when viscera or omentum plugs the diaphragm defect, a false negative evaluation is made.[19,20]

Ventilation can be evaluated by arterial blood gas analysis and noninvasive pulse oximetry.[21,22] These techniques may identify ventilation perfusion inequalities (alveolar arterial oxygen difference)[14] and physiologic shunting (estimated shunt equation).[14] Impaired ventilation (hemoglobin saturation) can be determined using pulse oximeter probes attached to the lip in the awake dog.[23] The ear, tail, and toe may also be used effectively in awake dogs if good contact is maintained across the vascular beds.[23]

Timing of Surgical Intervention

The timing of anesthesia and surgical correction of diaphragmatic injury has a profound effect on the outcome of treatment.[5,14] Approximately 15% of small animals with diaphragmatic hernia die before surgery.[5] Animals with diaphragmatic herniorrhaphy performed within the first 24 hours after injury have the highest mortality rate (33%).[8] When surgery must be done depends on the extent of the initial cardiopulmonary dysfunction, the presence or absence of organ entrapment, and the degree of compromised pulmonary function.[14] Diaphragmatic herniorrhaphy may become an emergency procedure if aggressive supportive care cannot stabilize respiratory function.[9] Acute dilatation of a herniated stomach and strangulated bowel are situations in which emergency surgery may be indicated.[9] Gastric outflow obstruction, metabolic alkalosis, and hypokalemia have been reported in a dog with diaphragmatic hernia.[24]

A herniated stomach can rapidly distend from aerophagia, decreasing pulmonary compliance and can compress the caudal vena cava, decreasing venous return resulting in a vicious cycle that can be rapidly fatal.[5]

A herniated parenchymal organ such as the spleen may tear as it passes through the diaphragm; the result may be acute hemothorax and a patient that may deteriorate rapidly after an initial response to shock therapy. Most small animals with diaphragmatic hernia can be stabilized over 24 to 72 hours because the mere presence of a diaphragmatic hernia is not an indication for emergency surgery.[8] For example, thoracic injuries such as pulmonary contusion improve dramatically in 24 to 48 hours, and pneumothorax may be managed by thoracostomy tube insertion. The goal of initial management is to improve the cardiorespiratory status of the patient, thus improving the patient's capability of tolerating the stress of anesthesia and surgery.

Anesthesia

Anesthesia in the patient with diaphragmatic hernia is induced with as little stress as possible. Intravenous catheterization, appropriate intravenous fluid adminstration (crystalloid or colloid), and cardiorespiratory monitoring are important. Premedication with a phenothiazine or a narcoleptic combination may relieve apprehension, but care is taken not to use cardiorespiratory depressing drugs when possible if decompensation of the patient's status is predictable.[8] Mask induction of anesthesia is avoided because it's stressful and does not allow control of respiration or provide the ability to assist ventilation.[8] An ultra short acting barbiturate or propofol is used because it allows rapid induction of anesthesia, quick intubation and near immediate control of ventilation with assitance or by a mechanical ventilator.[25] Isoflurane is preferred for maintenance of anesthesia because a surgical plane of anesthesia is attained more quickly, it is associated with decreased recovery time, it subjects the patient to less cardiac depression, and it does not sensitize the myocardium to arrhythmias.[8]

Ventilation assistance is important as soon as anesthesia is induced because of decreased pulmonary compliance secondary to the presence of air, fluid, or abdominal viscera within the pleural space.[5,14] Assisted ventilation should not exceed 20 cm H_2O, to limit potential barotrauma from pulmonary hyperinflation.[8] Overinflation of the lungs during surgery may result in rupture of pulmonary parenchyma, intrapulmonary hemorrhage, plumonary edema, and, rarely, pneumothorax.[26] Intraoperative elimination of atelectic areas subjects chronically atelectic lungs to mechanical and reperfusion injury.[8,26] In this situation, reperfusion of these collapsed vascular channels disrupts capillary integrity and causes fluid to leak into the interstitium; reexpansion pulmonary edema may result within several hours after surgery.[5,8,27] Atelectic areas that do not inflate with 20 cm H_2O gradually reexpand over several hours with a

continual negative pleural pressure of 10 cm H_2O.[28] Preoperative treatment with glucocorticoids and antihistamines has been recommended (based on experimental evidence) to inhibit the effects of mediators of pulmonary vascular permeability that are activated by lung injury in patients with chronic diaphragmatic hernia, but care is advised because antihistamines may potentiate hypotension.[6,8]

Surgical Approach

A ventral midline celiotomy extending from the xiphoid process to a point caudal to the umbilicus is used to provide initial exposure for diaphragmatic herniorrhaphy. The incision should be large enough to allow exploration of the abdominal cavity. This exposure allows access to all regions of the diaphragm. Most diaphragmatic tears are muscular and are located ventrally and may favor either the right[12] or left side.[10,29] The liver, small intestine, and pancreas are most commonly prolapsed into the thoracic cavity when the diaphragm defect is on the right side, whereas the stomach, spleen, and small intestine prolapse on the left side.[5] The surgeon must examine the entire diaphragm because more than one tear may occur.[14] Exploration of the abdominal cavity is indicated because injury to other abdominal organs may be present and are potentially treated concomitantly. Should additional exposure be required to retrieve abdominal viscera adhered to structures within the thoracic cavity, surgical exposure can be improved by enlargement of the rent in the diaphragm, by paracostal extension of the celiotomy, or by caudal midline sternotomy (Figure 22-1). Lateral thoracotomy is not a practical or appropriate method to expose a diaphragmatic tear because it requires preoperative knowledge of the extent and side of the hernia, and the approach does not allow exploration of the abdomen.[8,14] Lateral thoracostomy also decreases thoracic compliance from pain and thus may contribute to hypoventilation.[8]

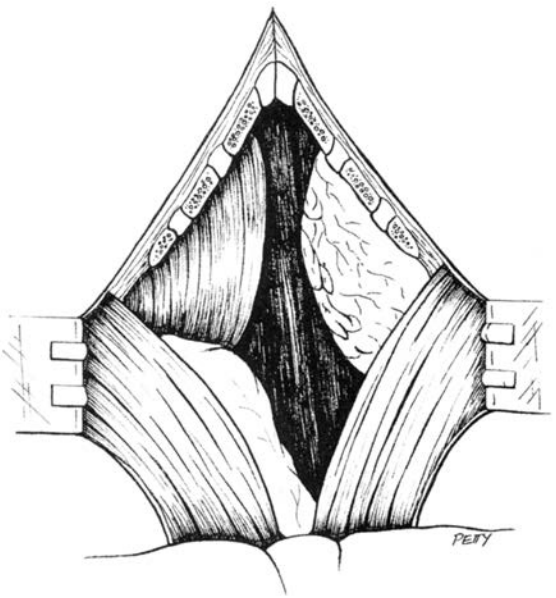


Figure 22-1. In this view, the midline celiotomy has been extended to expose the caudal thorax by caudal midline sternotomy. The diaphragm is incised to the hernia defect to allow blunt and sharp dissection to release abdominal viscera from restrictive thoracic adhesions.

Strangulated viscera found within the thoracic cavity should be resected in situ without reestablishing circulation if possible.[8] By doing so, prevention of toxemia from bacterial endotoxins and exotoxins and the by products of tissue autolysis is possible.[8] Viscera may be incarcerated, strangulated, or obstructed after passing through a diaphragmatic hernia and the systemic effects such as gastrointestinal obstruction or extrahepatic bile duct obstruction may occur acutely or chronically.[5,14,30] Chronic strangulation of a liver lobe results in a modified serosanguinous transudate approximately 30% of the time.[5] Before closing the diaphragm defect, a chest drain is placed from a paramedian stab incision, it is tunneled subcutaneously, and it is inserted intercostally into the pleural space (Figure 22-2). The advantages of placing the chest drain early are that the drain can be placed accurately with direct visualization and, after herniorrhaphy, control of the pleural space is obtained for the duration necessary. The diaphragm closure need not be airtight because the chest drain provides control. Should an inadvertent tear in the lung parenchyma occur during herniorrhaphy, the presence of the tube will detect it and allow simple management. The chest drain is managed for a short time, usually 8 to 12 hours, or until the volume of air or fluid is 2 to 3 mL/kg per day or less. Air can be aspirated from the pleural space as the last suture is tied, but if a parenchymal tear is leaking air or if the herniorrhaphy is not airtight, hypoventilation may result.

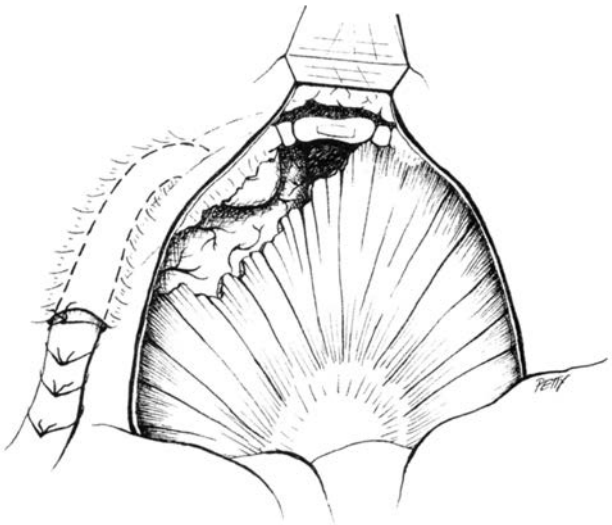


Figure 22-2. In this view, a chest drain has been inserted from a paramedian incision, tunneled over the costal arch, and placed within the pleural space under direct visualization before closing the diaphragmatic hernia.

Assessment of the wound margin of the diaphragm is important after viscera have been replaced into the abdominal cavity. Debridement of the wound margins is usually not necessary, but sutures should be placed through portions of the torn edge of the diaphragm that has an intact fascial surface to afford good suture holding strength. Chronic hernias that have produced scar tissue and collagen at the wound margins have good suture holding strength, but the scar restricts the normal elasticity of the diaphragm. Paracostal incisions are usually sufficient to release the maturing scar tissue and to allow the elastic portions of the diaphragm to be advanced to close the defect.

The suture material and pattern used to appose the diaphragm depend largely on the surgeon's preference. Radial tears are apposed with simple continuous patterns or a combination of a horizontal mattress pattern oversewn with a simple continuous pattern. A single layer simple continuous pattern is quickly completed, but it is susceptible to reherniation should the implant break. The surgeon should suture from the deepest portion of the tear toward the more superficial regions. Large tears or combined radial and paracostal tears may be apposed with several interrupted sutures to arrange apposition of the wound margins to minimize tension. Closure follows, using a simple continuous pattern (Figure 22-3). Polypropylene, monofilament nylon, poliglecaprone, (Monocryl, Ethicon, Inc., Somerville, NJ), polydioxanone, and polyglyconate are sutures materials acceptable for herniorrhaphy. Paracostal tears are sutured using simple continuous patterns by suturing the diaphragmatic wound edge to paracostal fascia or encircling the ribs. Mattress patterns that encircle the costal arch or paracostal muscle fascia may also be used. Preplacing sutures sometimes facilitates closure of chronic diaphragmatic defects. Use of 3-0 and 2 0 suture for small cats and dogs and 2 O and 1 0 for larger dogs is recommended. Larger sizes are appropriate for giant breeds.

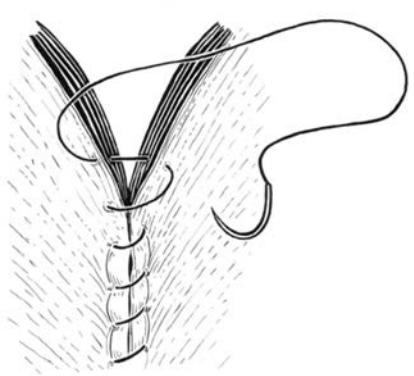


Figure 22-3. A simple continuous pattern may be used to appose the edges of the diaphragm. A fascial layer is included to ensure that encircling tissue is strong enough to hold sutures.

Closure of large diaphragm defects sometimes requires mobilization of the diaphragm or other tissues.[5,9,14] Paracostal incisions may be made to release the diaphragm from restrictive scar tissue, and the diaphragm may be advanced cranially to allow apposition ventrally (Figure 22-4).[5,14] Muscle flaps originating from the transversus abdominis muscle can be used to close diaphragm defects.[31,32] In chronic hernias, the liver capsule may be thickened in response to incarceration, and if the liver lobe is viable and can be oriented to cover the defect in the diaphragm partially without tension, it can be used to close or partially dose the defect.[33] Autologous fascia and omentum has also been used to close large diaphragm defects or small defects that remain after mobilization of the diaphragm.[34,35] Synthetic materials, such as polypropylene mesh or silicone rubber may also be used.[32,36,37] If a rough material such as polypropylene mesh is used, it is advisable to mobilize omentum to create an "omental envelope" that provides angiogenesis to aid incorporation of the prosthetic material and to protect the adjacent soft tissues from the mesh surfaces (Figure 22-5). Sometimes, the time and trauma required to mobilize muscular pedicles, especially in small kittens and puppies, result in significant hemorrhage. and can jeopardize the life of the patient. Prosthetic materials may be a better option if the potential to use autologous tissue may injure the patient.

Abdominal closure is accomplished routinely in patients with acute hernias. In those with chronic hernias, accommodation of the viscera within the peritoneal cavity may be difficult because of the contracted abdominal musculature. The abdominal musculature relaxes over time.[14] Increased intraperitoneal pressure may occur. If intra abdominal pressure increases over 13 cm H_2O, hepatic and portal venous flow may decrease.[39] Intra abdominal pressure (30 cm H_2O) in one dog necessitated surgical decompression.[39]

Postoperative Care

Evacuation of air from the pleural space should be done carefully in patients with atelectasis that does not reinflate with inflation pressures of 20 cm H_2O, such as may occur with chronic hernias. Air may be evacuated in these patients slowly over a 12 hour period by using periodic evacuations or by using a Pleurivac (water seal) with no greater than a negative pleural pressure of 10 cm H_2O.

Oxygen supplementation can be administered during recovery by mask, nasal insufflation or by placing the patient in an oxygen cage (40% oxygen).[8] Nasal insufflation allows the same degree of oxygen supplementation, but it offers the advantage of allowing frequent and close access to the patient should it be required. Heart rate, capillary refill time, mucous membrane color, pulse strength and character, and respiratory rate should be monitored. Direct or indirect blood pressure monitoring, blood gas analysis, and pulse oximetry may also be done.

Analgesics are administered to comfort the patient and to ease apprehension during recovery. Morphine, 0.1 to 0.2 mg/kg, may be used subcutaneously without significant respiratory depression.[5] If a caudal median sternotomy is performed, intrapleural bupivicane may be administered for short term local analgesia.

Prognosis

Death from diaphragmatic hernia is usually attributed to hypoventilation resulting from lung compression, shock, cardiac dysrrhythmias, and multiorgan failure.[5] The survival rate in dogs varies from 52 to 88%.[8,10,40,41] Approximately 1 in 3 dogs undergoing repair within the first 24 hours after trauma dies, as opposed to 1 in 10 dogs in which repair is delayed for 1 to 3 weeks.[5] In dogs that had chronic diaphragmatic hernias repaired more than 1 year after trauma, 73% of the deaths were attributed to a problem unrelated to the hernia.[5]

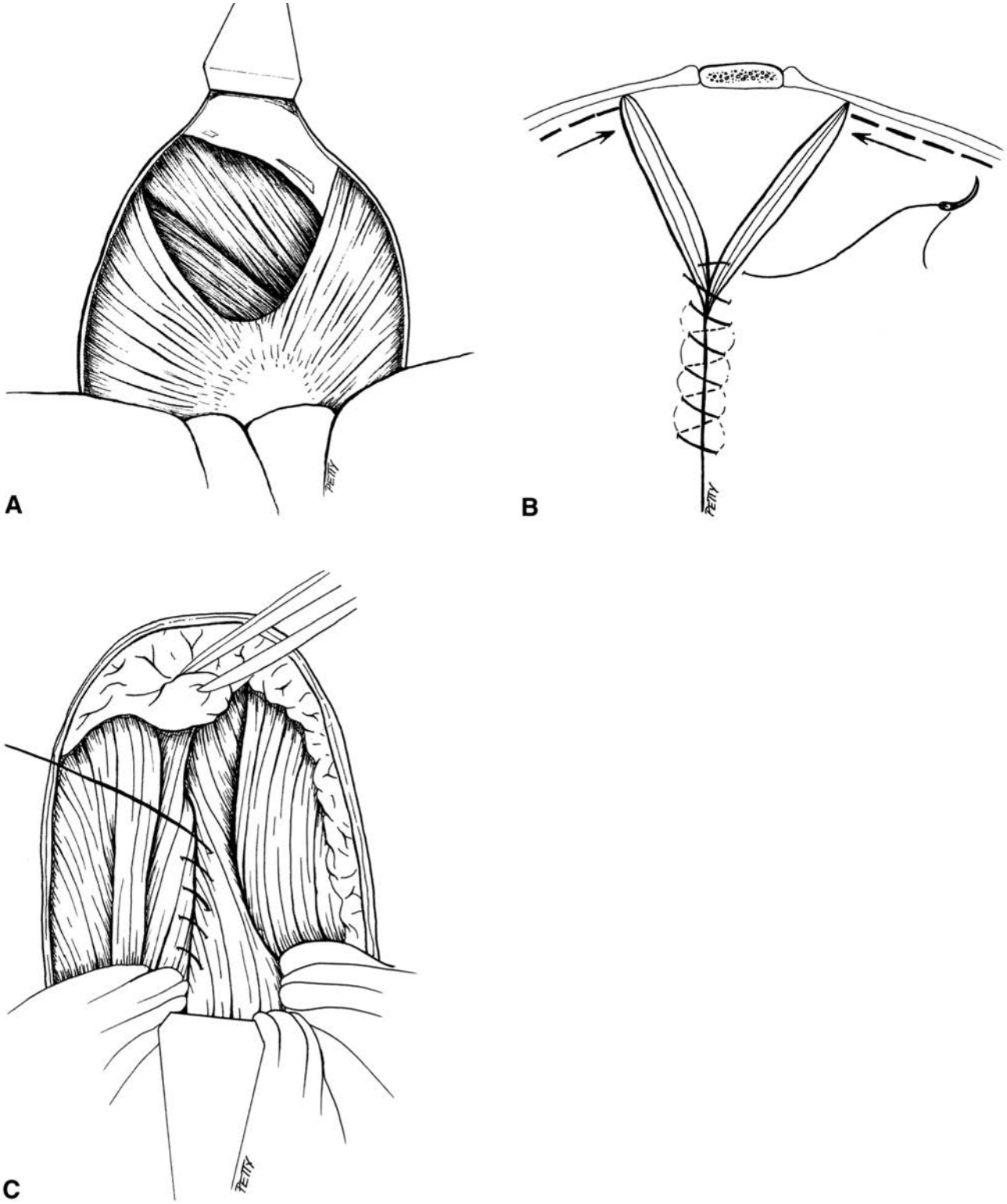


Figure 22-4. A. A large defect in the diaphragm is shown. **B.** Paracostal incisions are made to release the diaphragm from restrictive scar. **C.** The margins of the diaphragm are apposed using a simple continuous pattern. The paracostal margins may be apposed using interrupted mattress sutures or sutures that encircle the costal arch.

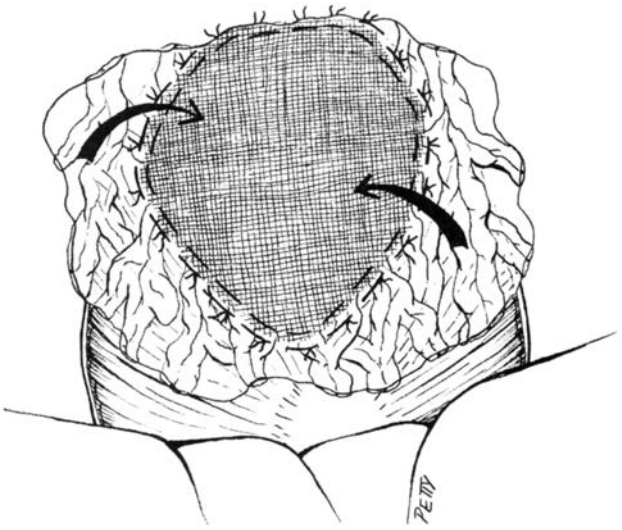


Figure 22-5. In this view, a large defect in the diaphragm is covered with an omental flap intitially. Polypropylene mesh is placed over the omentum and is secured to the margins of the diaphragm defect with mattress sutures. The remainder of the omental pedicle is sutured over the abdominal side of the mesh.

References

1. Dronen SC. Disorders of the chest wall and diaphragm. Bmerg Med Clin North Am 1983;1:449.

2. Ticer JW, Brown SG. Thoracic trauma. In: Ettinger SJ, ed. Veter. mary internal medicine. Philadelphia: WB Saunders, 1975.

3. Marchand P. A study of the forces productive of gastro oesopha. geal regurgitation and hemiation through the diaphragmatic hiatus. Thorax 1957;12:189.

4. Bellenger CR, et al. Bile pleuritis in a dog. J Small Anint Pract 1975;l6:575.

5. Johnson KA. Diaphragmatic, pericardial, and hiatal hernia. In Slatter DH, ed. Textbook of small animal surgery. 2nd ed. Phila. deiphia: WB Saunders, 1985:485.

6. Altura BM, Lefer AM, Schumer W. Handbook of shock and trauma. New York: Raven Press, 1983.

7. Spackman CJA, et al. Thoracic wall and pulmonary trauma in dogs sustaining fractures as a result of motor vehicle accidents. J Am Vet Med Assoc 1984;185:975.

8. Boudrieau RJ, Muir WE. Pathophysiology of traumatic diaphragmatic hernia in dogs. Compend Contin Educ Pract Vet 1987;9:379 385.

9. Bjorlirig DE. Management of thoracic trauma. In: Birchard S. Sherding S. eds. Saunders manual of small animal practice Philadelphia: WB Saunders, 1994:593 599.

10. Stokhof AA. Diagnosis and treatment of acquired diaphragmatic hernia by thoracotomy in 49 dogs and 72 cats. Vet Q 1986; 8:177.

11. Wilson GP, Muir WW. Diaphragmatic hernia, In: Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.

12. Wilson GP, Hayes HM. Diaphragmatic hernia in the dog and cat: a 25 year overview. Semin Vet Med Surg (Small Anim) 1986;1:318 326.

13. Wilson GP, Newton CD, Burt JK. A review of 116 diaphragmatic hernias in dogs and cats. JAm Vet Med Assoc 1971;159:11421145.

14. Boudrieau RJ. Traumatic diaphragmatic hernia. In: Bojrab MJ ed. Current techniques in small animal surgery. 3rd ed. Philadelphia: Lea Er Febiger, 1990:309 314.

15. Sullivan M, Lee R. Radiological features of 80 cases of diaphrafmatic rupture. J Small Anim Pract 1989;30:561.

16. Stowater JL, Lamb CR. Ultrasonography of noncardiac thoracic diseases in small animals. J Am Vet Med Assoc 1989;1955 p. 14.

17. Myer W. Diagnostic imaging of the respiratory system. Birchard S, Sherding S. eds. Saunders manual of small anufla practice. Philadelphia: WB Saunders, 1994:534 535.

18. Punch Pt, Slatter DR. Diaphragmatic hernias. In: Slatter DII ed. Textbook of small animal surgery. Philadelphia: WB SaUfl ders, 1985.

19. Evans SM, Biery DN. Congenital peritoneopericardial diaphrmatic hernia in the dog and cat: a literature review and 17 additional case histories. Vet Radiol 1980;21:108.

20. Stickle RL. Positive contrast celiography (peritoneograPhY) for the diagnosis of diaphragmatic hernia in dogs and cats. J Vet Med Assoc 1984;185:295.

21. Kolata RJ, Kraut NH, Johnston DE. Patterns of trauma in urban dogs and cats: a study of 1000 cases. J Am Vet Med Assoc S01974;164:499 502.

22. Shapiro BA, Harrison RA, Walton JR. Clinical application of blood gases. 3rd ed. Chicago: New York Medical Publishers, 1982.

Congenital Diaphragmatic Hernia

Jamie R. Bellah

Introduction

About 5% to 10% of diaphragmatic hernias are congenital.[1-3] Congenital pleuroperitoneal hernia[4-8] and congenital peritoneopericardial diaphragmatic hernia[8-14] have been reported in puppies and kittens. Pleuroperitoneal hernias are thought to develop when the pleuroperitoneal membrane fails to fuse with the pleuroperitoneal canal during development of the diaphragm. This defect is proposed to be heritable by an autosomal recessive mechanism.[6,16,17] Congenital peritoneopericardial diaphragmatic hernias are thought to be the result of a uterine accident during embryogenesis and are not heritable.[12,18,19] The ventral diaphragmatic defect is believed to result from faulty development of the septum transversum.[18] Because congenital peritoneopericardial diaphragmatic hernia may or may not be associated with craniventral abdominal defects, some of these hernias are not easily identified at birth and some are obvious.[12]

Clinical Signs

Clinical signs of congenital diaphragmatic hernia may be identified at any age. Multiple breeds of dogs have been affected and in cats the domestic longhair and Himalayan breeds are over represented.[20] Overt structural defects such as cranioventral abdominal hernia result in an earlier diagnosis, often before 2 years of age. The diagnosis may be incidentally noted while radiographing the thorax for another reason, or it may be found at necropsy.[11,12,14] Respiratory signs including dyspnea, tachypnea, coughing, and wheezing are common, but many nonspecific signs such as vomiting and diarrhea may be identified.[21] Respiratory signs may worsen after eating.[17] Auscultation of the thorax may reveal muffled heart sounds, a heart murmur, and abnormal position of the apex beat.[12,21,20] An electrocardiogram

may reveal electrical alternans or may be normal.[21] Radiographs of the thorax usually reveal an ovoid cardiac silhouette that joins the ventral diaphragm ventrally. Gas-filled loops of bowel may be seen over the cardiac silhouette.[14,21] Congenital peritoneopericardial hernias are often symmetrical in appearance on radiographs whereas thoracic abnormalities in pleuroperitoneal hernias may be assymetrical.[8] Pectus excavatum and sternal abnormalities may be seen with congenital diaphragmatic hernias in cats.[20] Other diagnostic procedures that may be used include administration of contrast material into the upper gastrointestinal tract, pneumoperitoneography or contrast peritoneography, and ultrasonography.[10] Pneumoperitoneogrpahy may induce pneumothorax and therefore may risk decompensation so use of aqueous contrast is preferred.[8] Ultrasonography from the right fifth intercostal space may reveal cardiac tamponade if liver lobes herniate into the pericardial sac and produce an effusion.[10,21] In general, ultrasonagraphic diagnosis of diaphragmatic hernia is difficult.[22] Thoracoscopy can be used to directly observe the abdominal structure but careful inflation pressures are necessary to avoid compromising ventilation.[22]

Congenital Diaphragmatic Hernia with Cranioventral Abdominal Defects

Congenital cranioventral abdominal wall defects in puppies occur cranial to the umbilicus, but they may extend caudally toward and to the umbilicus. (Figure 22-6). The cranial extent of the defect is often in the area of the commonly absent xiphoid process. Although cranioventral abdominal hernias are not frequently encountered in small animal practice, the clinician must recognize that the abnormality differs from the much more common umbilical hernia. Cranioventral abdominal hernias are commonly associated with four other defects, which are recognized as a syndrome in humans and which have been reported in dogs.[12,13] Cranioventral abdominal hernia, failure of caudal sternal fusion, intracardiac defects (most commonly ventricular septal defect) and caudoventral pericardial defect may commonly accompany a congenital diaphragmatic hernia.[12,13] These defects may occur in varying degrees, depending on the individual dog and they do not always appear together. Commonly, the heart has no apparent abnormality. This pentalogy of defects has been noted in several breeds, including cocker spaniels, Weimaraners dachshunds, and collies, and I have seen it in two kittens. This syndrome is similar in some respects to thoracoabdominal ectopia cordis in human infants and has been termed peritoneopericardial diaphragmatic hernia in small animals.[14,18] A recent report did not find abnormalities identical to the pentalogy found in puppies but skeletal and nonskeletal abnormalities did occur in 8 of 67 cats.[20] Peritoneopericardial diaphragmatic hernias are not always associated with cranioventral abdominal wall defects or intracardiac defects, and they are often difficult to detect unless clinical signs are obvious (usually exercise intolerance or a restrictive breathing pattern).

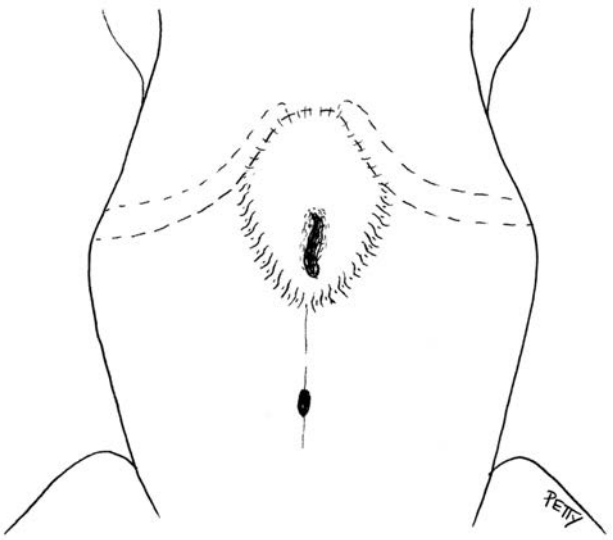


Figure 22-6. Drawing of the cranial abdominal region of a male puppy with a cranioventral abdominal hernia. The position of the hernia is cranial to the umbilicus and is centered in the region of the xiphoid process.

The sternum normally fuses from cranial to caudal in dogs, and the abdominal wall fuses from caudal to cranial. The ventral portion of the diaphragm is thought to originate from the septum transversum, which develops at the same time as cardiac septation; therefore, it seems reasonable that disruption of fetal development at this particular time could cause defects in both regions. Dogs do not have a communication between the pericardial cavity and the peritoneal cavity so if such a communication is present congenitally, it is due to a defect in development. The pericardium normally attaches to the ventral diaphragm by the sternopericardial ligament and visceral mediastinum. Communication of the peritoneal and pericardial cavities is not always obvious in this defect.

In human beings, these defects are attributed to a uterine accident and are not considered heritable. Parents with children affected with thoracoabdominal ectopia cordis have gone on to have anatomically normal children thereafter. No data support heritability of the pentalogy of defects in dogs or cats.

Surgical Correction

Surgical repair of the cranioventral abdominal defect and the diaphragmatic defect can be done early (I have performed such operations on animals as young as 7 weeks of age), usually between 8 and 12 weeks of age. The puppies are usually masked with isoflurane to induce and maintain general anesthesia unless they have significant respiratory restriction. In the latter example, anesthesia may be induced with propofol with prompt intubation, so ventilation may be carefully assisted. All puppies with these defects benefit from assisted ventilation because of the space-occupying abdominal viscera within their caudal mediastinum and/or pericardial sac.[13,23] Liver lobes, gall bladder, omentum and small intestine are commonly found in the caudal mediastinum or pericardial sac, and this appears to be similar in cats with congenital diaphragmatic hernias.[20]

Surgical correction of the defects follows a midline abdominal incision that allows identification of the triangular diaphragmatic defect, the pericardial defect, and the flared, unfused caudal sternebrae (Figures 22-7 to 22-10). In most puppies, the diaphragm

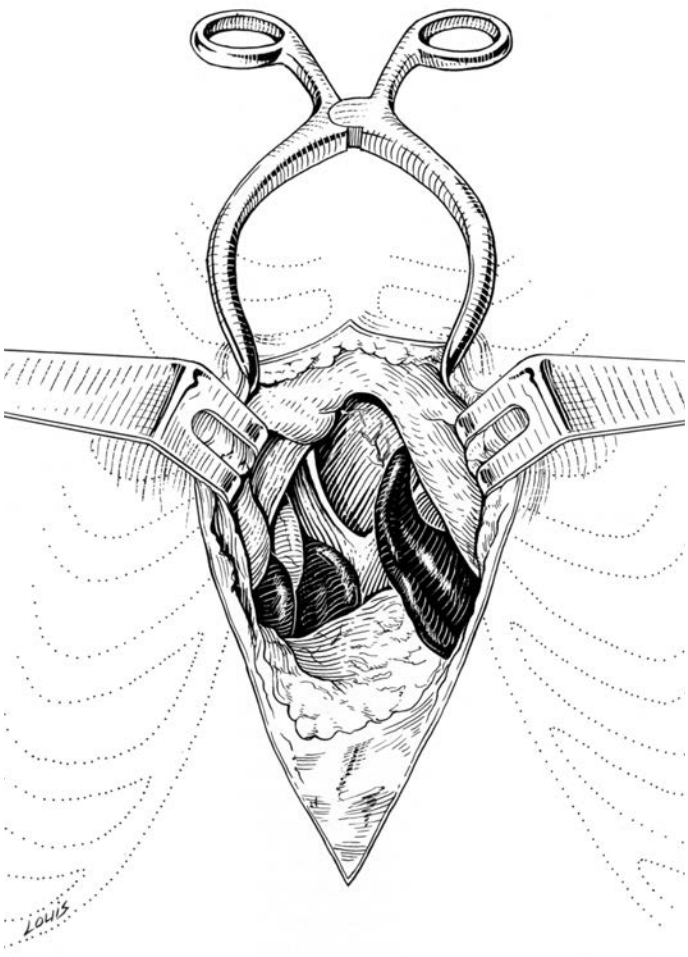


Figure 22-7. Drawing of the surgeon's view of a congenital diaphragmatic hernia before surgical correction. Notice the flared costal arches, absence of a xiphoid process, and a smooth-bordered V-shaped diaphragmatic defect. (From Bellah JR, Whitton DL, Ellison GW, et at. Surgical correction of concomitant cranioventral abdominal wall, caudal sternal, diaphragmatic, and pericardial defects in young dogs. Am Vet Med Assoc 1989; 195:1722.

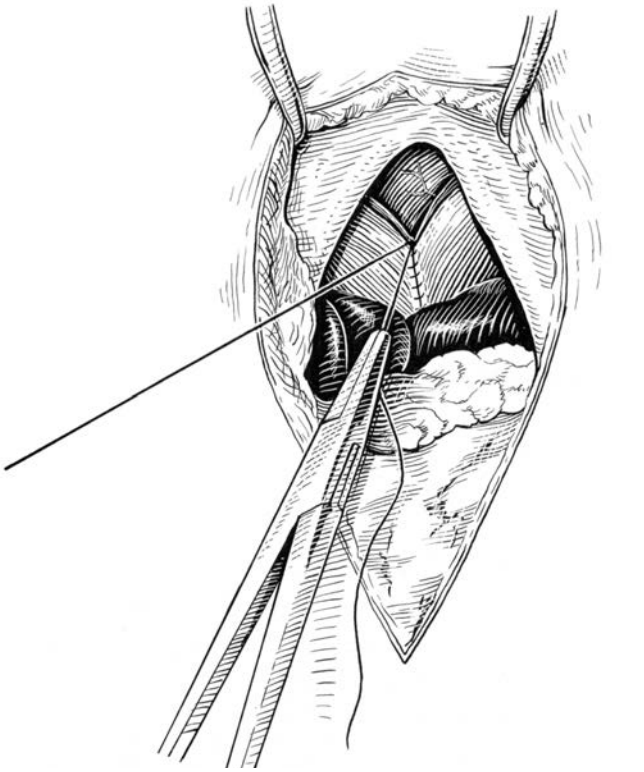


Figure 22-8. After incising the fascia on the abdominal side of the diaphragmatic defect, a simple continuous suture pattern of 3-0 polypropylene is used to appose the crura of the diaphragm. (From Bellah JR, Whitton DL, Ellison GW, et al. Surgical correction of concomitant cranioventral abdominal wall, caudal sternal, diaphragmatic, and pericardial defects in young dogs. J Am Vet Med.

defect can be closed by using a simple continuous pattern from the dorsalmost aspect of the defect and continuing in a ventral direction (toward the sternal defect). When the diaphragm apposition becomes tense, the suture can be tied, and mattress sutures can be preplaced from the diaphragm to the costal arch to complete the separation of the thoracic and abdominal cavities. The pleural cavity does not have to be invaded or opened when this defect is closed. Accidental opening of the pleural cavity by dissection or by needle penetration is possible while suturing. After the mattress sutures are tied, the abdominal defect can usually be apposed with simple interrupted nonabsorbable suture, followed by routine subcutaneous and skin apposition. When closure of the defects as described is routine, young puppies and kittens recover quickly and often do not require specialized postoperative care, other than that appropriate for pediatric patients. Sometimes, the diaphragmatic defect is too wide to appose without excessive tension. Three methods can be used to alleviate this problem. First, the caudal sternal costal arch can be apposed by encircling with nonabsorbable suture. This can effectively decrease the distance between the right and left edges of the diaphragm and therefore can reduce the tension on the closure. The pliability of the unfused costal arch in the young puppies and kittens makes this maneuver possible. If caudal sternal apposition does not narrow the defect to a size that can be apposed without tension, the pericardium can be incised cranial to the diaphragm and flaps can be created to close the defect.[24] A free graft of pericardium may also be used to close the defect.[24] The third method is insertion of polypropylene mesh to separate the body cavities. Omentum can be mobilized and sutured to each side of the implant to cover its surface. Other synthetic implants, such as lyophilized collagen sheeting (derived from porcine submucosa) have been used successfully.[17]

Congenital diaphragmatic hernias that are not associated with ventral abdominal wall defects and that lack obvious clinical signs may not be diagnosed until much later in the pet's life, often when the animal is radiographed for another reason. Correction of all congenital diaphragmatic hernias may not be necessary, especially hernias diagnosed in old animals with no clinical signs of abdominal viscera (usually omentum) in the caudal mediastinum or the pericardial sac. However, dogs or cats with clinical signs of congenital diaphragmatic hernia that are adults when the diagnosis is made are much more likely to have intrathoracic adhesions that prevent simple replacement of abdominal viscera into the abdominal cavity. These adhesions may require extension of the diaphragmatic defect or a caudal midline sternotomy to provide enough exposure for safe dissection within the caudal thorax. Closure of the diaphragmatic defect often requires releasing incisions from the paracostal

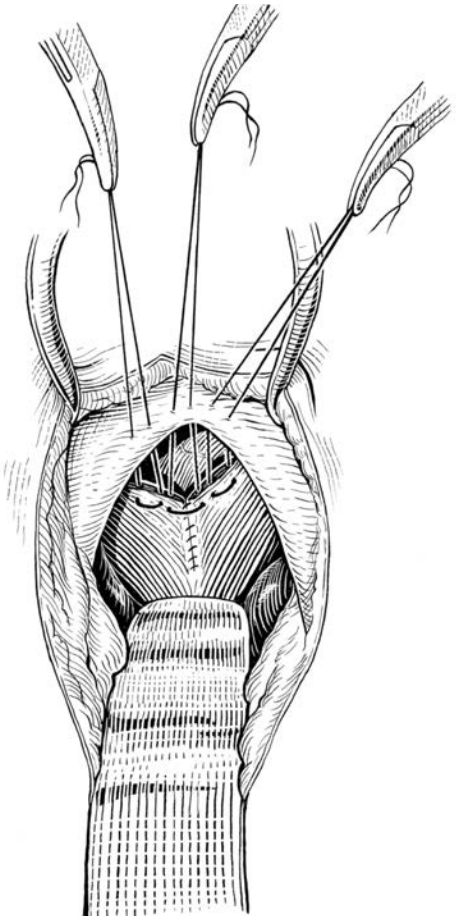


Figure 22-9. When placement of the continuous suture is complete, three horizontal mattress sutures are placed to close the remaining defect between the diaphragm and the costal arch. (From Bellah JR, Whitton DL, Ellison GW, et al. Surgical correction of concomitant cranioventral abdominal wall, caudal sternal, diaphragmatic, and pericardial defects in young dogs. J Am Vet Med Assoc 1989; 195:1722.)

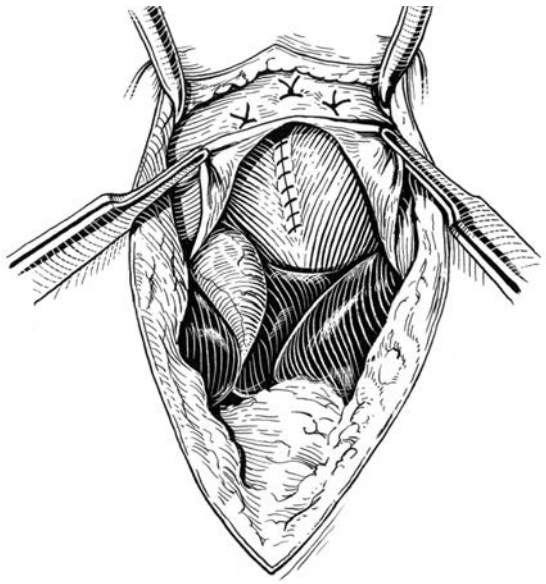


Figure 22-10. Closure of the diaphragmatic defect is complete after the mattress sutures are tied. (From Bellah JR, Whitton DL, Ellison GW, et al. Surgical correction of concomitant cranioventral abdominal wall, caudal sternal, diaphragmatic, and pericardial defects in young dogs. J Am Vet Med Assoc 1989; 195:1722.)

arch using the inherent elasticity of the diaphragm to facilitate apposition. Entrance into the pleural space is inevitable in most situations and requires assisted ventilation during surgery, chest drain insertion, and intensive postoperative management for 24 to 48 hours.

Postoperative management of pain in dogs that have undergone diaphragmatic herniorrhaphy and especially those that have exposure extended by caudal midline sternotomy require analgesia.[25] Use of opioids in combination with non-steroidal antiinflammatory drugs will provide sufficient analgesia. Chest drains, when necessary, are usually removed 12 to 24 hours postoperatively.

References

1. Boudrieau SJ, Muir WW. Pathophysiology of traumatic diaphragmatic hernia in dogs. Compend Contin Educ Pract Vet 1987;9:379.

2. Wilson GP, Hayes JIM. Diaphragmatic hernia in the dog and cat: a 25-year overview. Semin Vet Med Surg (Small Anim) 1986;1:318-326.

3. Wilson GP, Newton CD, Burt JK. A review of 116 diaphragmatic hernias in dogs and cats. J Am Vet Med Assoc 1971;159:11421145.

4. Noden DM, De Lahunta A. The embryology of domestic animals: developmental mechanisms and malformations. Baltimore: Williams & Wilkins, 1985.

5. Pass MA. Small intestines. In: Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1985.

6. Feldman DB, et al. Congenital diaphragmatic hernia in neonatal dogs. J Am Vet Med Assoc 1968;153:942.

7. Keep JM. Congenital diaphragmatic hernia in a cat. Aust VetJ 1950;26:193.

8. Mann FA, Aronson E. Surgical correction of a true congenital pleuroperitoneal diaphragmatic hernia in a cat. J Amer Anim Hosp Assoc 1991:27:501-507.

9. Frye FL, Taylor Don. Pericardial and diaphragmatic defects in a cat. J Am Vet Med Assoc 1968;152:1507.

10. Hay WH, et al. Clinical, echocardiographic, and radiographic findings of peritoneopericardial diaphragmatic hernia in two dogs and a cat. J Am Vet Med Assoc 1989;195:1245.

11. Punch P1, Slatter DH. Diaphragmatic hernias. In Slatter DH, ed. Textbook of Small Animal Surgery. Philadelphia: WB Saunders, 1985.

12. Bellah JR, Spencer CP, Brown DJ, Whitton DL. Congenital cranioventral abdominal wall, caudal sternal, diaphragmatic, pericardial, and intracardiac defects in Cocker Spaniel littermates. J Am Vet Med Assoc 1989; 194:1741-1746.

13. Bellah JR, Whitton DL, Ellison GW, Phillips L. Surgical correction of concomitant cranial ventral abdominal wall, caudal sternal, diaphragmatic, and pericardial defects in young dogs. J Am Vet Med Assoc 1989; 195:1722-1726.

14. Evans SM, Beiry DN. Congenital peritoneopericardial diaphragmatic hernia in the dog and cat: a literature review and 17 additional case histories. Vet Radiol 1980;21:108.

15. Eyster GJ, et al. Congenital pericardial diaphragmiatic hernia and multiple cardiac defects in a litter of collies. J Am Vet Med Assoc 1977;170:516.

16. Valentine BA, et al. Canine congenital diaphragmatic hernia. J Vet Intern Med 1988;2:109.

17. Hunt GB, Johnson KA. Diaphragmatic, Pericardial, and Hiatal Hernia. In Slatter D (Ed.), 3rd Edition, Saunders, Philadelphia, 2003; 471-487.

18. Kaplan LC, et al. Ectopia Cordis and cleft sternum: evidence for

mechanical teratogenesis following rupture of the choion or yolk sac. Am J Med Genet 1985;21:187.

19. Noden DM, De Lahunta A. The embryology of domestic animals: developmental mechanisms and malformations. Baltimore: Williams & Wilkins, 1985.

20. Reimer BS, Kyles AE, Filipowicz DE, Gregory, CR. Long-term outcome of cats treated conservatively or surgically for peritoneopericardial diaphragmatic hernia: 66 cases (1987-2002). J Amer Vet Med Assoc 2003;224: 728-732.

21. Thomas WP. Pericardial Disorders. In: Ettinger SJ, ed. Textbook of veterinary internal medicine: diseases of the dog and cat. 3rd ed. Philadelphia: WB Saudners, 1989.

22. Bellah JR. Diaphragmatic Hernias. Compendium's Standard of Care in Emergency Medicine and Critical Care. June 2005;7.5:1-7.

23. Bednarski RM. Diaphragmatic hernia: anesthetic considerations. Semin Vet Med Surg (Small Anim) 1986;1:256-258.

24. Johnson KA. Diaphragmatic, pericardial, and hiatal hernia. In: Slatter DH, ed. Textbook of small animal surgery. 2nd ed. Philadelphia: WB Saunder, 1985:485.

25. Bellah JR. Traumatic Diaphragmatic Hernia. In Bojrab MJ (Ed), Current Techniques in Small Animal Surgery, 4th Edition, Williams and Wilkins, Baltimore, 1998: 315-321.

Chapter 23

Peritoneum and Abdominal Wall

Closure of Abdominal Incisions

Eberhard Rosin

The most common surgical procedure in small animal practice is incision and closure of the abdominal cavity. Although use of simple interrupted sutures to appose the peritoneum and all fascial layers is the traditional method to close an abdominal incision, a simple continuous suture pattern for a single-layer closure of the rectus fascia, without concern for the peritoneum, is a faster and safe alternative. In paralumbar grid incisions, a layered simple continuous closure is used if the patient's musculature is well developed.

Surgical Anatomy

The external leaf of the rectus sheath is composed of the aponeurosis of the external abdominal oblique muscle, most of the aponeurosis of the internal abdominal oblique muscle, and, near the pubis, a portion of the aponeurosis of the transversus abdominis muscle. The internal leaf of the rectus sheath consists of a portion of the aponeurosis of the internal abdominal oblique muscle, the aponeurosis of the transversus abdominis muscle, and the transversalis fascia. In the caudal third of the abdominal wall the internal leaf disappears. The aponeurosis of the internal abdominal oblique muscle joins the external leaf, and the rectus abdominis muscle is covered only by a thin continuation of the transversalis fascia and peritoneum (Figure 23-1).[1]

Healing of the Peritoneum

The peritoneum is a layer of flat cells, cemented edge to edge at their intercellular margins. This mesothelial layer is supported by an underlying layer of areolar tissue that blends with the connective tissue of the transversalis fascia. Within the peritoneal cavity, a small amount of serous fluid contains freely floating cells including macrophages, desquamated mesothelial cells, and small lymphocytes.[2]

During the first 2 days after wounding, the peritoneal defect is red, with a glistening, slightly irregular surface. During the next 5 or 6 days, the color fades gradually, the surface becomes smoother, and the defect develops a homogeneous, transparent gray sheen. Abdominal tissues slide readily over the defect. Gradually, this gray sheen becomes more opaque until, after 2 or 3 weeks, the area usually is indistinguishable from normal peritoneum. Milky streaks beneath the wound area, apparently resulting from scar formation, may remain. These changes occur simultaneously throughout the entire defect. Large wounds heal as rapidly as small wounds.[2-4]

Microscopically, defects in the peritoneum are covered rapidly by macrophages, which are present in large number in the

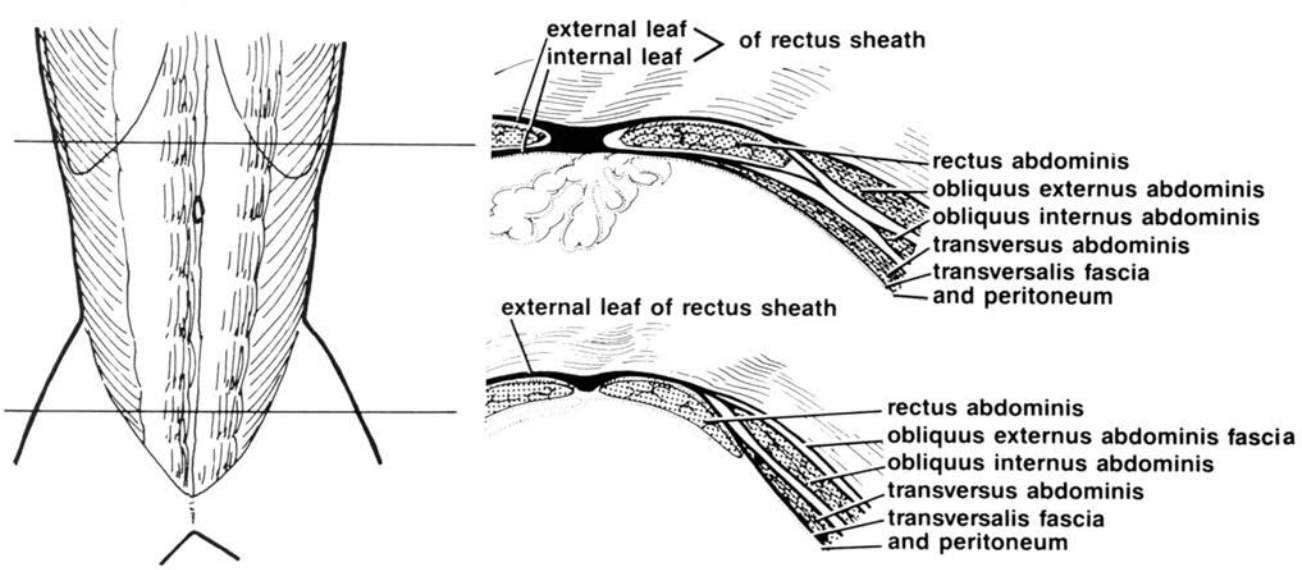


Figure 23-1. Cross sections showing the anatomy of the sheath of the rectus abdominis muscle in the cranial and caudal portions of the abdominal wall.

peritoneal fluid bathing the wound surface. The wound also is invaded by monocytes and histiocytes from blood and underlying exposed tissues. Cells from peritoneal fluid, blood, or underlying tissues differentiate to form fibroblasts, and the superficially located cells undergo metaplasia, gradually forming mesothelial cells. At the same time, intact mesothelial cells at the perimeter of the wound help in the repair by proliferation and migration. Small defects in the peritoneum are healed by proliferation of adjacent mesothelial cells, whereas large defects are covered by undifferentiated cells that then become mesothelial cells.[2-4]

Peritoneal defects that are sutured have a higher incidence of adhesions than defects that are left open to heal. The stimulus for adhesion formation is not the peritoneal defect itself, but rather the ischemic tissue that results when edges of the defect are brought together by sutures.

No evidence, experimental or clinical, supports the contention that closure of the peritoneum is necessary for wound strength, to minimize postoperative dehiscence or hernia formation, or to minimize the development of adhesions. On the contrary, experimental and clinical studies in dogs, horses, and human patients indicate that suturing the peritoneum should be avoided to minimize the incidence of postoperative intra-abdominal adhesions.[3-7]

Closure Alternatives

Closure of the Internal and External Leaves of the Rectus Sheath Versus Closure of the External Leaf Only

Closure of the paramedian abdominal incision by apposition of the internal and external leaves of the rectus sheath is traditional and has proved successful for years of clinical experience. However, closure of the internal leaf takes time and requires that the abdominal wall be manipulated to expose the internal leaf, which frequently retracts after incision. Studies have refuted the admonition that closing only the external leaf of the rectus sheath provides insufficient strength to the incision. In a biomechanical study of healing abdominal incisions in the dog, the strength of incisions closed by suturing the internal and external leaves of the rectus sheath and the strength of incisions closed by suturing the external leaf only were similar.[8]

Simple Interrupted Versus Simple Continuous Suture Pattern

The traditional method to close an abdominal incision is simple interrupted sutures. The same incision can be closed more quickly using a simple continuous pattern, with no difference in wound healing. In a randomized prospective trial of 3135 human patients comparing continuous and interrupted abdominal midline incision closure, no difference was found in the incidence of wound dehiscence.[9] In clinical use of simple continuous closure of abdominal incisions in over 5000 dogs and cats, the incidence of dehiscence is negligible.

Closure Techniques

Midline Incision

With an incision through the linea alba in the cranial two-thirds of the abdominal hall, fibers of the rectus abdominis muscle are not exposed, and the linea alba, including the peritoneum, can be apposed accurately by full-thickness sutures. An adequate portion of fascia must be included with each suture, and the falciform ligament must not be interspersed between the edges of the linea alba (Figure 23-2). Although the traditional suture pattern is simple interrupted, a simple continuous pattern is a safe and faster alternative.

In the caudal third of the abdominal wall, the width of the linea alba decreases. An incision here frequently exposes the rectus abdominis muscle. Because fibers of the rectus abdominis muscle have little holding power, sutures are not full thickness. Instead, sutures are placed to include an adequate portion of the

external leaf of the rectus sheath on each side of the incision and to appose this fascia accurately without interspersion of rectus abdominis muscle (Figure 23-3). The transversalis fascia and the peritoneum are not included in the sutures. Sutures traditionally are simple interrupted, but a simple continuous pattern is a satisfactory alternative.

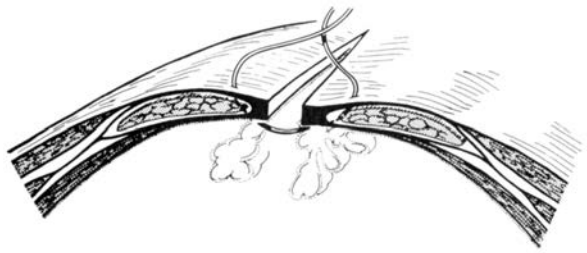


Figure 23-2. Linea alba incision in the cranial two-thirds of the abdominal wall closed by a full-thickness suture placed carefully to avoid the falciform ligament.

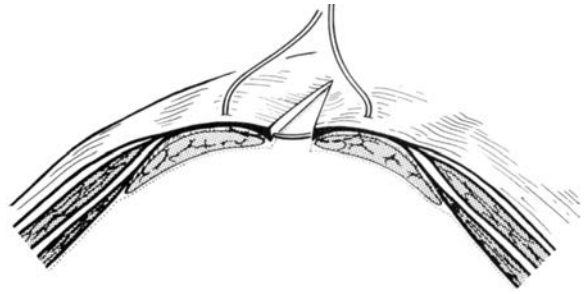


Figure 23-3. Midline incision in the caudal third of the abdominal wall closed by a suture placed to appose the external leaf of the rectus sheath accurately.

Paramedian Incision

If the incision is paramedian in the cranial two-thirds of the abdominal wall, the linea alba will be on one side and the external and internal leaves of the rectus sheath and rectus abdominis muscle will be exposed on the other side, or on both sides of the incision, the internal and external leaves of the rectus sheath and rectus abdominis muscle will be exposed. The external leaf of rectus sheath is closed with a simple interrupted or continuous pattern. The internal leaf of the rectus sheath and the peritoneum are left unsutured (Figure 23-4).



Figure 23-4. Single-layer closure of only the external leaf of the rectus sheath. Care is taken to avoid interspersing rectus muscle between the edges of the rectus sheath.

A paramedian incision in the caudal third of the abdominal cavity is closed by suturing the rectus fascia in a simple interrupted or continuous pattern. The transversalis fascia and peritoneum have little strength and are not sutured.

Simple Continuous Suture Technique

Acceptable suture materials include polyglycolic acid, polyglactin 910, polydioxanone, polyglyconate, polypropylene, and nylon. Surgical gut, stainless wire, and multifilament nonabsorbable suture materials should not be used. Suture size is based on patient size: 3-0 suture material should be used for cats and small breed dogs, 2-0 for medium-sized dogs, 0 for large dogs, and 1 for giant breed dogs.

For a simple continuous suture pattern used in long incisions, more than one strand of suture material is used. Sutures are placed through the linea alba or through the external leaf of the rectus sheath, depending on patient size, and, include a 3- to 10-mm width of fascia on each side of the incision. Sutures are placed 5 to 10 mm apart, depending on the size of the animal. Care is taken to ensure edge-to-edge apposition of the fascia without interspersion of muscle. The internal leaf of the rectus sheath and the peritoneum are not included in the suture pattern.

All knots are placed with care. The first throw is tied with appositional tension only to ensure that tissue is not strangulated. Five additional square, flat throws are placed.[10] After each throw is made, the ends of the suture are pulled tight to make the knot secure. The ends of the suture are cut 4 mm from the knot. As the continuous suture is placed, the rectus fascia must be loosely approximated, not apposed with tension. Wound strength is adversely affected if fascia is closed tightly.[11]

Subcutaneous tissues are closed with the same suture materials, usually a smaller size, placed in simple continuous pattern. Care is taken to avoid cutting the rectus fascia suture during closure of the subcutaneous tissue. Skin is closed with 3-0 nonabsorbable suture placed in a simple interrupted or cruciate pattern, or skin staples are used.

References

1. Evans HE, Christensen GC. Miller's anatomy of the dog. 2nd ed. Philadelphia: WB Saunders, 1979.

2. Ellis H, Ashby EC, Mott TJ. Studies in peritoneal healing: a review. J Abdom Surg 1969,11:110.

3. Hubbard TB, et al. The pathology of peritoneal repair: its relation to the formation of adhesions. Ann Surg 1967; 165: 908.

4. Ellis H. The cause and prevention of postoperative intraperitoneal adhesions. Surg Gynecol Obstet 1971;133:497.

5. Karipineni RC, Wilk PJ, Danese CA. The role of the peritoneum in the healing of abdominal incisions. Surg Gynecol Obstet 1976:142:729.

6. Swanwick RA, Milne FJ. The non-suturing of parietal peritoneum in abdominal surgery of the horse. Vet Rec 1973:93:328.

7. Ellis H, Heddle R. Does the peritoneum need to be closed at laparotomy? Br J Surg 1977;64:733.

8. Rosin E, Richardson S. Effect of fascial closure technique on strength of healing abdominal incisions in the dog: a biomechanical study. Vet Surg 1987; 16:269.

9. Fagniez P, Hay JM, Lacaine F, et al. Abdominal midline incision closure: a multicentric randomized prospective trial of 3,135 patients, comparing continuous vs interrupted polyglycolic acid sutures. Arch Surg 1985:120:1351.

10. Rosin E, Robinson GM. Knot security of suture materials. Vet Surg 1989:18:269.

11. Stone KI, vonFraunhofer JA, Masterson BJ. The biochemical effects of tight suture closure upon fascia. Surg Gynecol Obstet 1986,163:448.

Closed Peritoneal Drainage

Giselle Hosgood

Indications

The use of drains to remove fluid, pus, or contaminated material from the closed peritoneal cavity is hereby referred to as closed peritoneal drainage. The use of drains in the peritoneal cavity is primarily indicated in the management of peritonitis although there is some evidence to show that appropriate surgical and medical management without drainage is equally effective.[1-4] Other indications for peritoneal drainage include diagnostic peritoneal lavage, peritoneal dialysis and administration of peritoneal chemotherapy.[5] Placement of drains after routine abdominal procedures is discouraged, and the use of drains should not replace meticulous surgical technique. The use of drains can be associated with multiple complications, and peritoneal drainage is not a reliable indicator of wound or body cavity events; the absence of drainage does not always imply the absence of fluid and fluid production can be induced by the presence of the drain alone.[1]

Closed-collection systems

Connecting a drain to a collection system has several advantages, and is strongly recommended. A collection system, whether by passive or active drainage, reduces the risk of ascending infection through the lumen of the drain. Ascending infection is one of the most common complications of peritoneal drainage, a function of both bacterial load migrating up the drain and decreased local tissue resistance because of the presence of the drain.[6] Although bacteria can also migrate along the outside of the drain,[7] a closed system greatly reduces the bacterial load. Protection of the drain by a sterile bandage can reduce bacterial migration along the outside of the wound. Collection systems also eliminate the chance of saturating the bandage covering an open drain. A wet bandage over a freely draining passive drain provides an additional source of contamination by bacterial strike-through from the environment. Collection systems also allow accurate assessment of fluid character and volume.

Passive Drainage

The abdomen can be compared with a fluid-filled, flexible container with two separate pressure zones. Positive atmospheric pressure exists within the gastrointestinal tract, whereas the peritoneal cavity has an extraluminal subatmospheric pressure between -5 and -8 cm water; the pressure is most negative in the cranial abdomen near the diaphragm.[8] Passive drainage of fluid from the peritoneal cavity requires an air vent to break the vacuum and to create a positive atmospheric pressure within the peritoneal cavity.[8] Positive pressure occurs after celiotomy or after a stab incision into the abdomen for drain placement. Passive peritoneal drainage relies on a pressure differential between the peritoneal cavity and the environment and functions primarily by overflow. Passive drainage is gravity dependent, and the drain provides a tract of least resistance along which excess fluid flows.[2,8] An inexpensive and easily accessible passive collection system is through a sterile intravenous administration set into a sterile bag. Sterile urine collection systems can also be used. Although passive drains are gravity dependent,[1] the resting level of the drain and the collection bag proportionally affect the gravitational force and the rate of drainage. Increasing this distance excessively may promote obstruction of the drain by omentum or intestinal loops; for instance, having a dog in a high cage with the collection bag on the floor.

Active Drainage

Active drainage requires an external vacuum to create negative pressure within the peritoneal cavity. This allows drainage to occur independent of gravity. The vacuum is achieved by connection of the drain to a compressible container or a constant, low-pressure, suction device (Figure 23-5).[1,2] Some commercial collection systems have one-way valves to prevent fluid reflux from the collection system into the peritoneal cavity. Suction should be applied to the drain before complete abdominal closure to prevent occlusion of the drain by intraluminal blood clot formation or tissue debris. The optimal level of suction is unclear. Low-level suction is effective, but higher levels are not always harmful and may remove more fluid. Suction levels between -9 mm Hg (-12 cm water)[9] and -15 mm Hg (-20 cm water)[10] are typically used in wound drainage in people, although higher levels of suction, -80 mm Hg (-112 cm water)[11] and -150 mm Hg (-200 cm water),[12] have been used successfully. Closed active drains are effective in removing large volumes of fluid; however, as the volume of intraperitoneal fluid decreases, active drainage causes suction of tissue, viscera, omentum, or abdominal wall toward the drain, resulting in occlusion.[1,13] Tissue debris may also occlude the lumen. High-level suction may promote obstruction.

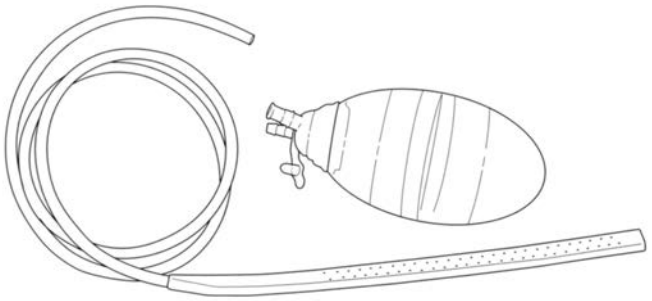


Figure 23-5. A silicone wound drain and compressible collection canister that can be connected together and used for active peritoneal drainage. Note the one-way valve on the canister. Alternately, the drain can be connected to a passive collection system.

Drains Suitable for Peritoneal Drainage

The most suitable drain for use in the peritoneal cavity is a simple tube drain with multiple fenestrations. Variations include channel drains and multilumen drains with channels (Figure 23-6).These tube drains can be connected to an active or passive collection system. Alternate techniques of open peritoneal drainage for the management of pancreatic masses[5] and peritonitis[3] are also reported.

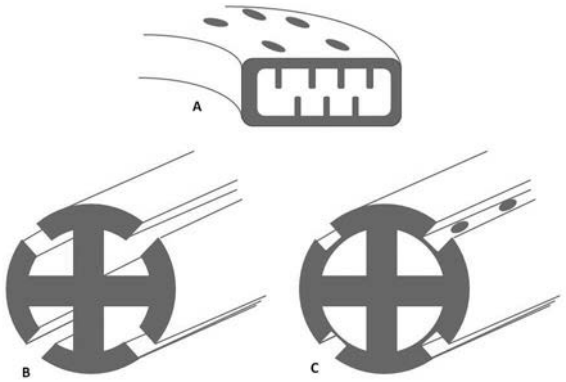


Figure 23-6. Cross-sectional images of multifenestrated silicone wound drain **A**., Channel drain **B**. and multilumen drain with channels **C**.

Simple Tube Drain

The simple tube drain is a single lumen drain that acts primarily by gravity-dependent intraluminal flow. Because most of the drainage is intraluminal, fenestration improves drainage efficiency.[14] However, fenestration reduces the tensile strength of the drain and may predispose to tearing on removal.[15] Channel drains function by extraluminal capillary flow along the channels of the drain. The channelling increases the surface area of the drain, thereby increasing the efficiency. Multilumen drains with channels function by both intra and extraluminal flow whereby channels empty into the lumens via multifenestrations along the length of the drain. Presumably, channelling reduces tissue occlusion against fenestration of the simple tube drains. Pre-fenestrated commercial drains are preferred but fenestrations can be made by hand in a solid drain. Fenestrations should be oval and less than one-third the diameter of the drain, to prevent kinking and tearing.[6] Fenestration using oval-tipped bone rongeurs rather than scissors may give a more precise, controlled cut with easy and safe removal of the fragment in the instrument's jaws.[16] Channel drains can only be purchased. Silicone drains are preferred over plastic (polyvinyl chloride) or rubber drains because silicone is relatively inert (red rubber tubes are the most irritating) and the silicone is soft and pliable. However, silicone drains have less tensile strength than polyvinyl chloride drains, and care is required on removal to prevent tearing.[15] Silicone wound drains are readily available (Cardinal Health Fluid Management Products, 1500 Waukegan Road McGaw Park, IL 60085)

Peritoneal Dialysis Catheter

A modification of the simple tube drain is the multi-fenestrated peritoneal dialysis catheter (Quinton Tenckhoff Peritoneal Catheter, Kendal Healthcare, Covidien, Mansfield, Massachusetts; Figure 23-7).

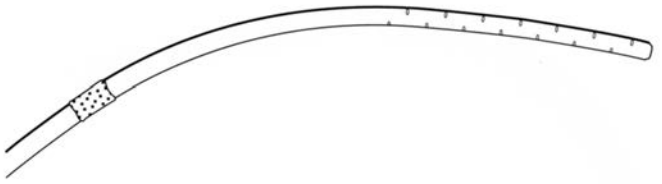


Figure 23-7. A commercial, multifenestrated, peritoneal dialysis catheter. Note the Dacron cuff toward the end of the drain and the radiopaque ridge on top of the drain.

Most peritoneal dialysis catheters are now made of silicone. Some peritoneal dialysis catheters have one or two Dacron cuffs around the tubing that is sutured to the body wall and subcutaneous tissue to stimulate a fibroblastic reaction and to prevent subcutaneous fluid leakage. These catheters are also used for intraperitoneal chemotherapy. Some peritoneal dialysis catheters come with an introducer or trochar which allows for easy percutaneous insertion into the peritoneal cavity. These types of peritoneal catheter are particularly useful for diagnostic peritoneal lavage or intraperitoneal administration of drugs because they can be inserted through a small abdominal incision using local anesthesia in a sedated animal.[5]

Drain Placement

Efficient peritoneal drainage is difficult because of the convoluted nature of the peritoneal cavity, the sometimes intense fibrinous and fibrous reactions encountered during peritonitis, and the ability of the omentum to isolate the drain from the peritoneal cavity. Normal forces associated with movement of the diaphragm, abdominal wall, and intestine affect the intraperitoneal circulation of fluid and cause fluid to pool beneath the diaphragm[16] and in the peritoneal reflections near the distal colon. In addition to normal forces, fluid can become isolated by peritoneal adhesions.[9] Drain placement is extremely important to maximize drainage. Drains are usually placed during celiotomy. Alternately, in acute situations such as diagnostic peritoneal lavage, emergency drainage of fluid from the abdomen (uroabdomen), or for establishment of peritoneal dialysis, a stab incision in the skin of the ventral midline is made, and the drain is "punched" through the body wall. Commercial, simple, peritoneal dialysis catheters and some tube drains come with a stylet-trocar for this purpose. Insertion of these drains in an emergency can often be performed under local anesthesia and sedation.

To drain the peritoneal cavity effectively, two tubular drains may be required, one directed cranially along the ventral abdominal wall toward the diaphragm and the other caudally along the ventral abdominal wall to the peritoneal reflections near the distal colon.[9] Alternately, commercial drains are available that "split", allowing the two sections of the drain to be placed in different directions with the advantage of only having a single collection tube and exit point. The drains should exit close to the midline, in a dependent position, usually between the umbilicus and the xiphoid. The exit incision through the abdominal wall and skin should be only as large as the diameter of the drain.

A small exit incision reduces subcutaneous fluid leakage and subsequent cellulitis and possible incisional herniation. The exit incision should not be so small as to obstruct the drain. The epigastric vessels, which run through the middle of the mammary chains, should be avoided. If the exit incision is small, it can be made between the epigastric vessel and the midline (incision) without weakening the midline celiotomy incision. Exiting lateral to the epigastric vessels moves away from a dependent exit site and may promote subcutaneous fluid leakage and cellulitis. If celiotomy is performed, tacking the omentum to the stomach may help to prevent it from enveloping the drains. The omentum can be excised if it is obviously compromised or heavily contaminated. Excising the falciform fat may help to reduce tissue obstruction of the drains.

The exit tubing can be connected to a collection system, to function by passive drainage or low-pressure suction (40 to 60 mm Hg). All drains should be sutured to the skin using a secure suture such as the Chinese finger trap suture.[18] Suction is applied as soon as the drain is placed, to prevent intraoperative obstruction of the drain with blood clots or tissue debris. All drain exit points should be covered with a sterile bandage on completion of the surgical procedure. If for some reason a closed system is not used, multilayered, thick, absorbent bandage material is indicated to cover the drain, noting that the contact layer must be sterile. Sterile cloth towels and sterile disposable diapers (sterilized with ethylene oxide) make useful absorbent bandage layers.

Postoperative Management

The bandage should be changed as often as required to prevent complete soaking by exudate and possible strikethrough of bacteria from the environment. The frequency of bandage changes is considerably reduced for drains using a collection system, but some leakage can occur through the exit site around the drain. Contamination of the bandage from the environment (urine, feces) can also occur. Use of an indwelling urinary catheter, particularly in male dogs, may help to prevent urine contamination. This is especially useful if the animal is recumbent. Bandaging also helps to prevent self-mutilation of the drainage area and premature removal or damage to the drain by the animal. The volume and nature of the fluid should be monitored closely, at least three to four times a day or more if profuse. The collection system should be changed using sterile technique when it is full or the vacuum has been lost. The vacuum may be lost before the collection system is completely full. Without vacuum and fluid flow, the risk of obstruction of the drain by tissue debris or fibrin and blood clots is increased. In addition, fluid that remains in the collection system for a prolonged period may promote bacterial growth. The drain is removed once the volume of fluid becomes significantly reduced and the fluid becomes serosanguineous. Drainage beyond 2 to 3 days is rarely necessary and persistent fluid production may indicate non-resolving peritonitis or other problems with response to management. The presence of a drain incites an inflammatory reaction and some fluid production (2 to 4 mls/kg/day), hence drainage usually does not cease completely. If drainage ceases suddenly, it may represent drain obstruction rather than resolution of the disease. Fluid may continue to drain for 1 to 2 days after drain removal, and a bandage should remain in place over the exit point to collect drainage and to prevent contamination of the exit site until it is sealed.

Complications

The most common complications of abdominal drains are obstruction and ascending infection. Nosocomial bacterial contamination of the drain and drainage site is a common complication of any drain placement. Retraction of the drain may occur once the animal begins to move and stand. This tends to occur with drains that are not connected to a collection system and that are cut short at the exit site. Suturing the drain securely, at several sites, is also important. Exit site and drain tract cellulitis is not uncommon. This complication is not serious and usually resolves once the drain is removed.

Subcutaneous fluid leakage is more common when peritoneal lavage is used and is particularly noted in the first few hours after surgery. Subcutaneous fluid leakage and cellulitis can be reduced by using a short subcutaneous tunnel between the skin and the abdominal wall exit site for the drain and by having the exit site in a dependent position. The Dacron cuffs on the peritoneal dialysis catheter and disc catheter also help to reduce this complication. Applying a water-repellent ointment to the skin around the exit site (petroleum jelly) may help to prevent skin irritation from drainage fluid. Hypoproteinemia and hypoalbuminemia are significant complications of peritonitis and drainage, but are not complications of drainage per se. Close monitoring of plasma protein concentrations in animals with peritonitis is imperative, and intravenous plasma or colloid infusion may be required.

Negative Pressure Wound Therapy – Modified Closed Drainage

A modified application of suction drainage for septic peritonitis is the use of negative pressure wound therapy.[19,20] The septic abdomen is essentially treated as an open wound with removal of exudate through the application of a sealed, absorbant dressing over the open abdomen which is connected to a commercial, portable suction apparatus. The suction apparatus provides continuous subatmospheric pressure at -80 mmHg to -125mmHg. While the abdomen is open, the drainage system is a closed system, isolated from the environment. Once infection is controlled, delayed abdominal closure is then performed.

References

1. Donner GS, Ellison GW. The use and misuse of abdominal drains in small animal surgery. *Compend Contin Educ Pract Vet* 1986;8:705-715.

2. Hosgood G. Drainage of the peritoneal cavity. *Compend Contin Educ Pract Vet* 1993;15:1605-1617.

3. Staatz AJ, Monnet E, Seim HB 3rd. Open peritoneal drainage versus primary closure for the treatment of septic peritonitis in dogs and cats: 42 cases (1993-1999). *Vet Surg* 2002;31(2):174-80.

4. Lanz OI, Ellison GW, Bellah JR, Weichman G, VanGilder J. Surgical treatment of septic peritonitis without abdominal drainage in 28 dogs. *J Am Anim Hosp Assoc* 2001;37(1):87-92.

5. Hunt CA. Diagnostic peritoneal paracentesis and lavage. *Compend Contin Ed Pract Vet* 1980;11:449-453.

6. Hampel NL, Johnson RG. Principles of surgical drains and drainage. *J Am Anim Hosp Assoc* 1985;21:21-28.

7. Raves JJ, Slitkin M, Diamond DL. A bacteriologic study comparing closed suction and simple conduit drainage. *Am J Surg* 1984;148:618-620.

8. Gold E. The physics of the abdominal cavity and the problem of peritoneal drainage. *Am J Surg* 1956;91:415-416.

9. Tenta LT, Maddalozzo, Friedman CD, et al. Suction drainage of wounds of the head and neck. *Surg Gynecol Obstet* 1989;169:558.

10. Kern KA. Technique for high volume drainage beneath large tissue flaps. *Surg Gynecol Obstet* 1990;170:70.

11. Garcia-Rinaldi R, Defore WW, Green ZD, et al. Improving the efficiency of wound drainage catheters. *Am J Surg* 1975;130: 372-373.

12. Moss JP. Historical and current perspectives on surgical drainage. *Surg Gynecol Obstet* 1981;152:517-527.

13. Formeister JF, Elias EG. Safe intra-abdominal and efficient wound drainage. *Surg Gynecol Obstet* 1976;142;415-416.

14. Hanna EA. Efficiency of peritoneal drainage. *Surg Gynecol Obstet* 1970,131:983-985.

15. Paton RW, Powell ES. Which drain? A comparison of the tensile strengths of vacuum drainage tubes. *J R Coll Surg Edinb* 1988;33:127-129.

16. Arnstein PM. Custom tube drains. *Lancet* 1988;1:215.

17. Hosgood G, Salisbury SK, Cantwell HD, et al. Intraperitoneal circulation and drainage in the dog. *Vet Surg* 1989;18:261-268.

18. Smeak DD. The Chinese finger trap suture technique for fastening tubes and catheters. *J Am Anim Hosp Assoc* 1990;26:215-218.

19. Cioffi KM, Schmiedt CW, Cornell KK, Radlinsky MG. Retrospective evaluation of vacuum-assisted peritoneal drainage for the treatment of septic peritonitis in dogs and cats: 8 cases (2003-2010). J Vet Emerg Crit Care 2012: 22: 601-609.

20. Buote NJ, Havig ME. The use of vacuum-assisted closure in the management of septic peritonitis in six dogs. *J Am Anim Hosp Assoc* 2012;48:164-171.

Omentum as a Surgical Tool

Giselle Hosgood

Introduction

The omentum is a mesothelial membrane with a unique vascular and lymphatic network that supports its use in various abdominal and extraabdominal surgical procedures. In any surgical procedure where there is a need for increased vasculature, lymphatics, or tissue bulk, the omentum may prove useful.[1]

Anatomy and Physiology[2]

The peritoneum is a mesothelial membrane that lines the abdominal cavity and covers the the abdominal organs. The peritoneal folds which leave the greater and lesser curvatures of the stomach are known as the greater and lesser omentum, respectively. The lesser omentum is derived from the ventral mesogastrium and extends between the lesser curvature of the stomach and the initial part of the duodenum to the liver hilus. The greater omentum is derived from the dorsal mesogastrium and comprises the large bursal portion and the smaller splenic and veil portions. Both omenta are composed of a double peritoneal leaf that is transparent, except for the lacey appearance of fat around the blood vessels that run through it.

The bursal portion of the greater omentum is of most clinical and surgical significance and is hereafter referred to as the omentum. The bursal portion is attached cranioventrally to the greater curvature of the stomach and extends caudally to the urinary bladder. The omentum reflects on itself forming a double layer (visceral and parietal layer) that covers the intestines (Figure 23-8). The potential cavity between the layers is the omental bursa (lesser peritoneal cavity). The only natural opening of the omental bursa is the epiploic foramen.

Important anatomical features of the omentum in the dog, which differ from that of people, may affect the surgical extension procedures that are sometimes performed depending upon its surgical use. In the dog, the spleen is attached to the parietal layer of the omentum. There is no colonic attachment of the omentum in the dog.[1] The primary omental blood supply comes from right and left border vessels that arise from the right gastroepiploic and splenic arteries, respectively.[3] Approximately nine smaller vessels originate from the gastroepiploic arcade along the greater curvature of the stomach.[1] The gastroepiploic arcade does not require mobilization in the dog.[1] The omentum is one of the major fat repositories in obese animals. Lymphatic drainage occurs by blind, bulbous capillaries present in the milk spots on the surface of the omentum. The mesothelial membrane is discontinuous over the milk spots, allowing material access to the lymphatics.[4] Lymphatics follow the vascular paths and anastomose with lymphatics of the stomach and spleen which drain by regional and celiac lymph nodes into the thoracic duct.[4] Drainage into the lacunae on the visceral surface of the diaphragm also occurs.[2] Milk spots are collections of cells of lymphoid and myeloid origin, mainly T and B lymphoctes, monocytes and macrophages. These sites may provide cells that have roles in inflammation, angiogenesis and immune responses.

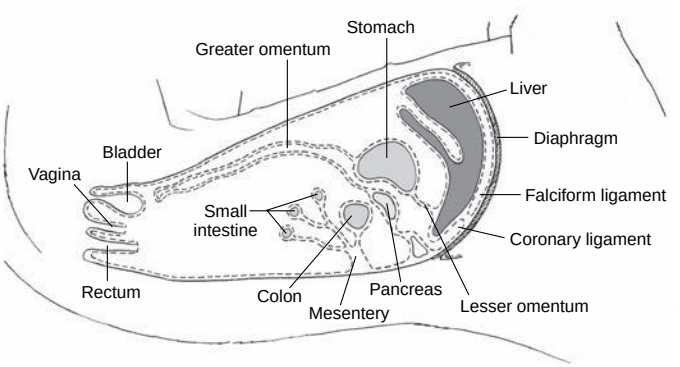


Figure 23-8. Peritoneal reflections of the dog in sagittal section. The dog is on its back, head to the right. (From Evans HE. The abdomen. Miller's Anatomy of the Dog. Philadelphia: W.B. Saunders Co; 1993:434).

Surgical Techniques

Mobilization of the Omentum

For use in local abdominal recipient sites, the free edge of the folded greater omentum can simply be moved to the recipient site. If movement of the omentum to a distant recipient site is needed, the length of the omentum can be extended by "unfolding" the

double layer after freeing the dorsal layer.[1] The omentum and spleen are exteriorized and the dorsal omental layer is reflected ventrally and cranially to identify the pancreatic attachments (Figure 23-9). The dorsal layer is freed from the pancreas using sharp dissection proceeding from right to left. As the dissection approaches the tail of the left lobe of the pancreas, vessels entering the spleen are encountered. Several omental vessels originating from the splenic artery may be encountered and are ligated close to the spleen. Hemorrhage is controlled with ligation, radiosurgery or ligature clips. Care must be taken to avoid hematoma formation which will compromise the vascularity of the omentum.[1] The omentum is now unfolded and extended caudally (Figure 23-10). The extension procedure provides considerable mobility and length with the free edge of the omentum reaching as far as the thoracic inlet cranially and the stifle caudally.[1]

Full extension of the omentum is achieved by making an inverted "L-shaped" incision through the dorsal extension and creating an omental pedicle (Figure 23-11). Beginning on the left side just caudal to the gastrosplenic ligament, the omental vessels are transected across one-half to two-thirds of the width. This makes the foot of the L incision. The incision should only be extended as far as necessary to preserve the width of the pedicle and subsequently the number of longitudinal omental vessels supplying the pedicle. The incision is then extended caudally and parallel to the remaining omental vessels. This incision forms the vertical limb of the L. The vertical incision can be extended as far as necessary, up to two-thirds of the length of the dorsal extension.

Hemorrhage is controlled with ligation, radiosurgery or ligature clips. The completed L-incision provides maximum extension of the omentum, reaching the muzzle cranially and the toes of the hindlimbs caudally.[1]

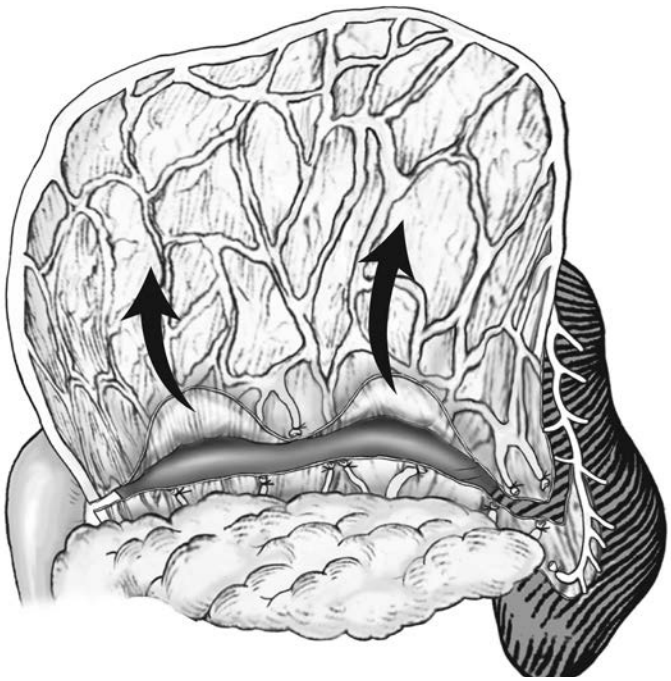


Figure 23-9. Dorsal extension of the omentum. The omentum and spleen are exteriorized, the dorsal leaf of the omentum is retracted ventrally and cranially and the omentum is freed from its pancreatic attachments. One or two vessels originating from the splenic artery are transected. (From Ross WE, Pardo AD. Evaluation of an omental pedicle extension technique in the dog. *Vet Surg* 1993;22:37-43.)

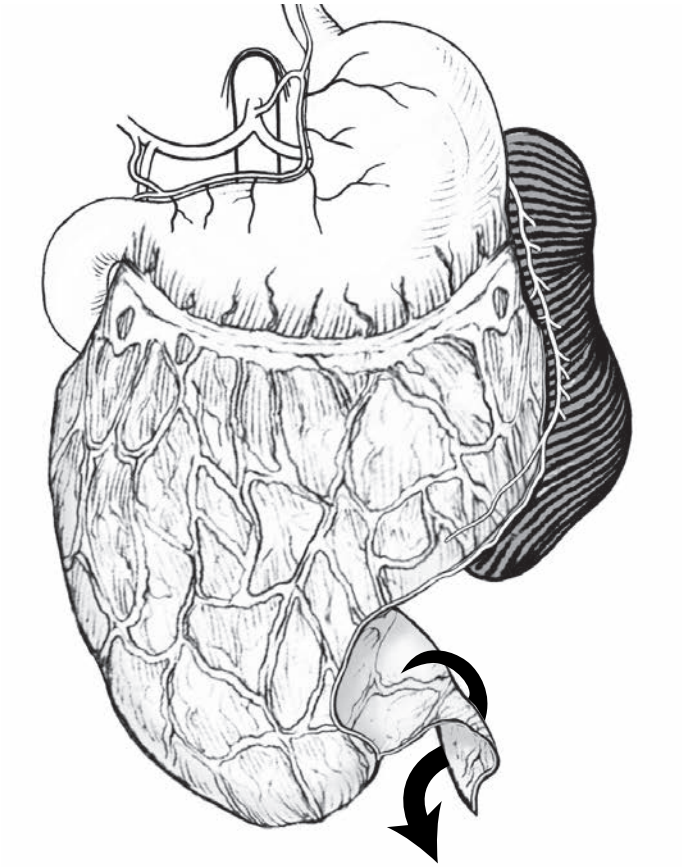


Figure 23-10. The dorsal leaf of the omentum is extended caudally. (From Ross WE, Pardo AD. Evaluation of an omental pedicle extension technique in the dog. *Vet Surg* 1993;22:37-43.)

Microvascular transfer of a free omental graft is used frequently in people since extension of the omentum is restricted by the vascular pattern. Microvascular transfer of an omental graft to the distal extremity in dogs has been reported however ischemia and failure of the grafts occurred in three of the five dogs.[5] Based on the success of omental extension described above, free transfer of the omentum is unlikely to be required in the dog or cat.

Extrabdominal Translocation of the Omentum

The omentum is most effectively translocated to the thoracic cavity by an incision in the diaphragm. Alternately, the omentum can be brought through the body wall, tunneled subcutaneously and then placed into the thoracic cavity through a lateral thoracic incision.

For other extrabdominal sites, the omentum is passed through an incision in the body wall, usually paracostal, and tunneled subcutaneously to the recipient site. Care must be taken to preserve the integrity of the omentum as it is grasped and tunneled through the subcutaneous tissue. Small tunnels that might constrict the omentum should be avoided.

Alternatively, the skin can be incised along the length of the tunnel and sutured over the length of the extrabdominal extension.

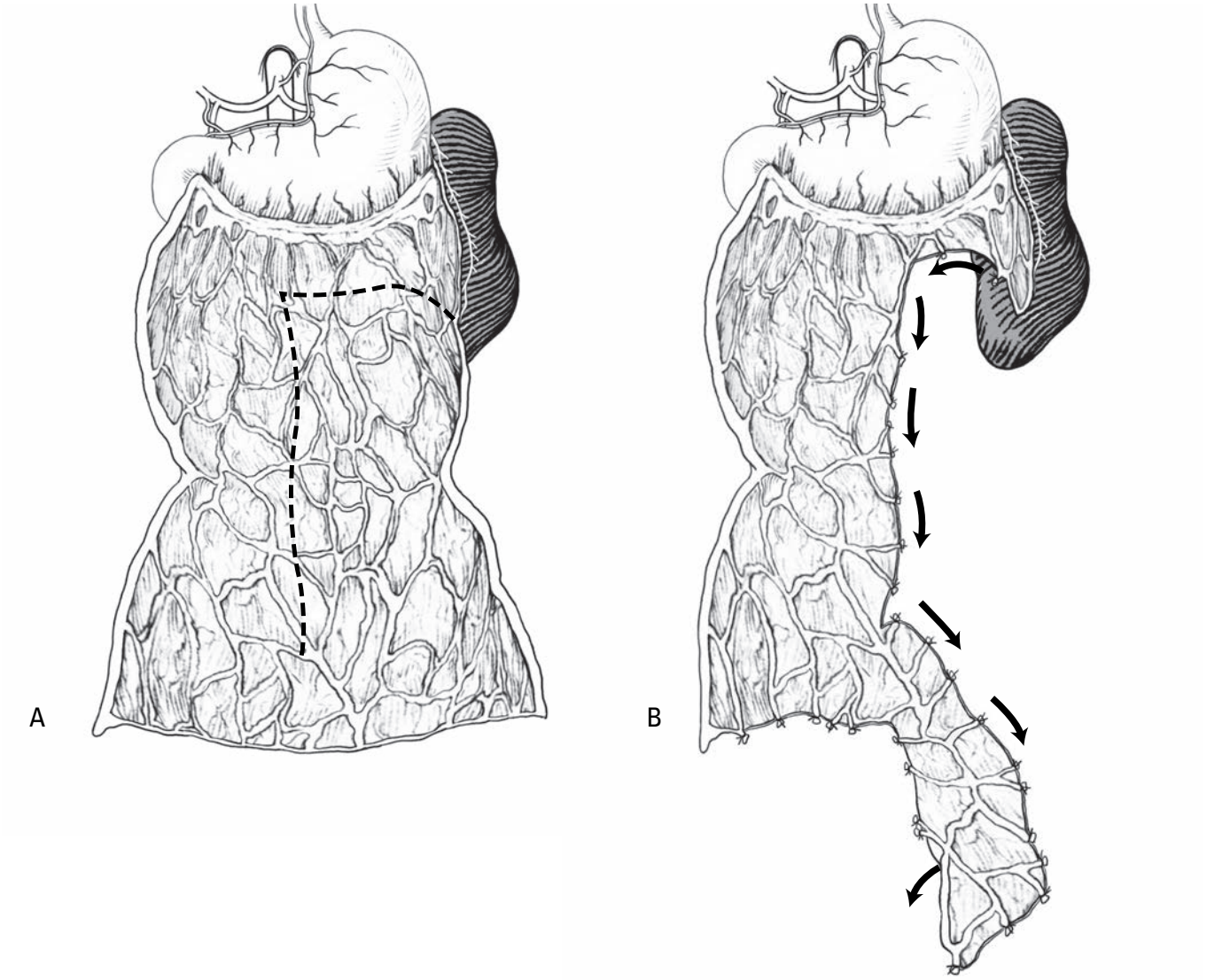


Figure 23-11. Creation of the omental pedicle. The inverted L-shaped incision is begun just caudal to the gastrosplenic ligament **(A)** and extended caudally for full extension **(B)**. (From Ross WE, Pardo AD. Evaluation of an omental pedicle extension technique in the dog. *Vet Surg* 1993;22:37-43.)

Specific Applications using the Omentum

Omentalization of Cystic Organs and Abscesses

The technique for using the omentum in the management of cysts and abscesses of abdominal organs is the same, regardless of the organ affected by disease. Extension of the omentum is usually not necessary for intraabdominal use. Omentalization of prostatic abscesses and cysts, pancreatic cysts and abscesses, uterine stump abscess, perinephric cysts, liver cysts and sublumbar lymph nodes has been reported.[6-12] The technique requires the cyst to be partially or almost completely removed. The omentum is then packed into the remaining shell of the cyst and loosely sutured in place with monofilament, absorbable suture material. Abscess cavities are first cultured and drained and as much of the outer surface wall is removed as possible. Omentum is packed into the remaining abscess cavity and sutured in place.

Chylothorax

Translocation of the omentum into the thorax of a 6 year-old Rhodesian ridgeback[15] and a 6-year-old Himalayan cat[16] with chylothorax have been reported. The omentum was brought through an incision in the muscle of the diaphragm, spread out in the thorax and sutured in the region of the mediastinum. The basis for the use of the omentum in the treatment of chylothorax is to take advantage of the considerable lymphatic drainage provided by the omentum. Both animals were free of disease 16 and 13 months after surgery, respectively. Since the omental lymphatics drain into the cysterna chyli, the rationale for treatment of chylothorax with omental transposition has been questioned.[17]

In theory, non-chylous effusion that may occur following correction of chylothorax may be reduced following omentalization.

Chronic Wounds

Extraabdominal translocation of the omentum to sites of non-healing wounds has been reported in the dog and the cat.[15-17] The omentum provides a vascular bed for free skin grafting or for random cutaneous or axial pattern skin flap reconstruction. The omentum is first extended and an omental pedicle is created if necessary. The omentum is then passed through a paracostal incision in the abdominal wall and tunneled subcutaneously to

the wound bed. The skin is reconstructed over the omentum. Wound drainage with a closed, active drain may be required.

Thoracic and Abdominal Wall and Diaphragm Reconstruction

The omentum has been used in conjunction with mesh reconstruction of thoracic and abdominal wall defects.[23,24] The omentum is first extended and an omental pedicle is created if necessary. The omentum is then passed through a paracostal incision in the abdominal wall and tunneled subcutaneously to the defect and placed on top of the mesh.

The omentum fills the soft tissue defect and also brings vascularity and lymphatic drainage to the wound site. The skin is reconstructed over the omentum. Wound drainage with a closed, active drain may be required.

The omentum has been used to cover experimentally created defects in the diaphragm in the dog. The omentum was folded over on itself and sutured to the edges of defect. After three weeks, the omentum remained viable with evidence of fibrometaplaisa with fibrosis to the diaphragm edges. Despite promising experimental results, reconstruction of the diaphragm is rarely required in dogs and cats. Primary closure of tears in the diaphragm is usually possible, even in chronic cases.

Other Applications

Application of the omentum to other surgical situations is possible, based on the ability of the omentum to enhance vascularity, lymphatic drainage and immune response at a recipient site. Use of the omentum to pack traumatic fractures in parenchymatous organs such as the liver, kidney and spleen is reported in humans. Support of gastrointestinal anastomotic sites is possible and widely used. Autgenous omental grafts, as free non-vascularized grafts, have been used to enhance bone healing in experimental non-union models in dogs.[25,26] Radial osteotomies treated with free autogenous omentum had union by 16 weeks while untreated osteotomies remained as a non-union.[25] In a second study using a similar non-union model in dogs, the effect of the omental graft was potentiated by the inclusion of adipose-derived stem cells.[26] The surgical applications for use of the omentum are numerous and varied however, the use of omentum should be viewed as an adjunct to sound surgical practice and not as a substitute for good surgical technique.

References

1. Ross WE, Pardo AD. Evaluation of an omental pedicle extension techinque in the dog. *Vet Surg* 1993;22:37-43.

2. Evans HE. The abdomen. Millers Anatomy of the Dog. Philadelphia: W.B. Saunders Co; 1993:425.

3. Gravenstein H. Uber die arterien des grossen netzes beim hunde. *Morph Jahrb* 1938;82:1-26.

4. Nylander G, Tjernberg B. The lymphatics of the greater omentum: An experiemental study in the dog. *Lymphology* 1969;1:3-7.

5. Roa DM, Bright RM, Daniel GB, McEntee MF, Sackman JE, Moyers TD. Microvascular transplantation of a free omental graft to the distal extremity in dogs. *Vet Surg* 1999;28:456-465.

6. Bray JP, White RAS, Williams JM. Resection and omentalization: A new technique for management of prostatic retention cysts in dogs. *Vet Surg* 1997;26:202-209.

7. Campbell BG. Omentalization of a nonresectabe uterine stump abscess in a dog. *J Am Vet Med Assoc* 2004;224:1799-1803.

8. Friend EJ, Niles JD, Williams JM. Omentalisation of congenital liver cysts in a cat. *Vet Rec* 2001:149:275-276.

9. Hill TP, Odesnik BJ. Omentalisation of perinephric pseudocysts in a cat. *J Sm Anim Pract* 2000;41:115.

10. White RAS, Williams JM. Intracapsular prostatic omentalization: A new techinque for management of prostatic abscesses in dogs. *Vet Surg* 1995;24:390-395.

11. Hoelzler MG, Bellah JR. Omentalization of cystic sublumbar lymph node metstases for long-term palliation of tenesmus and dysuria in adog with anal sac carcinoma. *J Am Vet Med Assoc* 2001;219:1729-1731.

12. Johnson MD, Mann FA. Treatment for pancreatic abscesses via omentalization with abdominal closure versus open peritoneal drainage in dogs: 15 cases (1994-2004). *J Am Vet Med Assoc* 2006;228:397-402.

13. Jerram RM, Warman CG, Davies ES, Robson MC, Walker AM. Successful treatment of a pancreatic pseudocyst by omentalisation in a dog. *N Z Vet J.* 2004;52:197-201.

14. Franklin AD, Fearnside SM, Brain PH. Omentalisation of a caudal mediastinal abscess in a dog. *Aust Vet J* 2011;89:217-220.

15. Williams JM, Niles JD. Use of omentum as a physiologic drain for treatment of chylothorax in a dog. *Vet Surg* 1999;28:61-65.

16. LaFond E, Weirich WE, Salisbury SK. Omentalization of the thorax for treamment of idiopathic chylothorax with constrictive pleuritis in a cat. *J Am An Hosp Assoc* 2002;38:74-78.

17. Sicard GK, Waller KR, McAnulty JF. The effect of cisterna chyli ablation combined with thoracic duct ligation on abdominal lymphatic drainage. *Vet Surg* 2005;34:64-70.

18. Brockman DJ, Pardo AD, Conzemius MG, Cabell LM, Trout NJ. Omentum-enhanced reconstruction of chronic nonhealing wounds in cats: Techniques and clinical use. *Vet Surg* 1996;25:99-104.

19. Lascelles BDX, White RAS. Combined omental pedicle grafts and thoracodorsal axial pattern flaps for the reconstruction of chronic, nonhealing axillary wounds in cats. *Vet Surg* 2001;30:380-385.

20. Smith BA, Hosgood G, Hedland CS. Omental pedicle used to manage a large dorsal wound in a dog. *J Sm Anim Pract* 1995;36:267-270.

21. Gray MJ. Chronic axillary wound repair in a cat with omentalisation and omocervical skin flap. *J Small Anim Pract.* 2005;46:499-503.

22. Roa DM, Bright RM, Daniel GB, McEntee MF, Sackman JE, Moyers TD. Microvascular transplantation of a free omental graft to the distal extremity in dogs. *J Small Anim Pract.* 1998;39:475-480.

23. Bright RM, Thacker LH. The formation of an omental pedicle flap and its experimental use in the repair of a diaphragmatic rent in the dog. *J Am An Hosp Assoc* 1982;18:283-289.

24. Liptak JM, Dernell WS, Rizzo SA, Monteith GJ, Kamstock DA, Withrow SJ. Reconstruction of chest wall defects after rib tumor resection: a comparison of autogenous, prosthetic, and composite techniques in 44 dogs. *Vet Surg* 2008;37:479-487.

25. Saifzadeh S, Pourreza B, Hobbenaghi R, Naghadeh BD, Kazemi S. Autogenous greater omentum, as a free nonvascularized graft, enhances bone healing: an experimental nonunion model. *J Invest Surg.* 2009;22:129-137.

26. Bigham-Sadegh A, Mirshokraei P, Karimi I, Oryan A, Aparviz A, Shafiei-Sarvestani Z. Effects of adipose tissue stem cell concurrent with greater omentum on experimental long-bone healing in dog. *Connect Tissue Res.* 2012;53:334-342.

Section D

Respiratory System

Chapter 24

Nasal Cavity

Resection of the Nasal Planum

Rodney C. Straw

Cats with unpigmented skin of the nasal planum may, over several years, develop squamous cell carcinoma with prolonged exposure to ultraviolet (UV-B) irradiation.[1] One paper suggests a papillomavirus may be involved in the etiology of feline squamous cell carcinoma. Older, white cats or those with lightly pigmented noses and that live in sunny climates are at risk. Lesions progress slowly through early solar damage with crusting and erythema to carcinoma in situ to invasive squamous cell carcinoma.[3] Invasive squamous cell carcinoma initially is confined to the nasal planum, but it slowly becomes more extensive, affecting deep and adjacent tissues late in the course of the disease. Lymph node or lung metastases are rare.[3] Cutaneous hemangiosarcoma of the nasal planum also occurs and is also thought to be associated with solar irradiation.[4,5] Basal cell tumor has been reported to occur on the nose of cats.[6] Cancer involving the nasal planum or premaxilla is uncommon in dogs, but such tumors include squamous cell carcinoma, fibrosarcoma, melanoma, mast cell tumor, and osteosarcoma.[7] Biopsy with histopathologic examination is necessary to diagnose cancer of the nasal planum and is important to rule out nonneoplastic causes of nasal ulceration.

Indications

Various methods have been described to treat cats with squamous cell carcinoma of the nasal planum including radiation therapy, hyperthermia, intratumoral administration of carboplatin, cryosurgery, conservative (marginal or intralesional) surgery, and photodynamic therapy.[8-13] Unfortunately, with most of these treatments, the tumor margins cannot be evaluated to ensure that an adequate volume of tissue is treated. Each of these modes of therapy has other disadvantages, including the need for special equipment and facilities for some techniques, high rates of tumor recurrence, and reported control rates for deeply infiltrating lesions of up to 55% at 1 year. Most of these techniques may work for early, small lesions or carcinoma in situ, but the most cost-effective, reliable treatment for selected patients with invasive squamous cell carcinoma is nasal planum resection. Fifteen of 20 cats with invasive squamous cell carcinoma treated with nasal planum resection were free of recurrent disease at 1 year.[6] Nasal planum resection can also be effectively used to treat other invasive neoplasms in dogs and cats. Although the cosmetic results in cats are generally good and acceptable to most owners, dogs are more noticeably deformed by the surgery. Function is usually excellent.

Nasal Planum Resection

The animal is maintained under general anesthesia and intubated with a cuffed endotracheal tube. A maxillary nerve block is performed and the cat is anesthetized and positioned in sternal recumbency with the head slightly elevated. The surgical area is carefully palpated to try to estimate tumor extension into adjacent tissue. A small area of hair is clipped, but the tactile vibrissae are avoided, and the site is prepared for aseptic surgery. A drape with a circular hole is placed over the prepared site. The nasal planum is completely removed with a 360° skin incision made with a No. 15 scalpel blade (Figure 24-1). The incision is made so it transects the underlying turbinates. If the tumor does not extend to the lip margin, then a thin strip of skin and buccal mucous membrane is preserved at the rostral lip margins on the midline. If tumor has extended into this region, then the lip margin must be removed, resulting in a closure involving rostral advancement of the lips. This may leave the incisor teeth slightly exposed. The cartilage of the nasal planum and the turbinates are cut with an incision angled at about 45° to the hard palate (Figure 24-2). Bleeding is usually brisk. Hemorrhage is controlled by direct pressure with a sponge. Electrocautery should only be used sparingly to avoid thermal necrosis, which delays healing.

Once the nasal planum is removed, the skin edges retract and the nasal conchae are exposed. A pursestring suture of 3-0 monofilament nonabsorbable suture material is placed through the skin around the incision. The surgeon does not need to place any deep sutures into the cartilage or nasal mucosa. It is only

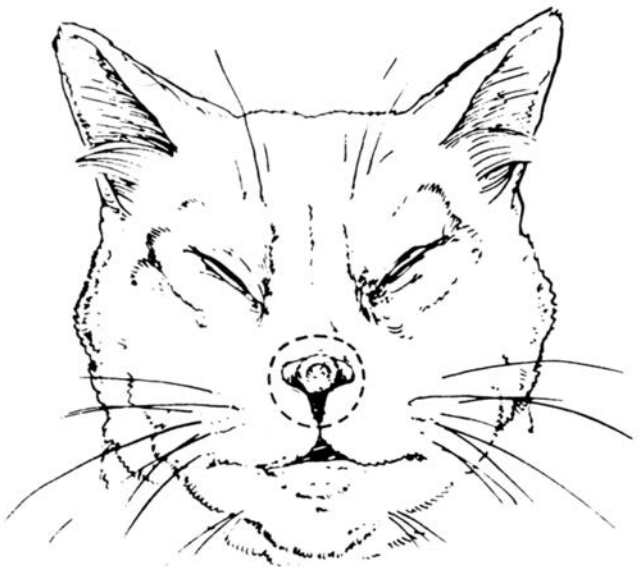


Figure 24-1. The 360° incision around the nasal planum is indicated by the dotted line. If possible, a strip of skin is left ventrally so the lips are left attached at the midline. (From Withrow SJ, Straw RC. Resection of the nasal planum in nine cats and five dogs. J Am Anim Hosp Assoc 1990;26:219-222.)

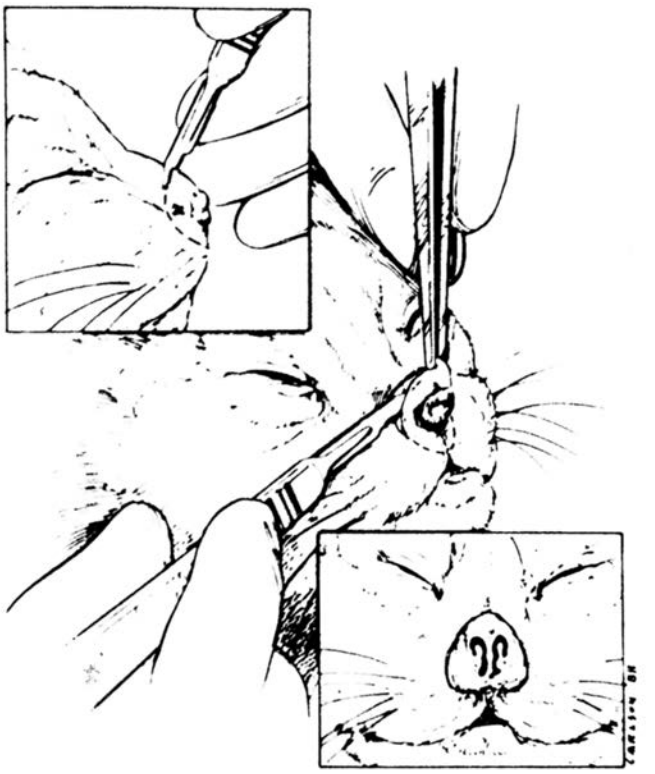


Figure 24-2. The angle of the deep incision as seen from the lateral side is angled at approximately 45°. The turbinates are sharply divided. Skin retracts after removal of the nasal planum, exposing the nasal cavity. (From Withrow SJ, Straw RC. Resection of the nasal planum in nine cats and five dogs. J Am Anim Hosp Assoc 1990;26:219-222.)

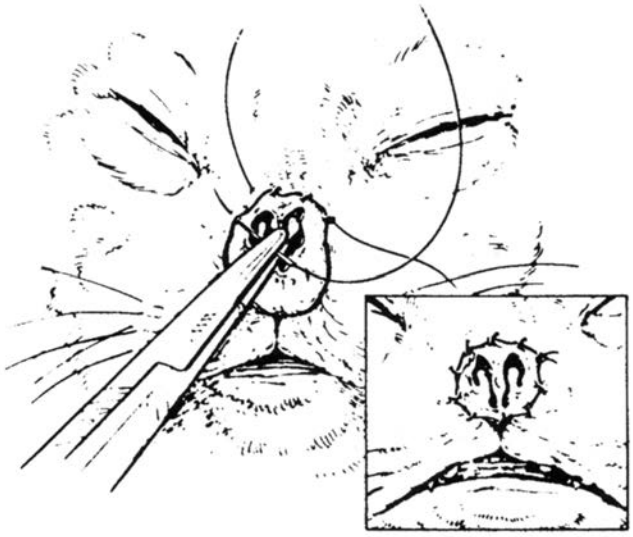


Figure 24-3. A continuous pursestring suture is used to reduce the nasal orifice to about I cm diameter. No sutures are placed in cartilage. (From Withrow SJ, Straw RC. Resection of the nasal planum in nine cats and five dogs. J Am Anim Hosp Assoc 1990;26:219-222.)

necessary to tighten the pursestring suture lightly; for cats, the new nasal orifice is closed to approximately 1 cm in diameter (Figure 24-3). The entire excised nasal planum is submitted for histopathologic examination, with a request for the pathologist to examine the surgical margins carefully. India ink or other tissue marking ink may be painted on the cut edges of the specimen to delineate the surgical margins. Analgesics are used, and patients are usually sent home within 24 hours. Owners are advised not to try to clean the surgical site and are warned that the patient may sneeze blood for several days. Patients should be tempted with favored food, but they may be reluctant to eat for a few days after surgery. Older animals with compromised renal function need fluid support until water intake becomes adequate. Elizabethan collars are usually not necessary. Sutures are removed approximately 10 days after surgery, and sedation or a short course of anesthesia may be required.

Combined Resection of the Nasal Planum and Premaxilla

For extensive neoplasms of the nasal planum and premaxilla, nasal planum resection or premaxillectomy alone may be inadequate. Wide surgical margins can be attained using combined resection of the nasal planum and premaxilla.[7] This technique offers a surgical treatment for large tumors in dogs that obviates

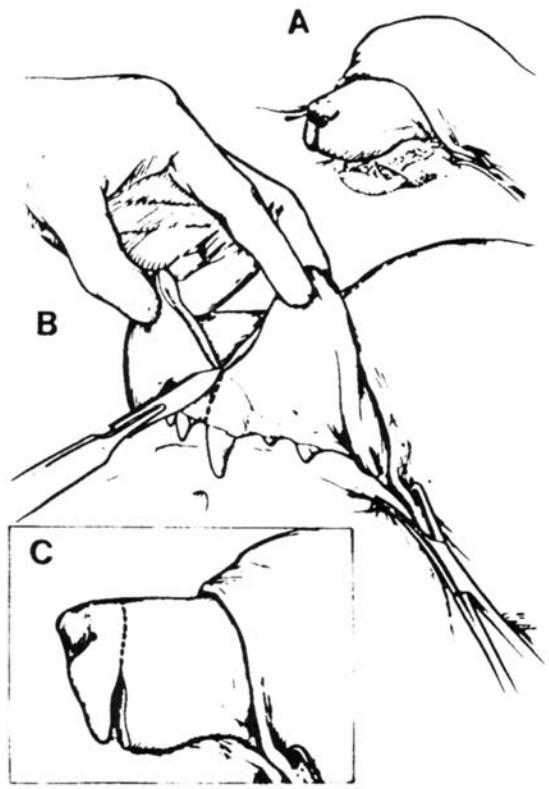


Figure 24-4. A. The dog is placed in sternal recumbency and is draped after preparation for aseptic surgery. The mouth is open, and the lower drape is within the mouth. **B.** The upper lip is incised full thickness on each side of the nasal planum. **C.** The two incisions are united on the dorsal midline of the nose caudal to the nasal planum. (From Kirpensteijn J, Withrow SJ, Straw RC. Combined resection of the nasal planum and premaxilla in three dogs. Vet Surg 1994;23:341-346.)

the need for adjuvant or primary radiation therapy. Cosmetic results are considered acceptable by most owners.

The dog, maintained under general anesthesia and intubated with a cuffed endotracheal tube, is positioned in sternal recumbency with the mouth slightly open. The skin overlying the maxilla and upper lip is clipped and prepared for aseptic surgery. The oral mucosa of the lips and hard palate is prepared with a disinfectant such as a dilute povidone-iodine solution. The area is draped, allowing access to the oral cavity (Figure 24-4A). The upper lip is incised from the skin through the mucosa on each side of the nasal planum (Figure 24-4B). The two incisions are connected at the dorsal midline of the nose caudal to the nasal planum (Figure 24-4C). The nasal cartilages are incised to the palatal region of the maxillary bone. At the level just either rostral to or caudal to the canine teeth, depending on the extent of invasion of the tumor, the mucosa of the hard palate is incised transversely with a scalpel blade down to bone. An oscillating saw is used to cut the palatal and maxillary or incisive bone (Figure 24-5). The excised specimen is submitted for histopathologic examination, with emphasis on evaluation of margins for completeness of resection. Hemorrhage is controlled by a combination of direct pressure, electrocautery, and vessel ligation. Four or five small holes are drilled 2 to 3 mm from the cut edge of the hard palate. The submucosa of the incised lip is sutured through the holes in the hard palate with 2-0 monofilament absorbable suture material. The lip is joined on the midline of the palate with sutures that are placed approximately in the middle of each lip incision (Figure 24-6A). The mucous membrane of the lip is sutured to the mucous membrane of the hard palate, and the contralateral lip is sutured with 3-0 monofilament absorbable suture material in a continuous or interrupted pattern. This technique results in closure of the oral cavity in the form of a "T" (Figure 24-6B). The skin of the lips is closed on the midline with 2-0 or 3-0 monofilament nonabsorbable suture material. As with closure after nasal planum resection alone, the diameter of the nasal opening is reduced using a pursestring suture of monofilament nonabsorbable suture material (Figure 24-6C). The nasal opening

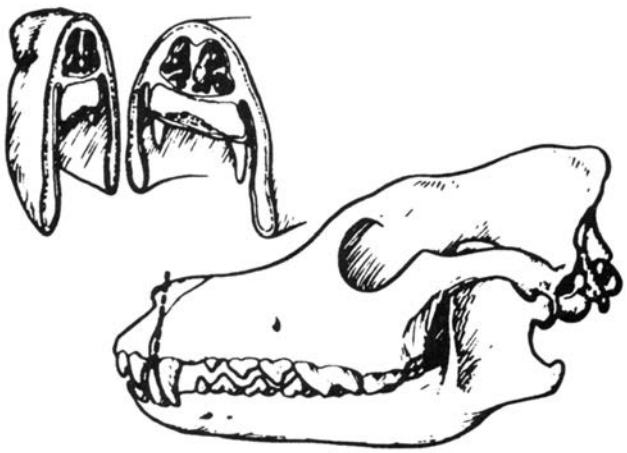


Figure 24-5. The nasal cartilages are incised perpendicular to the long axis of the skull down to the floor of the nasal cavity. The mucosa of the hard palate is transversely incised at a level just rostral to the canine teeth (or caudal to the canine teeth, depending on the extent of tumor invasion) down to bone. An oscillating saw is used to cut the bone of the hard palate and lateral bodies of the maxilla. (From Kirpensteijn J, Withrow SJ, Straw RC. Combined resection of the nasal planum and premaxilla in three dogs. Vet Surg 1994;23:341-346.)

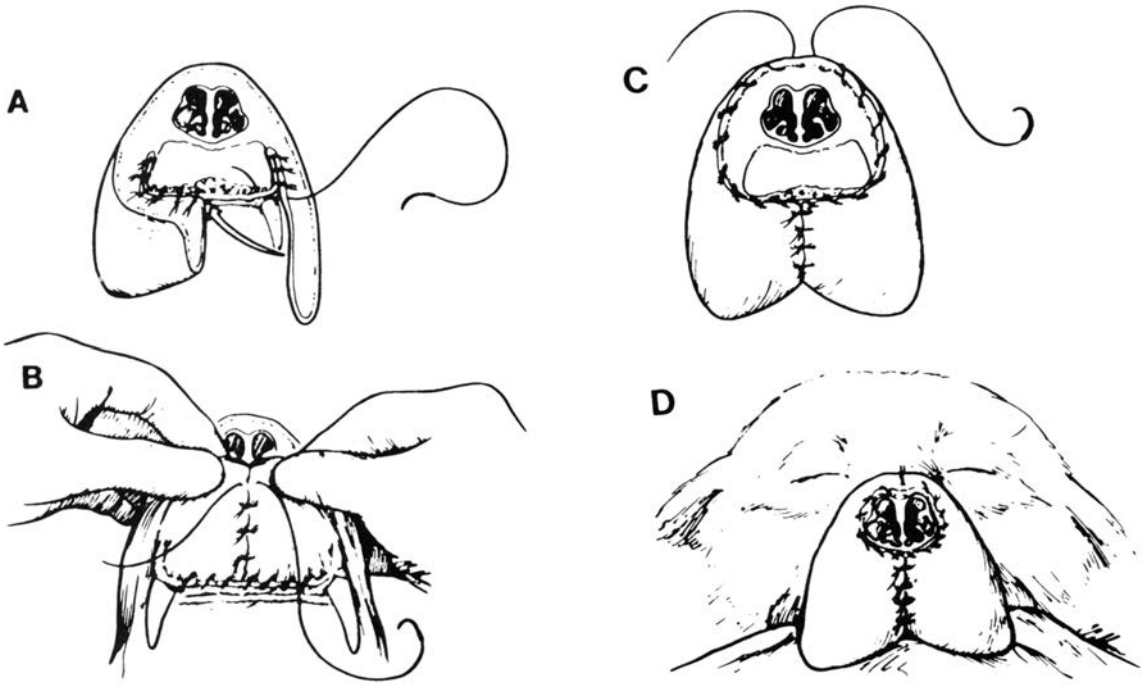


Figure 24-6. A. The submucosa and mucosa of the lip is sutured through drill holes in the hard palate and to the contralateral lip. **B.** This results in closure of the oral cavity from the nasal cavity in the form of a "T." **C.** The nasal orifice is reduced in diameter by placing a simple continuous pursestring suture. **D.** View from the front of the dog after surgery. The new nasal orifice is approximately the diameter of the resected nasal planum. (From Kirpensteijn J, Withrow SJ, Straw RC. Combined resection of the nasal planum and premaxilla in three dogs. Vet Surg 1994;23:341-346.)

is reduced to a size corresponding to the diameter of the nasal planum removed (Figure 24-6D).

Analgesia is provided using narcotics as necessary. An Elizabethan collar may be needed to prevent mutilation of the wounds. Dogs are allowed to drink water on recovery and are offered food 24 hours after surgery. Antibiotics can be given during the immediate perioperative period, but they are usually not necessary. Dogs are sent home within 2 to 3 days, and sutures are removed 10 days postoperatively.

Mild postoperative bleeding may occur and resolves within a day or so. Lip dehiscence can be avoided if the closure is tension free. Stenosis of the new nares can occur if the pursestring suture is too tight. Crusting of the nasal orifice is possible and resolves after suture removal; however, serous nasal discharge can persist.

Combined Resection of the Nasal Planum and Rostral Maxilla

For animals with malignant rostral maxillary tumors a technique has been described where the maxilla and nasal planum can be resected between PM2 and PM3.[14] The postoperative appearance was acceptable to owners and there was a low risk of local recurrence which can produce long term survival for animals with certain malignancies. A preoperative biopsy is performed with appropriate tumor staging before definitive resection with this aggressive rostral maxillectomy procedure. Computed tomography (CT) is excellent for tumor staging and surgical planning.

The animal is positioned in ventral recumbency and anesthesia, analgesia and surgical preparation are similar to previously described procedures in this chapter. The mouth is held slightly open with a mouth gag or similar device and care is taken to pack the pharynx with moistened gauze swabs adjacent to a cuffed or snug fitting endotracheal tube to avoid aspiration of blood and fluid during surgery. The commissures of the lips need to remain mobile after draping to allow for labial advancement during reconstruction. The preoperative CT scan defines the extent of tissue infiltrated with tumor, and its relation to the dentition. The teeth are used as landmarks to allow the approximate edges of the tumor to be marked using a sterile marker pen. A sterile ruler is used to mark 1 or 1.5 cm beyond the borders of the tumor so that a line of "planned complete resection" can be drawn. The line of bone excision is level with or slightly caudal to the caudal-most aspect of the soft-tissue resection. This results in sufficient soft tissues to reconstruct a lip rostrally and cover the exposed maxilla. Full-thickness, labial incisions are made perpendicular to the labial margin. The incisions are continued perpendicular from the labial margin for a minimum of 1 to 2 cm and then curved to meet on the midline of the maxilla. Once the skin is scribed with a scalpel, electrocautery is used for most of the tissue division, and hemostasis is maintained by a combination of cautery and vascular clips or ligatures. The incisions are continued deeper through the subcutis and nasolabial muscles and fascia to the maxillary bone at predetermined resection levels. If this is the rostral zygomatic arch, the infraorbital neurovascular bundles will need to be divided between ligatures. If this is near the canine tooth the skin, subcutis, nasolabial muscle, and labium are reflected while preserving their vascular support from the infraorbital neurovascular bundle. These soft tissues and labium are reflected to the rostral zygomatic arch, exposing the maxilla. Once exposed, the rostral maxilla, nasal turbinates, and bony palate are amputated with a reciprocating saw. The transection is perpendicular to the maxillary axis. The rostral maxilla can then be removed following transection of the palatine mucosa parallel to and at the level of the hard palate. The palatine and sphenopalatine arteries are ligated.

Labial reconstruction is performed by transposing either a unilateral labial flap or bilateral labial flaps depending on the amount resected and the conformation of the animal. Regardless of whether a unilateral or bilateral flap is used, the lip and palate are united first. Dehiscence may be less likely when bilateral flaps are used. It may be necessary to relieve tension by incising the labiogingival reflection to mobilize the labial flap. The mucosa of the labial flap is removed except for a 0.5- to 1.0-cm width adjacent to the labial margin. This distance is determined by bringing the tissues together and identifying the contact point of the palatine mucosa and labium, and then assessing how much "new lip" there would be projecting ventrally from the palatine mucosa. Avoid making this margin overly large which may result in prehension problems after surgery. Once the mucosa is excised, the remaining mucosal margin is sutured to the palatine mucosa with interrupted 4-0 absorbable sutures, thus providing strong support and preventing mucosal inversion.

Bilateral advancement flaps are also prepared by incision of the labiogingival borders as necessary to permit tension-free advancement of the flaps on the approximate midline. The labial mucosa is once again débrided leaving only a 0.75- to 1.0-cm margin of labial mucosa to be sutured to the palatal incision as a palatobuccal recess. This length of recess is chosen to ensure the margin will not be trapped between the teeth during chewing or interfere with food transfer into the mouth. Prior to suturing, the left and right lips are aligned toward the midline using temporary sutures. As the palatolabial suturing progresses from lateral to medial, the labial margins are drawn into apposition. As with the unilateral flap the labial submucosa can be first sutured to the edge of the incised palatine bone using small holes drilled in the palatine bone with a 0.0625-inch Kirschner wire. The remaining lip union is reconstructed beginning along the ventral aspect, aligning the labial margin with a nonrolling figure-of-eight suture. Suturing progresses using the same suture pattern in the submucosa, muscle, subcutaneous, and dermal layers.

The dorsal and rostral portions of the incision are left open forming the nasal orifice. And it is advisable to create an orifice approximately twice the desired final size to compensate for the expected contraction during healing. The nasal orifice size can be controlled using a purse-string type pattern of suture as with simple nasal planectomy.

Analgesic protocols are aggressive and include premedication with an opioid (i.e., oxymorphone at 0.2 to 0.5 mg/kg intramuscularly [IM] or morphine at 0.2 to 0.6 mg/kg IM) and infraorbital nerve

blocks performed bilaterally prior to surgery using bupivacaine (0.5 to 1.0 mL of a 0.75% solution used per site). During general anesthesia, constant-rate infusions of fentanyl (0.01 mg/kg per hour) may be administered. At the time of extubation, the opioid administered preoperatively is repeated, and a postoperative analgesic opioid protocol is instituted. This can be buprenorphine (0.07 mg IM q 6 hours) which can be continued for up to 60 hours. Following a loading dose of the appropriate opioid (i.e., morphine 0.5 mg/kg intravenously [IV]; oxymorphone 0.2 mg/kg IV; or fentanyl 0.002 mg/kg IV), dogs can receive constant-rate infusions of morphine (0.05 mg/kg per hour), oxymorphone (0.13 mg/kg per hour), or fentanyl (0.002 to 0.006 mg/kg per hour) for 24 hours to provide a constant level of analgesic drug. Carprofen (2.0 mg/kg per os [PO] q 12 hours) may be initiated 12 hours after surgery and continued postoperatively as necessary.

An Elizabethan collar is often used until healing is complete and it may be necessary for oronasal suction to be instituted as needed to keep the nasal passages clear, using a pediatric suction device. Some animals do not eat readily, and feeding can be supplemented with a food gruel administered through a pharyngostomy tube for a short term up to 7 days. Topical petrolatum-based antibiotic ointment can be placed around the nasal orifice wounds to reduce wound crusting and debris. Additionally, topical misting of physiological saline can be delivered via a conventional spray bottle to humidify and cleanse the nasal turbinates. Some animals are able to eat soft food offered on a plate between 12 and 30 hours after surgery and may be discharged to their owners once eating on their own. Owners may be advised to keep the new rostral orifice patent and clean using saline-soaked cotton balls for 1 month postoperatively. Antibiotics such as cefazolin 20 mg/kg IV are given immediately preoperatively and every 90 minutes during surgery and postoperative antibiotics are generally not necessary.

Although this technique is very similar to the combined resection of the nasal planum and premaxilla it is more extensive allowing wide resection of larger tumors. The advantage of such a technique is that it has the potential to increase the number of animals in which "complete" resections can be performed. However, the disadvantage of such a surgery is the possibility of interfering with the animal's ability to eat and drink making oral spillage of both food and water possible. The technique does offer the opportunity for prolonged tumor-free remission times for animals with certain neoplasms that involve the rostral maxilla, if tumor-free margins can be obtained.

References

1. Hargis AM. A review of solar-induced lesions in domestic animals. Compend Contin Educ Pract Vet 1981: 3: 287-293.

2. Munday JS, Dunowska M, DeGrey S: Detection of two different papillomaviruses within a feline squamous cell carcinoma: case report and review of the literature, NZ Vet J 57: 248-251, 2009.

3. Withrow SJ. Tumors of the respiratory system. In: Withrow SJ, MacEwen EG, eds. Veterinary oncology 2nd ed. Philadelphia: WB Saunders, 1996: 268-286.

4. Hargis AM, Ihrke PJ, Spangler WL, et al. A retrospective clinic-pathological study of 212 dogs with cutaneous hemangiomas and hemangiosarcomas. Vet Pathol 1992: 29: 316-328.

5. Miller MA, Ramos JA, Kreeger JM. Cutaneous vascular neoplasia in 15 cats: clinical, morphologic, and immunohistochemical studies. Vet Pathol 1992: 29: 329-336.

6. Withrow SJ, Straw RC. Resection of the nasal planum in nine cats and five dogs. J Amer Anim Hospt Assoc 1990; 26: 219-222.

7. Kirpensteijn J, Withrow SJ, Straw RC. Combined resection of the nasal planum and premaxilla in three dogs. Vet Surg 1994; 23: 341-346.

8. Carlisle CH, Gould S. Response of squamous cell carcinoma of the nose of the cat to treatment with X rays. Vet Radio 1982; 5: 186-192.

9. VanVechten MK, Theon AP. Strontium-90 plesiothcrapy for treatment of early squamous cell carcinomas of the nasal planum in 30 cats. In: Proceedings of the 13th Annual Conference of the Veterinary Cancer Society. Columbus, OH 1993: 107-108.

10. Theon AP, Madewell BR, Shearn VI, et al. Prognostic factors associated with radiotherapy of squamous cell carcinomas of the nasal plane in cats. Am J Vet Assoc 1995; 206: 991 – 996.

11. Theon AP, VanVechten MK, Madewell BR. Intratumoral administration of carboplatin for treatment of squamous cell carcinomas of the nasal plane in cats. Am J Vet Res 1996; 57: 205-210.

12. Peaston AE, Leach MW, Higgins RJ. Photodynamic therapy for nasal and aural squamous cell carcinoma in cats. J Am Vet Med Assoc 1993; 202: 1261-1265.

13. Fidel JL, Egger E, Blattmann H, et al: Proton irradiation for feline nasal planum squamous cell carcinoma using an accelerated protocol. Vet Radiol and Ultrasound, 42: 569-575, 2001.

14. Lascelles BDX, Henderson RA, Sequin B, Liptak JM, Withrow SJ. Bilateral rostral maxillectomy and nasal planectomy for large rostral maxillofacial neoplasms in six dogs and one cat. J Amer Anim Hospt Assoc 2004; 40: 137-146.

Rhinotomy Techniques

Cheryl S. Hedlund

Introduction

Dogs and cats with chronic nasal and paranasal sinus disease are usually diagnosed and treated without the need for rhinotomy (surgical exploration of the nasal cavity). Rhinotomy is only indicated if other diagnostic techniques fail to provide a definitive diagnosis or if required as part of a therapeutic protocol. Potential candidates for rhinotomy have symptoms that may include: nasal discharge, epistaxis, sneezing, gagging, stertorous breathing, dyspnea, fetid breath, nasal discomfort, or nasal deformity. Causes of diseases of the nasal cavity and paranasal sinus can be difficult to identify, but are commonly of infectious (fungal, bacterial, or viral) or neoplastic origin. Other inciting causes include foreign bodies, trauma, parasites (Pneumonyssus caninum, Linguatula serrata), dental disease, congenital anomalies, and lymphocytic plasmacytic inflammation.[1]

Diagnostic Procedures

A standard protocol for evaluation should be used for all dogs and cats presenting with chronic nasal disease. The protocol should include a thorough history and physical examination. In addition, a complete blood count, serum chemistry profile, coagulation profile, radiographs, computed tomography (CT scan), magnetic resonance imaging (MRI), serology, cytology, culture, rhinoscopy, and nasal biopsy may be required for

accurate diagnosis and prognosis.[2-6] The clinical history provides important diagnostic clues. A destructive process is suspected if the discharge changes from unilateral to bilateral. Sneezing suggests involvement of the rostral or middle nasal chambers and gagging suggests nasopharyngeal involvement. A history of trauma or dental disease might suggest an oronasal fistula.

Physical examination findings are as follows: Epistaxis may indicate a systemic disease, an acute nasal disease, or an ulcerative, destructive disease. A mucopurulent discharge with or without epistaxis suggests chronic rhinitis. Obstruction of nasal airflow through one or both nostrils suggests a unilateral or bilateral condition. Facial or palatal deformity suggests neoplasia. Mouth breathing may indicate nasopharyngeal obstruction. Labored breathing suggests possible pulmonary involvement with a fungal or neoplastic condition. An ocular discharge may indicate nasolacrimal duct erosion. General debility suggests systemic disease.

A complete blood count, serum chemistry panel, and urinalysis should be obtained to assess overall patient status. A coagulation profile is indicated if exploratory rhinotomy is planned or if epistaxis is a major clinical sign. In addition, serologic evaluation for Ehrlichia canis may be beneficial when epistaxis is the predominant clinical sign. Serologic evaluation for Aspergillus and Penicillium species can be beneficial when fungal disease is suspected. Serologic tests for Crytptococcus, FeLV, FIV and heartworms may also be indicated. Nasal swabs for culture or cytologic evaluation are of limited value but may be helpful in identifying parasites, cryptococcoses organisms and single bacterial infections. Positive fungal cultures can be obtained in 40% of normal dogs.

Radiographs of the thorax and skull are taken to demonstrate the extent of disease involvement. Radiographs of the thorax are taken in the awake patient to evaluate for evidence of cardiac or pulmonary disease (metastasis or infection). Skull radiographs require general anesthesia to allow accurate evaluation of the nasal cavity and paranasal sinuses. Skull images are performed prior to rhinoscopic, flush, or biopsy procedures to avoid iatrogenic fluid densities within the cavities. Skull radiographs should include lateral, ventrodorsal, rostrocaudal, and rostroventral caudodorsal open mouth or occlusal views. The two most useful radiographic views are the ventrodorsal view of the maxilla made using intraoral radiographic film and the rostrocaudal projection highlighting the frontal sinuses. Skull radiographs are examined for evidence of increased or decreased tissue densities, distortion or loss of turbinates and bone, and symmetry between right and left sides of the nasal cavity and sinuses. The same changes are evident on CT and MRI images but they localize lesions better than radiographs. CT images provide good anatomic detail of bony tissues while MRI images are superior for evaluating soft-tissue structures.[3]

Rhinoscopy is useful because it allows visual assesment of lesions and acquisition of specimens for further evaluation.[4-6] The diagnostic success of rhinoscopy-assisted biopsy is 83% (78 of 94 dogs) when performed by an experienced clinician.[6] Rhinoscopy is performed on an anesthetized patient in sternal or lateral recumbency following skull imaging and sample collection for cultures. Violent sneezing with possible damage to instruments and mucosa resulting in hemorrhage may occur if anesthetic depth is inadequate. The nasal mucosa is sensitive to manipulation; it bleeds easily, and this may obscure visualization. Therefore, patience, gentleness, suction, and lavage are advantageous during this procedure. The least affected side of the nasal cavity is examined first. The rostral aspect of the nasal cavity may be visualized with an otoscope and appropriate speculum. The caudal choanae and nasopharynx can be viewed with a dental mirror or rigid scope with a 120° lens when the soft palate is retractated rostrally. Visualization of the entire cavity is achieved with a flexible pediatric bronchoscope (< 1 cm diameter) or a rigid scope (bronchoscope or arthroscope, 2 to 5 mm diameter) with a working piece (outer sheath) to allow suction, lavage, and biopsy. Both normograde and retrograde rhinoscopy is performed to completely visualize the nasal cavity and nasopharynx. After complete rhinoscopic examination, suitable biopsy forceps are used to collect tissue for culture and histologic evaluation.

Lesions that are not accessible to biopsy during rhinoscopy may be sampled by nasal flushing or coring procedures. These procedures are performed in the anesthetized patient. Gentle flushing of the nasal cavity with saline does not usually dislodge tissue for evaluation. Nasal coring, pinch, punch, or needle biopsy are more effective biopsy techniques.[6] To prevent aspiration, the endotracheal tube cuff is inflated, gauze sponges are placed in the nasopharynx and the nose is tilted ventrally during sampling. To prevent penetration of the cribriform plate, biopsy instruments should be marked and not advanced further than the distance from the external nares to the medial canthus of the eyes. One technique for nasal coring uses a stiff plastic tube inserted through the nares and vigorously moved in and out of the nasal passages while flushing saline and aspirating tissue. The collected lavage fluid, debris and tubing are examined for tissue fragments. Repeating biopsies when samples are nondiagnostic is preferred to rhinotomy in most cases.

Patients whose disease has not been diagnosed by the foregoing procedures are candidates for exploratory surgery. Rhinotomy may also be included in treatment protocols for fungal diseases, tumors, and foreign bodies. Rhinotomy can be performed using dorsal, ventral, or lateral approaches. The approach chosen depends on the location and extent of the lesion. The objectives of rhinotomy include the following: 1) To obtain sufficient samples from the nasal cavity or sinuses to achieve a definitive diagnosis. 2) To completely remove or debulk a lesion. 3) To facilitate administration or effectiveness of adjuvant therapy. 4) To minimize patient morbidity. 5) To maintain a cosmetically acceptable appearance.

In addition to a standard surgical pack, equipment which may be needed for rhinotomy includes a periosteal elevator, Gelpi retractor, oscillating saw, air drill, pins and pin chuck, osteotome and mallet, bone curette, rasp, bur, rongeur, trephine, fenestrated tubes, and synthetic mesh. If temporary carotid artery occlusion is performed in conjunction with rhinotomy, vascular occlusion

is accomplished with umbilical tape, vascular tape (Vas-Tie@, Sil-Med Corp., Taunton, MA) or bulldog vascular clamps.

Surgical Anatomy

The nasal cavity is bound by the nasal bones dorsally, the maxilla laterally, and the hard palate ventrally. The orbit contributes to the lateral boundary of the nasal cavity and frontal sinuses. The nasal cavity is separated into two fossae by the nasal septum. The maxilloturbinates fill the rostral portion of each fossa and the ethmoturbinates extend caudally to the cribriform plate and frontal sinus (Figure 24-7). When dividing the dorsoventral nasal height at the medial canthi of the eyes, the nasofrontal opening occupies the dorsal third, the cribriform plate the middle third and the sphenoidal sinus recess and caudal nasal meatus (internal nares or choanae) the ventral third. The paranasal sinuses are hollow, membrane lined, air-filled diverticuli from the nasal cavity that invaginate into adjacent bones. They are not fully developed at birth and continue to grow as the animal matures. The limits of the frontal sinus vary with the age, breed and head shape of the patient. Dogs have a frontal sinus divided into three compartments and a maxillary sinus (recess). Cats

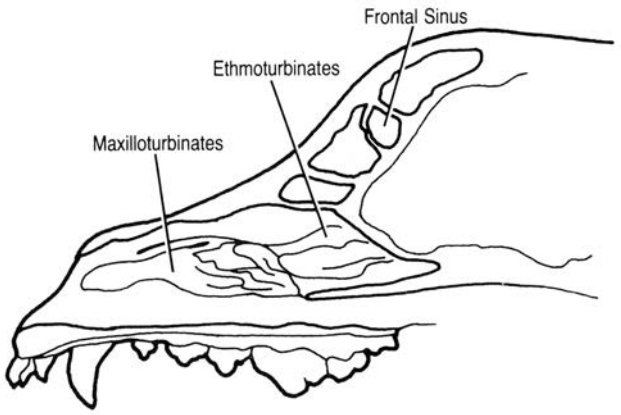


Figure 24-7. The nasal fossae are filled with maxilloturbinates in the rostral portion and ethmoturbinates in the caudal portion. The ethmoturbinates extend caudally to the cribriform plate and frontal sinus.

have an undivided frontal sinus, and in addition to the maxillary sinus, they have a sphenoid sinus.

Communication between the frontal sinus and the nasal cavity occurs through small ostia in the ethmoid region. Mucous membrane swelling reduces the size of these openings and can obstruct drainage, leading to sinus mucocele formation. The blood supply to the nasal cavity is extensive and originates from the branches of the maxillary artery, a terminal vessel of the external carotid artery.

Preoperative Preparation

Analgesics are administered in the preoperative period. After the anesthetized animal is intubated, the endotracheal tube cuff is inflated, and the pharynx is packed with gauze sponges to prevent drainage of fluids into the distal trachea. Hair is clipped and the surgical site is aseptically prepared for the selected approach.

Surgical Techniques

Temporary Carotid Artery Occlusion for Rhinotomy[7-8]

Occluding the common carotid arteries reduces blood loss during exploration of the nasal cavity, improves visualization during surgery, facilitates exploration and obviates blood transfusions in most patients. Although hemorrhage (50 to 100 ml/25 kg body weight) still occurs during removal of the turbinates and nasal mucosa, it usually diminishes within a few minutes. Suction is advantageous but not necessary for visualization. Release of the carotid arteries at the conclusion of surgery does not result in clinically significant hemorrhage and nasal packing is not necessary. The common carotid arteries can be occluded for two to three hours with no evidence of neurologic or ischemic damage in dogs. Carotid artery occlusion in cats is not recommended because collateral blood supply is inadequate to maintain cerebral perfusion.[9]

Temporary carotid artery ligation is performed after positioning the patient in dorsal recumbency with the front legs secured caudally along the chest and the neck dorsiflexed by positioning it over a pad. Incise skin along the ventral cervical midline from the larynx to midtrachea. The paired sternohyoideus muscles are separated and retracted to expose the trachea. To locate the carotid sheath, the surgeon palpates the carotid pulse dorsolateral to the trachea, then bluntly dissects the adjacent loose connective tissue and exteriorizes the carotid sheath. The surgeon carefully incises the carotid sheath and separates the external carotid artery from the vagosympathetic trunk and internal jugular vein. The carotid artety is occluded with a vascular tie (Vascular Ties®, Sil-Med Corporation, 700 Warner Blvd., Taunton, MA 02780), umbilical tape or a vascular clamp (Figure 24-8). The procedure is repeated on the opposite carotid artery and the skin incision is closed with a continuous suture pattern or staples. The surgical site is covered with an adherent, sterile dressing. Immediately after rhinotomy, the surgeon exchanges contaminated instruments and gloves and positions the patient to allow reexposure of the carotid arteries. The ventral midline incision, is opened, the carotid arteries are exposed, and the vascular clamps or ties removed. The surgeon

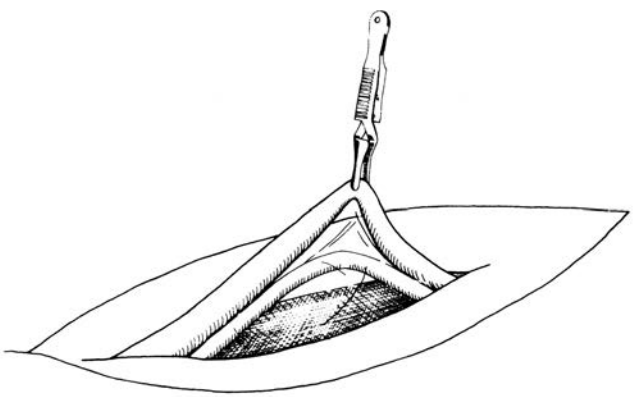


Figure 24-8. The common carotid artery is occluded with a bulldog clamp after being separated from the vagosympathetic trunk and internal jugular vein.

lavages the area thoroughly and apposes sternohyoid muscles, subcutaneous tissue and skin in separate layers.

Dorsal Rhinotomy

Dorsal rhinotomy allows access to the entire nasal cavity and the frontal sinuses.[8] After the anesthetized animal is intubated, the endotracheal tube cuff is inflated, and the pharynx is packed with gauze sponges to prevent drainage of fluids into the trachea. The patient is positioned in ventral recumbency, then the dorsum of the head is clipped and prepared for surgery. The surgeon begins the rhinotomy by making a midline skin incision over the nasal cavity and frontal sinus which extends caudal to the orbits (Figure 24-9). The dense fascia and periosteum overlying the bone are incised, elevated and retracted laterally. The bone is scored with a scalpel blade to outline a unilateral or bilateral bone flap depending on the extent of the disease and the exposure necessary (Figure 24-10). The flap is made using an oscillating saw, drill, osteotome and mallet, or trephine and rongeurs. The margins of the bone are beveled inward if bone flap replacement is anticipated. In addition, pre-drilling holes in the flap and adjacent bone margin for suture placement aids in easier bone flap reattachment. The bone flap is elevated from the underlying turbinates with an osteotome or periosteal elevator. The bone flap is reflected rostrally leaving it attached to the dorsal parietal cartilage of the rhinarium by the nasal ligaments if flap replacement is planned (Figure 24-11). After exposing the nasal cavity and frontal sinus, the surgeon suctions secretions or exudate and explores the area. The lesion and involved turbinates are removed or sampled for biopsy with forceps, a bone curette and Metzenbaum scissors. (Figure 24-12). Total turbinectomy is often necessary to eliminate extensive areas of nasal mucosa with chronic irreversible hyperplasia. One should avoid traumatizing or perforating the cribriform plate during turbinectomy. Identifiable bleeding vessels are ligated. When external carotids are not occluded it may be necessary to control hemorrhage with cautery, iced saline, or pressure. Tissues are submitted for histologic and culture evaluation . During a unilateral rhinotomy,

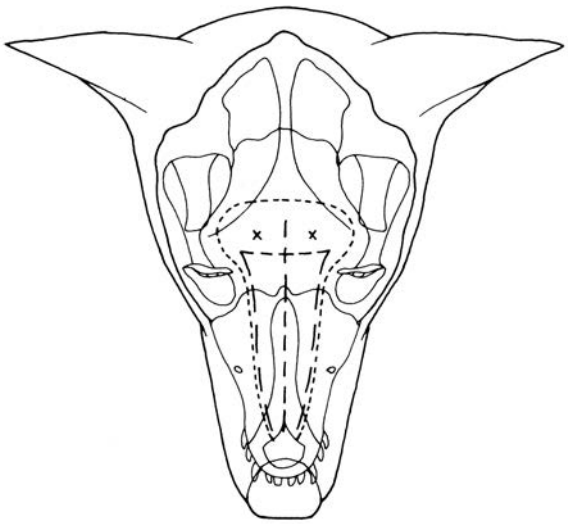


Figure 24-9. The outer dotted line outlines the approximate extent of the nasal cavity and frontal sinus. The inner dashed lines outline the bone flap for a unilateral or bilateral rhinotomy. The X's over the frontal sinuses indicate the site for insertion of a drain(s).

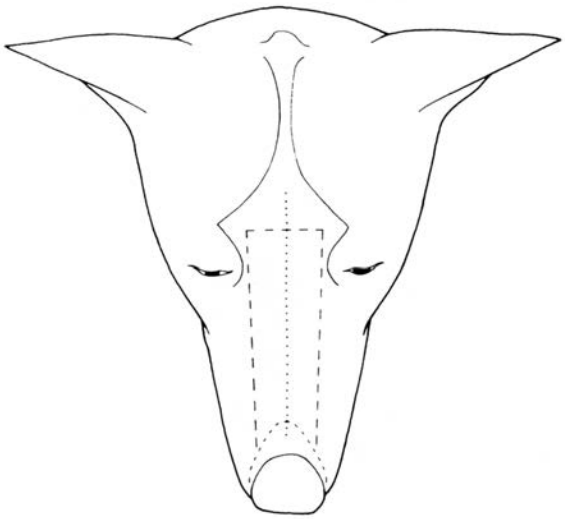


Figure 24-10. The dashed line represents bone scoring for a bilateral bone flap. The dotted line represents the location of the nasal septum, which divides the nasal cavity into two fossae.

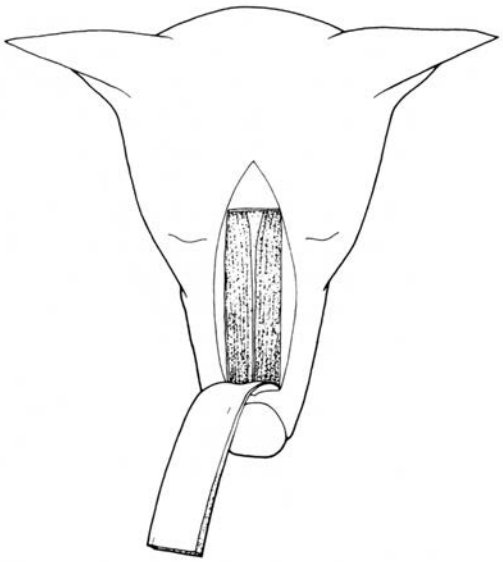


Figure 24-11. The bone flap is reflected rostrally and remains attached to the dorsal parietal cartilages.

if the nasal septum has been perforated or eroded by the disease process, the other fossa is explored and curetted through the septal defect or by creating a second bone flap. When mucoid secretions fill the frontal sinuses, the surgeon enlarges the ostia and breaks down the septae to facilitate drainage. The caudal nasal meatus (internal nares/choanae) should be probed with a hemostat to verify patency. The nasal cavity and sinuses are lavaged with saline or lactated Ringer's solution before closure to remove debris and blood clots. Fenestrated indwelling tubes are placed if necessary for adjuvant therapy. These drains are placed through a trephine hole into the frontal sinus and extend into the nasal fossa.

The bone flap is replaced or discarded depending on the extent of disease and the surgeon's preference. The flap is discarded if it is involved in the disease process or if fragmentation occurs during removal. If the flap is being replaced, drill three or

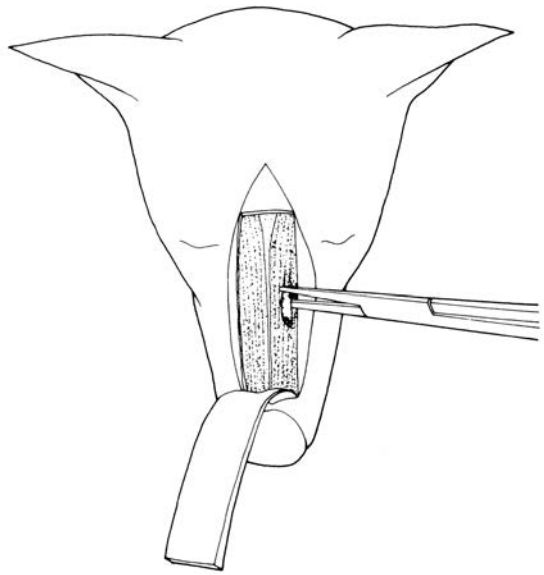


Figure 24-12. Turbinectomy begins by removal of the diseased turbinates with forceps.

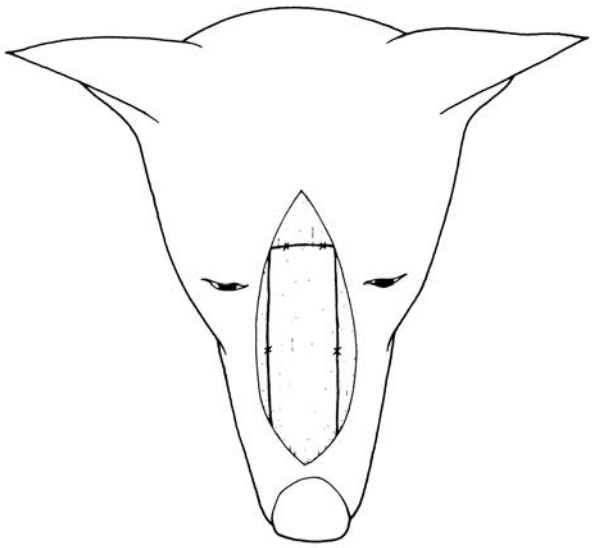


Figure 24-13. The bone flap is replaced by placing sutures through holes drilled in the flap and margins of the defect.

four holes in the flap and the adjacent margins of the defect. The surgeon then preplaces nonabsorbable sutures (nylon, polypropylene) through the holes, positions the flap, and ties the sutures to secure the flap. (Figure 24-13). One should not use wire to secure the bone flap if radiation therapy is being planned. Occasionally, when the defect is large, if the flap is discarded and cosmetics are critical, a bone graft or synthetic mesh is stretched across the bony defect and secured. Potential risks with the use of such implants include sequestration and infection. Soft tissues are apposed in three layers (fascial/periosteal layer, subcutaneous tissues, and the skin) using continuous suture patterns. Air leakage from the rhinotomy site and subcutaneous emphysema may be controlled by suturing a stent over the surgical site, placing a drain in the frontal sinus and nasal cavity or leaving a small gap between tissue edges during closure.

Technique variations may be necessary depending on the disease type and extent. Postoperative nasal flushing, prevention of emphysema, and brachytherapy for tumors is facilitated by placing a drain in the frontal sinus and nasal cavity through a trephine hole (Figure 24-14). An incision is made through the soft tissues and a hole in the bone is drilled or trephined just lateral to the midline on a line connecting the rostral margins of the supraorbital processes. Biopsy and culture specimens may be collected through this hole if not previously obtained. A fenestrated tube is inserted into the sinus, advanced into the nasal cavity and secured to the skin. The hole is allowed to heal by second intention after tube removal. Protocols for treatment of nasal fungal diseases may include packing the nasal cavity with medicated gauze or creating a stoma. Stomas are created by securing the skin edges directly to the margins of the bony defect.[10-11] Creation of a stoma facilitates topical therapy postoperatively. If the stoma is small it may heal by second intention, otherwise following conclusion of medical therapy the skin edges are debrided, undermined, and apposed. Removal of lesions in the rostral nasal cavity may be facilitated by extending the incision through the rhinarium lateral to the nasal septum.

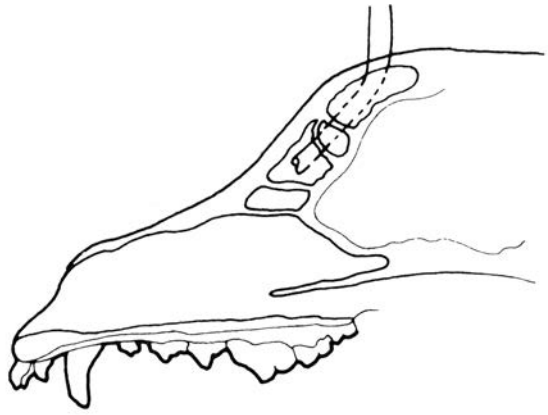


Figure 24-14. A drain can be positioned in the frontal sinus for adjuvant therapy or to reduce subcutaneous emphysema.

Ventral Rhinotomy

Ventral rhinotomy allows exploration of the nasal cavity and nasopharynx.[8] Evaluation and evacuation of the frontal sinuses is limited to the rostral half with ventral rhinotomy. Concurrent mandibulotomy may be performed to improve access to the caudal nasal cavity and nasopharynx. Although most surgeons prefer dorsal rhinotomy, advantages of ventral rhinotomy include improved cosmesis and less risk of subcutaneous emphysema. Disadvantages include incomplete access to the frontal sinuses and the potential for oronasal fistula formation.[9]

The patient is positioned in dorsal recumbency with the oral cavity maximally exposed by hanging and securing the mandible in a wide, open-mouth position. One should use mild antiseptic solutions (0.05% chlorhexidine or 0.1% or 1% povidone-iodine) to cleanse the oral cavity prior to incising tissue.

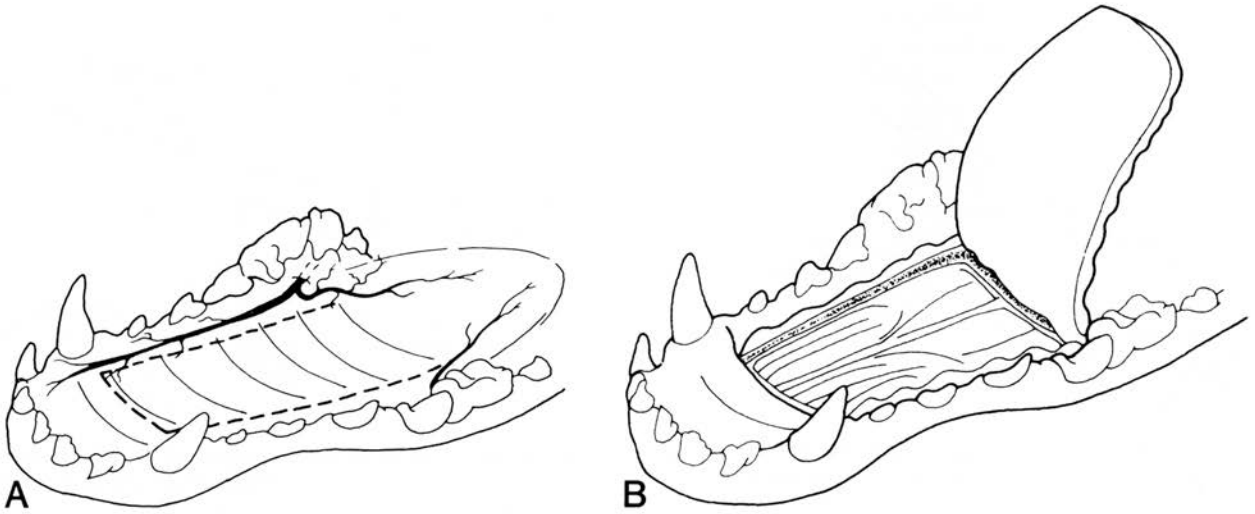


Figure 24-15. Ventral Rhinotomy: **A.** The dashed line represents a U-shaped mucoperiosteal incision made just medial to the major palatine artery when performing a ventral approach to the rostral aspect of the nasal cavity. **B.** A rectangular palatine bone flap of similar size is created and removed to expose the nasal turbinates.

Cranial Ventral Rhinotomy

The mucoperiosteum of the hard palate is incised on the midline from the level of the canine teeth to the fourth premolar to expose lesions restricted to the rostral nasal cavity. Alternatively, the nasal cavity may also be exposed using a "U" shaped mucoperiosteal incision parallel to the dental arcade (Figure 24-15A). After incision, the surgeon elevates and retracts the mucoperiosteum to expose the hard palate while preserving the major palatine arteries during incision and dissection. The major palatine arteries emerge from the major palatine foramen at the caudal edge of the fourth upper premolar and course rostrally, midway between the midline and dental arcade. Remove a rectangular palatine bone flap with an oscillating saw, air drill or osteotome (Figure 24-15B). Alternatively, rongeurs are used to create an access window in the hard palate. The lesion and involved turbinates are removed with forceps and curettage. The surgeon lavages and suctions the area prior to replacing or discarding the bone flap as with dorsal rhinotomy (Figure 24-16). The mucoperiosteum is apposed using a one or two layer closure with simple interrupted sutures (3-0 or 4-0 polydioxanone, polypropylene).

Caudal Ventral Rhinotomy

Caudal ventral rhinotomy is selected for exposure of lesions in the caudal nasal passages and nasopharynx. A midline cranial ventral rhinotomy incision can be extended to expose the nasopharynx when necessary. A midline soft palate incision is made beginning 5 to 10 mm rostral to the tip of the soft palate and extending through the mucoperiosteum of the hard palate as far as necessary to expose the lesion adequately (Figure 24-17) Stay sutures are placed in the incised edges of the soft palate to facilitate retraction and to minimize trauma. The mucoperiosteum is elevated and the hard palate is rongeured as far rostrally as necessary for exposure. The surgeon explores, removes the lesion, and lavages the area. The soft palate is apposed in two (nasal and pharyngeal mucosa) or three layers (nasal mucosa, muscle and connective tissue, and pharyngeal mucosa) with simple interrupted or continuous monofilament sutures (4-0 polydioxanone, polypropylene) (Figure 24-18) The mucoperiosteum is apposed with one or two layers of simple interrupted sutures.

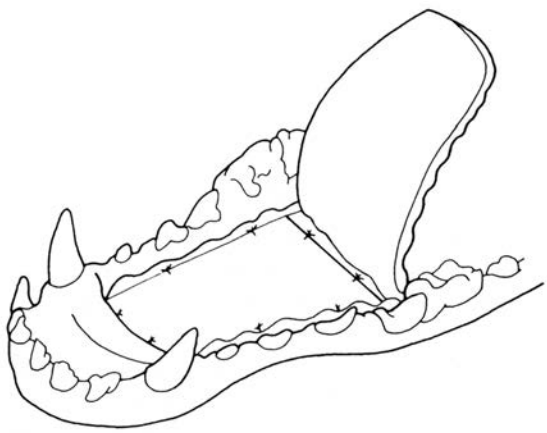


Figure 24-16. The palatine bone flap is replaced by sutures secured through holes drilled in the flap and bone margins.

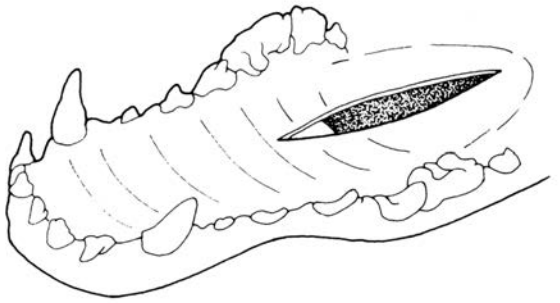


Figure 24-17. The caudal aspect of the nasal cavity and nasopharynx is approached ventrally by incising the soft and hard palates for varying distances.

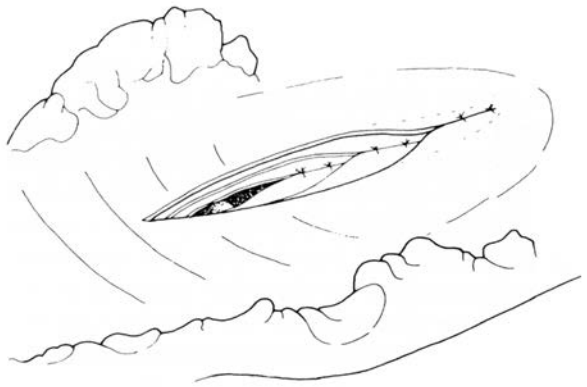


Figure 24-18. The soft palate incision is closed with two or three layers of sutures to allow good apposition of the nasal and oral mucosae.

Lateral Rhinotomy

Lateral rhinotomy is occasionally used to approach lesions in the rostral one fourth to one third of the nasal passages. Approaches using incisions through either the skin or the alveolar mucosa have been described. These approaches are performed with the animal in lateral or sternal recumbency. The surgeon directs the incision dorsocaudally from the angle of the rhinarium toward the nasomaxillary notch between the dorsal and ventral parietal cartilage. (Figures 24-19 and 24-20) The accessory cartilage is invariably transected. The edges of the incision are retracted with stay sutures to expose the rostral nasal passages. The incision is closed in three layers (nasal mucosa, cartilage or subcutaneous tissue and skin).

Alternatively, the alveolar mucosal technique provides acceptable exposure to the rostral nasal cavity and avoids transection of nasal cartilage or bone.[12] The surgeon retracts the lip dorsally and palpates the rostrolateral aspects of the right nasal and incisive bones. An incision is made through the alveolar mucosa along this ridge from the nasal bone to the rostral end of the interincisive suture. Using a periosteal elevator, the mucosa is reflected in a dorsal and medial direction along with the dorsal lateral nasal cartilage. After exploring and collecting tissue samples the alveolar mucosa is apposed with simple interrupted sutures.

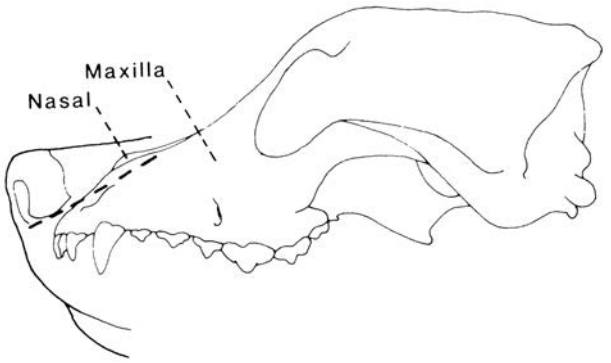


Figure 24-19. The incision for a lateral rhinotomy is directed dorsocaudally from the angle of the rhinarium toward the nasomaxillary notch.

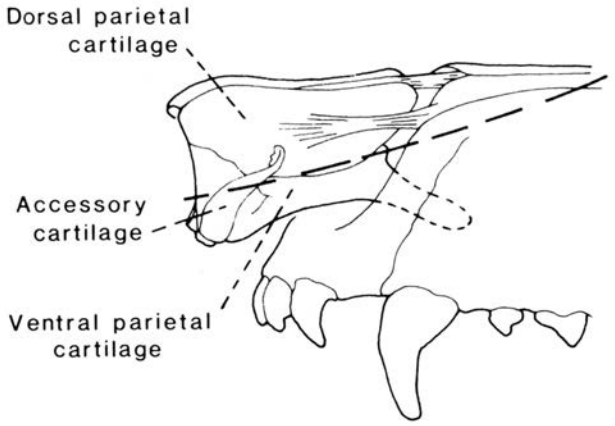


Figure 24-20. The lateral rhinotomy incision is directed between the dorsal and ventral parietal cartilages but transects the accessory cartilage.

Postoperative Management

After surgical procedures involving the nasal cavity and sinuses, pharyngeal sponges (if placed) are removed, and the animal is recovered in a slightly head down position. The endotracheal tube is removed with the cuff slightly inflated to prevent tracheal aspiration of fluid and other debris. Analgesics are given for three to five days as needed. Good analgesia is obtained with parenteral hydromorphone (or a constant rate infusion of morphine/lidocaine (See Chapter 9). The patient's vital signs are monitored carefully and supportive care is administered as needed.

Blood transfusions are sometimes (16% of cases) necessary even following carotid occlusion.[9] Sneezing and mild epistaxis are expected for several days. A serous to serosanguineous discharge occurs for several days to weeks depending on the primary disease condition and the effectiveness of adjuvant therapy. Breathing sounds are harsh and resonant. Inward and outward movement of the skin flap is expected if the bone flap is discarded. Appetite may be depressed for several days. Cats tolerate rhinotomy poorly and may not readily resume eating. Diazepam or oxazepam may be given to stimulate their appetite. Chewing on hard objects is forbidden if the hard palate bone flap is discarded. Patients are discharged from the hospital within 2 to 3 days following surgery unless complications or adjuvant therapy dictates longer hospitalization.

Complications

Complications of rhinotomy include hemorrhage, entrance into the cranium, pain, subcutaneous emphysema, airway obstruction, nasal discharge, fistula and disease recurrence. Intraoperative hemorrhage is minimized by temporary occlusion of the external carotid arteries and good hemostasis during surgery. Packing the nasal cavity is discouraged as it may lead to hyperventilation and subcutaneous emphysema; in addition removal of the packing material 2 to 3 days after surgery is painful. Postoperative hemorrhage is rare however blood transfusions are sometimes necessary to replace lost volume.

Disease erosion of the cribriform plate or curettage may result in exposure of the brain and subsequent cerebral edema. Tumor extension into the cranium should be suspected when

the animal exhibits neurologic signs or when defects in the cribriform plate are identified with computed tomography. Animals with brain edema should be treated with rapid-acting water soluble intravenous corticosteroids, osmotic agents (mannitol), hyperventilation, hyperbaric oxygen, calcium channel blockers and antioxidants.

Subcutaneous emphysema occurs when air leaks from the nasal cavity into the subcutaneous tissues at the surgical site and is usually associated with violent sneezing or obstruction to nasal airflow. Airflow may be obstructed by nasal packing, occlusion of the nares with crusted blood and secretions, or severe mucosal edema. Subcutaneous emphysema is usually self-limiting and resolves within one to two weeks. It may be prevented by suturing a stent over the surgical site, inserting a drain, or creating a stoma and avoiding obstruction of the nasal passages. Subcutaneous emphysema is primarily a cosmetic concern although it could facilitate spread of infection. The animal's comfort may improve if the subcutaneous air is aspirated and a drain is placed into the nasal cavity to reduce recurrence.

Rhinotomy is a painful procedure. Analgesics should be given at the conclusion of surgery and as needed for 3 to 5 days. Anorexia is expected following surgery and may be due to pain or a diminished sense of smell. Anorexia is more severe in cats than dogs because they depend on their ethmoturbinates for olfaction and appetite stimulation. Cats are given diazepam or oxazepam to stimulate their appetite if necessary. Dogs usually require no treatment and have a normal appetite within a few days. After ventral rhinotomy, animals should not be allowed to chew on hard objects. Oronasal fistulas develop if dehiscence occurs or when soft tissues are perforated by hard, sharp objects.

Although airway obstruction is uncommon it may occur following rhinotomy. Animals should be monitored closely during recovery. Obstruction may be due to failure to mouth breath, mucosal edema and anxiety. These animals should be sedated and provided with supplemental oxygen in a quiet, cool environment. Corticosteroids should be given to reduce mucosal edema. An endotracheal or tracheostomy tube is indicated if dyspnea is severe.

A serosanguineous nasal discharge is expected following rhinotomy. The discharge diminishes and becomes more serous as denuded bone is covered with epithelium. If the primary disease has been eliminated the discharge remains minimal and serous. If the disease progresses or the area becomes infected, the nasal discharge increases and becomes mucopurulent or hemorrhagic. Chronic infections are treated with antibiotics selected on the basis of culture and sensitivity tests.

Recurrence of most diseases is expected after rhinotomy unless appropriate adjuvant therapy is instituted. Rhinotomy for foreign body removal might be an exception if irreversible chronic rhinitis and osteomyelitis have been avoided. Rhinotomy for fungal disease should be followed with administration of topical antifungal agents, and rhinotomy for neoplasia should be followed by radiation therapy, to extend the animal's disease free period.

References

1. Gieger T, Northrup N: Clinical approach to patients with epistaxis. *Compend Contin Educ* 26:30, 2004.

2. Schoenborm WC, Wisner ER, Kass PP, et al: Retrospective assessment of computed tomographic imaging of feline sinonasal disease in 62 cats. *Veterinary Radiology & Ultrasound* 44:185, 2003.

3. De Rycke LM, Saunders JH, Gielen IM, et al: Magnetic resonance imaging, computed tomography and cross-sectional view of the anatomy of normal nasal cavities and paranasal sinuses in mesaticephalic dogs. *Am J Vet Res* 64:1093, 2003.

4. Noone K: Rhinoscopy, pharyngoscopy, and laryngoscopy. *Vet Clin N Am Sm Anim Pract* 31 (4):671, 2001.

5. McCarthy TC, McDermaid SL: Rhinoscopy. *Vet Clin N Am Sm Anim Pract* 20 (5):1265, 1990.

6. Lent SE, Hawkins EC: Evaluation of rhnoscopy and rhinoscopy-assisted mucosal biopsy in diagnosis of nasal disease in dogs: 119 cases (19851989). *J Am Vet Med Assoc* 201: 1425, 1992.

7. Hedlund, C.S., Tangner, C.H., Elkins AD, et al: Temporary bilateral carotid artery occlusion during surgical exploration of the nasal cavity of the dog. *Vet Surg* 12:83, 1983.

8. Hedlund CS : Rhinotomy techniques. In Bojrab, M.J.,ed: Current Techniques in Small Animal Surgery. 4th ed. Baltimore: Williams & Wilkins, 1998.

9. Holmberg DL: Sequelae of ventral rhinotomy in dogs and cats with inflammatory and neoplastic nasal pathology: A retrospective study. *Can Vet J* 37:483, 1996.

10. Pavletic MM, Clark GN: Open nasal cavity and frontal sinus treatment of chronic canine aspergillosis. *Vet Surg* 20:43, 1991.

11. Moore AH: Use of topical povidone-iodine dressings in the managment of mycotic rhinitis in three dogs. *J Sm Anim Pract* 44:326, 2003.

12. Priddy, NH, Pope ER, Cohn LA, et al: Alveolar mucosal approach to the canine nasal cavity. *J Am Anim Hosp Assoc* 37: 79, 2001.

Chapter 25

Larynx

Brachycephalic Syndrome

Cheryl S. Hedlund

Introduction

Brachycephalic animals (especially English bulldogs, Boston terriers, Chinese Pugs, Pekinese, Shar Pei dogs, and Himalayan and Persian cats) often exhibit signs of upper airway obstruction due to anatomic and functional abnormalities. Brachycephalia is a local chondrodysplasia that occurs as a result of domestication. Brachycephalic animals are characterized by having a compressed face with poorly developed nares and a distorted nasopharynx. Their head shape is the result of an inherited developmental defect in the bones of the base of the skull. These bones grow to a normal width but reduced length. The soft tissues of the head are not proportionally reduced and often appear redundant. These anatomic exaggerations result in increased airflow resistance and increased inspiratory effort which lead to functional airway abnormalities. Brachycephalic animals with these anatomic exaggerations and clinical signs are diagnosed as having the "Brachycephalic Syndrome".

The major components of the "Brachycephalic Syndrome" include 1) stenotic nares, 2) elongated soft palate, and 3) eversion of the laryngeal saccules. Most dyspneic brachycephalics have more than one and often all components of the syndrome. Some animals, especially English bulldogs, also have tracheal hypoplasia. These abnormalities may restrict airflow so severely that the condition progresses to include laryngeal and pharyngeal inflammation and edema, tonsil eversion from their crypts, and epiglottic, laryngeal and/or tracheal collapse.

Presentation and Diagnosis

Affected brachycephalics exhibit mild to severe signs of respiratory distress depending on the degree and location(s) of the obstruction. Signs of upper airway obstruction include exercise intolerance, stertorous breathing, mouth breathing, gagging, restless sleep ("sleep-disordered breathing"), cyanosis and collapse. Other signs may include restlessness, tachypnea, dysphagia, fever and an abnormal posture. Excitement, stress, and increased heat and humidity frequently make clinical signs worse. Dogs present for stridorous breathing and exercise intolerance, gagging or episodes of cyanosis and collapse.

Clinical evaluation of patients with severe respiratory distress should be conducted in a manner that does not upset the animal to avoid exacerbating its condition. The animal should be allowed to maintain a position of comfort and be minimally restrained during initial evaluation. Prior to a more thorough evaluation and work-up, patients with severe respiratory distress are provided emergency therapy. Emergency treatment includes controlling the environment to keep the animal cool and minimize stress, providing supplemental oxygen and a patent airway, and administering corticosteroids, sedatives and other drugs as needed to stabilize the patient. Sedatives given to relieve anxiety or facilitate examination sometimes exacerbate signs by relaxing upper airway dilating muscles. Further diagnostics and treatment follow stabilization of the patient.

A tentative diagnosis of the patient's upper respiratory tract obstruction is usually achieved by obtaining a complete history, thorough physical examination, and clinical pathology results. Clinical pathology results are usually normal but may reveal polycythemia in animals with chronic hypoxia.[1] These diagnostic measures are followed by lateral neck and routine thoracic radiographs or other imaging modalities, endoscopic respiratory tract examination, and sample collection for bacterial culture and biopsy as needed. Additional diagnostic measures might include blood gas analysis and respiratory function testing.

Components of the Syndrome

Stenotic Nares

Stenotic nares are congenital malformations of the nasal cartilages which are commonly seen in brachycephalic breeds. The nasal cartilages of animals with stenotic nares lack normal rigidity and collapse medially causing occlusion of the external nares. Normally during inspiration the levator nasolabialis muscle contracts dilating the nares to facilitate air intake. In animals with stenotic nares there is little or no dilation during inspiration, and in severe cases, collapse of the opening. Airflow into the nares is restricted and greater inspiratory effort is necessary, causing mild to severe dyspnea. Severe inspiratory dyspnea results if airflow obstruction is marked. Marked occlusion of the nares results in open-mouthed breathing and can interfere with olfaction, and air warming, moisturizing, and filtering. Stenotic nares are diagnosed on physical exam by recognizing that the external nares opening in the nasal planum is narrowed, restricted or compressed by this collapsed tissue.

Elongated Soft Palate

Congenital soft palate elongation is the most commonly recognized component of the Brachycephalic syndrome. The normal soft palate just touches or slightly overlies (1 to 3 mm) the tip of the epiglottis. The elongated soft palate extends more than 1 to 3 mm caudal to the tip of the epiglottis, is often thickened and obstructs the dorsal aspect of the glottis (Figure 25-1). The elongated palate is pulled caudally during inspiration and is sometimes pulled between the corniculate processes of the arytenoids. Consequently, increased inspiratory effort is required and airflow is more turbulent. The arytenoids and palate become inflamed and irritated due to the movement of the palate against the arytenoids and airflow turbulence. At times the soft palate may obscure the epiglottis by displacing it dorsally. Diagnosis of soft palate elongation is made during laryngoscopic or endoscopic examination of the nasopharynx and larynx.

Laryngeal Saccule Eversion

Laryngeal saccule eversion,or prolapse of the mucosa lining the laryngeal crypts, is the first stage of laryngeal collapse.

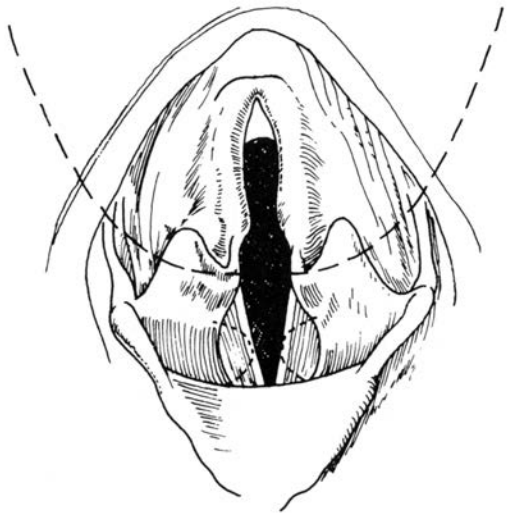


Figure 25-1. The dorsal dashed line represents the position of an elongated soft palate obstructing the dorsal aspect of the larynx. Everted laryngeal saccules (ventral dashed line) protrude from their crypts cranial to and partially obscure the vocal folds.

In their normal position between the vocal cords and the ventricular bands (false vocal cords), the laryngeal saccules are not visualized. Increased airflow resistance and increased negative pressure generated to move air past obstructed areas due to stenotic nares and soft palate elongation pulls the saccules from their crypts and causes them to swell. Everted and edematous saccules obstruct the ventral aspect of the glottis further restricting airflow (See Figure 25-1). Diagnosis of laryngeal saccule eversion is made during laryngoscopic or endoscopic examination. The everted saccules are recognized as edematous or fleshy soft tissue masses immediately rostral to and often obscuring the vocal folds. Acutely everted saccules are whitish and glistening in appearance. Chronically everted saccules are pink and fleshy. It is difficult to visualize and thoroughly evaluate the laryngeal saccules and larynx prior to soft palate resection as the soft palate obscures the other structures, and the severely affected patient may become cyanotic. For these reasons, laryngeal saccule eversion is diagnosed less often than elongated soft palate or stenotic nares. Saccule eversion may also be suspected during ultrasonographic examination of the larynx when there is a narrowed air shadow within the rima glottis.[2]

Advanced Laryngeal Collapse

Advanced laryngeal collapse is caused by chronic upper airway obstruction which results in increased inspiratory efforts and causes the cartilages to fatigue and lose their rigidity. Stage two and three laryngeal collapse may be recognized during laryngoscopic or endoscopic evaluation of animals with the brachycephalic syndrome. In stage two collapse or collapse of the aryepiglottic fold, the cuneiform process of the arytenoid cartilage and the fold of tissue connecting it to the epiglottis weaken and deviate medially (Figure 25-2). Medial deviation of this aryepiglottic fold causes further obstruction of the ventral aspect of the glottis. In stage three collapse or collapse of the corniculate processes of the arytenoid cartilages, the corniculate processes loose their rigidity and deviate medially

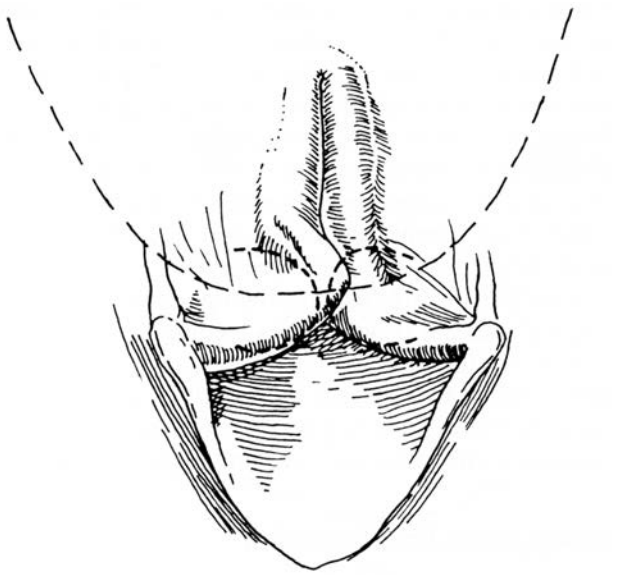


Figure 25-2. Severe collapse of the arytenoid cartilages in conjunction with an elongated soft palate (dorsal dashed line) and eversion of the laryngeal saccules (ventral dashed lines). The aryepiglottic folds and cuneiform cartilage collapse medially obstructing the ventral aspect of the glottis in stage two laryngeal collapse. The corniculate processes of the arytenoid cartilages collapse medially narrowing the dorsal glottis with stage three laryngeal collapse.

obstructing the dorsal aspect of the glottis (See Figure 25-2). The normal glottic diameter at rest is narrowed and widening of the glottis during inspiratory abduction of the corniculate processes is reduced.

Associated Abnormalities

During laryngoscopic and endoscopic examination of the airway the pharynx should be assessed for degree of inflammation and edema, evidence of redundant dorsal pharyngeal mucosa, and tonsil eversion. Tonsil eversion, inflammation and edema are secondary to air turbulence and increased breathing effort. Aberrant nasal turbinates and gastrointestinal lesions have also been described. Tracheoscopy is performed to assess the tracheal conformation and degree of inflammation. Many brachycephalics have concurrent tracheal hypoplasia and a few have tracheal collapse. Hypoplasia results in a narrow lumen due to the cartilages meeting or overlapping. These cartilages are often abnormally rigid and the trachealis muscle is often obscured or rolled into the lumen. Tracheal collapse is usually a dorsoventral narrowing of the trachea with cartilages being more flaccid than normal and the trachealis muscle is stretched and droops into the lumen. These abnormalities further restrict airflow.

Treatment

After definitive diagnosis, the syndrome is treated with the goal of achieving long-term relief from respiratory distress and preventing progression of the disease. Partial resection of the nares, soft palate and laryngeal saccules is recommended for all patients with these brachycephalic abnormalities. Patients with advanced laryngeal collapse who do not improve adequately following palate and saccule resection or those who improve and then later relapse with severe signs of respiratory distress

often benefit from a permanent tracheostomy which allows airflow to by-pass the upper airway. In addition to surgery, medical management may be beneficial. A weight reduction program is instituted for obese animals. Exercise restriction and elimination of precipitating causes may be beneficial. Provision of a cool environment and exclusion of respiratory irritants from the animal's environment (smoke, fragrances, sprays, etc) are beneficial. Perioperative administration of metaclopramide and gastroprotectants may decrease signs associated with gastrointestinal lesions.

Before surgical evaluation and treatment, special precautions must be taken because brachycephalic animals with respiratory distress are at extreme risk for hypoxia, especially during anesthetic induction and recovery. Sedatives and anesthetic agents relax the upper airway by dilating muscles and relaxing accessory muscles employed by brachycephalics to facilitate breathing. This allows the upper airway to collapse and reduces respiratory drive. Risk of complete airway obstruction at induction can be minimized by pre-oxygenating the patient, rapid induction of anesthesia with an injectable agent, and then quickly intubating the patient. Risk of complete airway obstruction during recovery are minimized by intensive monitoring and prevention of nasopharyngeal and laryngeal edema. I recommend administering an anti-inflammatory dose of corticosteroids (dexamethasone 0.5 to 2 mg/kg SQ, IM) immediately prior to or after induction of anesthesia. This reduces swelling and edema of pharyngeal and laryngeal tissues during and after surgery. Corticosteroid administration may be repeated as needed after surgery to reduce airway obstruction caused by swollen pharyngeal and laryngeal tissues. Nasopharyngeal and laryngeal inflammation and edema are also minimized by using atraumatic examination and surgical techniques. Sedation of the patient as anesthetic recovery begins will allow a slow, smooth recovery with the endotracheal tube in place for as long as possible. Administration of oxygen through a nasal catheter facilitates a slow smooth recovery and minimizes anxiety due to hypoxia. Alternatively, a tracheostomy tube is placed at the beginning of surgery and removed when the animal is fully recovered from anesthesia and shows minimal signs of respiratory distress.

Surgical Techniques

Various surgical techniques have been described to resect portions of the nares, soft palate and laryngeal saccules. Resections should be performed early in the animal's life (often before 1 year of age) to prevent progressive deterioration of airway function. I prefer resection using sharp incisions with a scalpel or scissors rather than using electrosurgical, heat sealing or laser instruments. Prior to surgery, the patient is positioned to allow for optimal visualization and lighting of the oral and pharyngeal cavities (Figure 25-3). The patient is positioned in sternal recumbency with the neck extended and the maxilla suspended from an overhead rod. The mandible is pulled ventrally with tape to maximally open the mouth and the tongue is retracted rostrally. The cheeks may also be retracted laterally to further improve visualization.

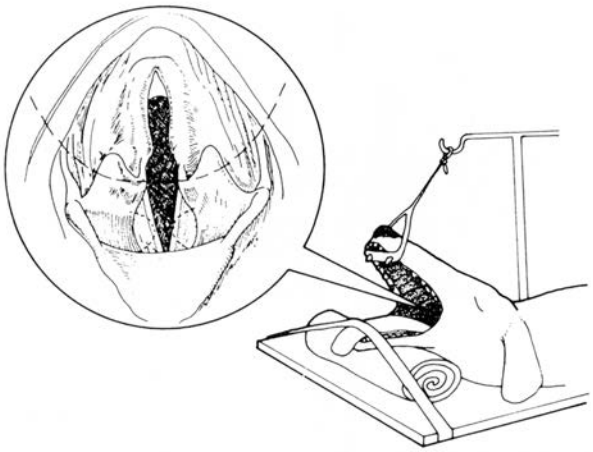


Figure 25-3. The dog is positioned in ventral recumbency with its maxilla suspended to allow and oral approach to the soft palate and laryngeal ventricles.

Soft Palate Excision

Surgery is begun by resecting the elongated soft palate. This will allow subsequent resection of the laryngeal saccules if necessary with a less obstructed view. An Allis tissue forceps is used to grasp the tip of the soft palate and retract it cranially (Figure 25-4A). The line of excision is along an imaginary line at the level of the caudal pole of the tonsil. The epiglottis may also be used for anatomic reference and the finsished resected palate should just touch the tip of the epiglottis. Once the length of palate to be resected is determined, stay sutures using 3-0 or 4-0 poliglicaprone 25 (monocryl, Ethicon, Inc., Somerville, NJ) are placed and tied in the lateral margins of the palate adjacent to the line of incision. Cranial retraction using the tissue forceps and stay sutures provides good visualization.

A scalpel blade or a sharp pair of Metzenbaum scissors is used to incise half the width of the soft palate (Figure 25-4B). The incised edges of the nasal and oral palatal mucosa are apposed using a simple continuous pattern of 3-0 or 4-0 poliglicaprone 25. Care is taken to include the nasal mucosa which tends to retract from the incision line. The remaining palate is incised, and suturing continued to the opposite margin (Figure 25-4C). The stay sutures can be used as part of the suture placed in the palate or remain separate from the incision line. Blood clots or mucus should be aspirated from the pharynx prior to recovery and extubation of the patient.

Laryngeal Saccule Resection

Stay sutures previously placed on the edges of the soft palate are maintained to facilitate retraction of the palate and improve visualization of the everted laryngeal saccules. Blood and mucus are aspirated from the glottis as necessary. The endotracheal tube is elevated dorsally and deviated to one side to allow access to the laryngeal saccule on the opposite side. Alternatively, the endotracheal tube may be temporarily removed to allow less restricted access to the laryngeal saccules, this however increases the intraoperative risks of aspiration and hypoxia. An Allis tissue forceps is used to grasp and gently retract the everted saccule rostrally and medially to allow positioning of a

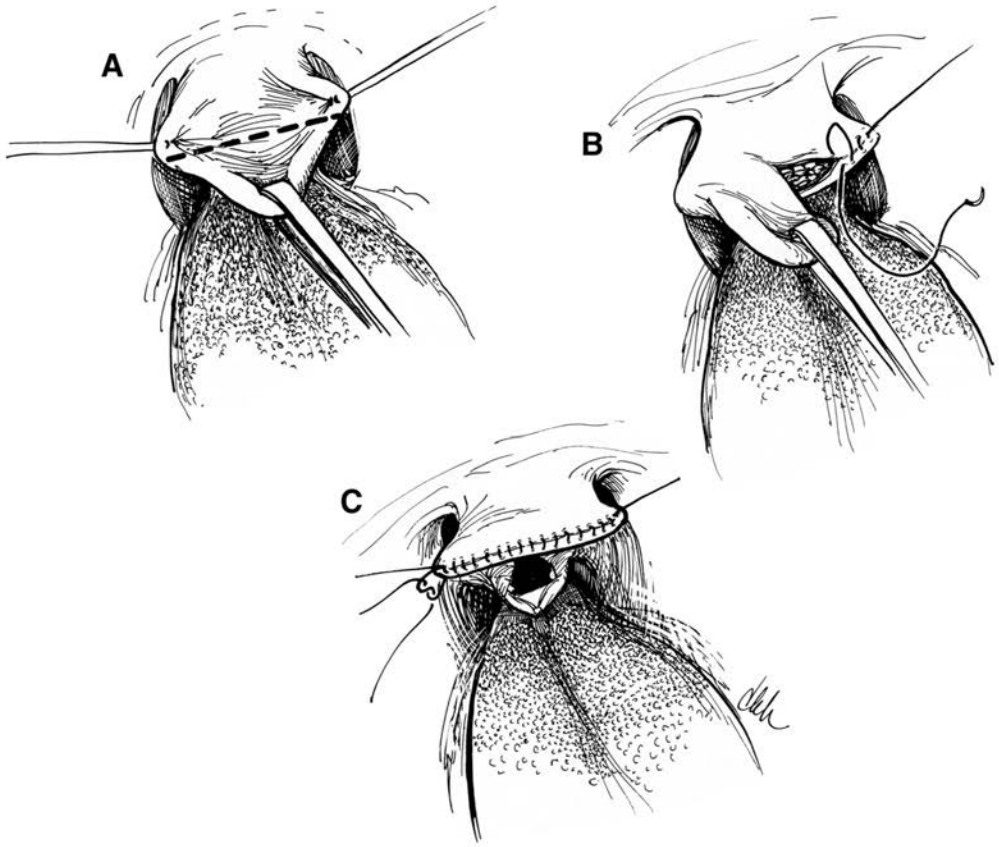


Figure 25-4. A. The tip of the soft palate is grasped with Allis tissue forceps. After noting the length of soft palate to be amputated, stay sutures are placed just cranial to the proposed line of resection. **B.** The full thickness of the soft palate is incised with a surgical blade approximately half the width of the soft palate. A length of the "stay" suture with the needle attached is used to appose the edges of the cut surface while one takes care to incorporate both the pharyngeal and nasal mucosa. **C.** After completing mucosal apposition, the suture is tied to a length of suture being used as a "stay" suture on the opposite side.

long-handled, curved Metzenbaum scissors across the base of the saccule. (Figure 25-5). The everted tissue is excised using the scissors. Amputation may also be accomplished using laryngeal cup forceps or similar biopsy instruments, laser or electrosurgery. Hemorrhage is usually mild but some surgeons twist the saccule after it is grasped to reduce hemorrhage post-excision. More severe hemorrhage is rare and is controlled with direct pressure. Care is used during excision to not inadvertently resect the vocal fold which lies immediately caudal to the everted saccule. The procedure is repeated to remove the opposite laryngeal saccule and the resection sites are allowed to heal by second intention.

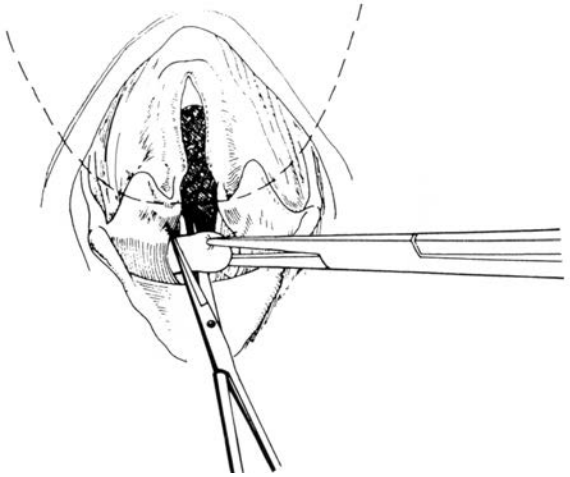


Figure 25-5. The laryngeal saccule is grasped with tissue forceps and amputated at its base.

Stenotic Nares Wedge Resection (Alaplasty)

The patient is positioned in sternal recumbency and the head taped to the table to avoid rotation. The obstructing portion of the lateral nasal planum is grasped with Brown-Adson thumb forceps to delineate and stabilize the segment of nares to be resected. Maintaining this grip, make a "V" shaped incision around the forceps with a #11 scalpel blade. First make a medial incision angled in a caudolateral direction. Then make a second incision from the lateral aspect of the nares in a caudomedial direction to meet the first incision at the vortex of the wedge (Figure 25-6) Remove the wedge of nasal planum and cartilage. Hemorrhage is controlled by applying pressure and apposing the cut edges. Occasionally, vessels are identified which may be occluded with hemostats or electrocoagulation. Align the ventral margin of the nares and mucocutaneous junction and appose the incised edges with three or four simple interrupted sutures using a monofilament absorbable suture (4-0 polydioxanone). Repeat the procedure by removing a similar wedge of tissue from the opposite naris and apposing the edges. Alternative techniques include removal of wedges of various shapes and orientations from the lateral aspect of the nasal planum or alapexy.

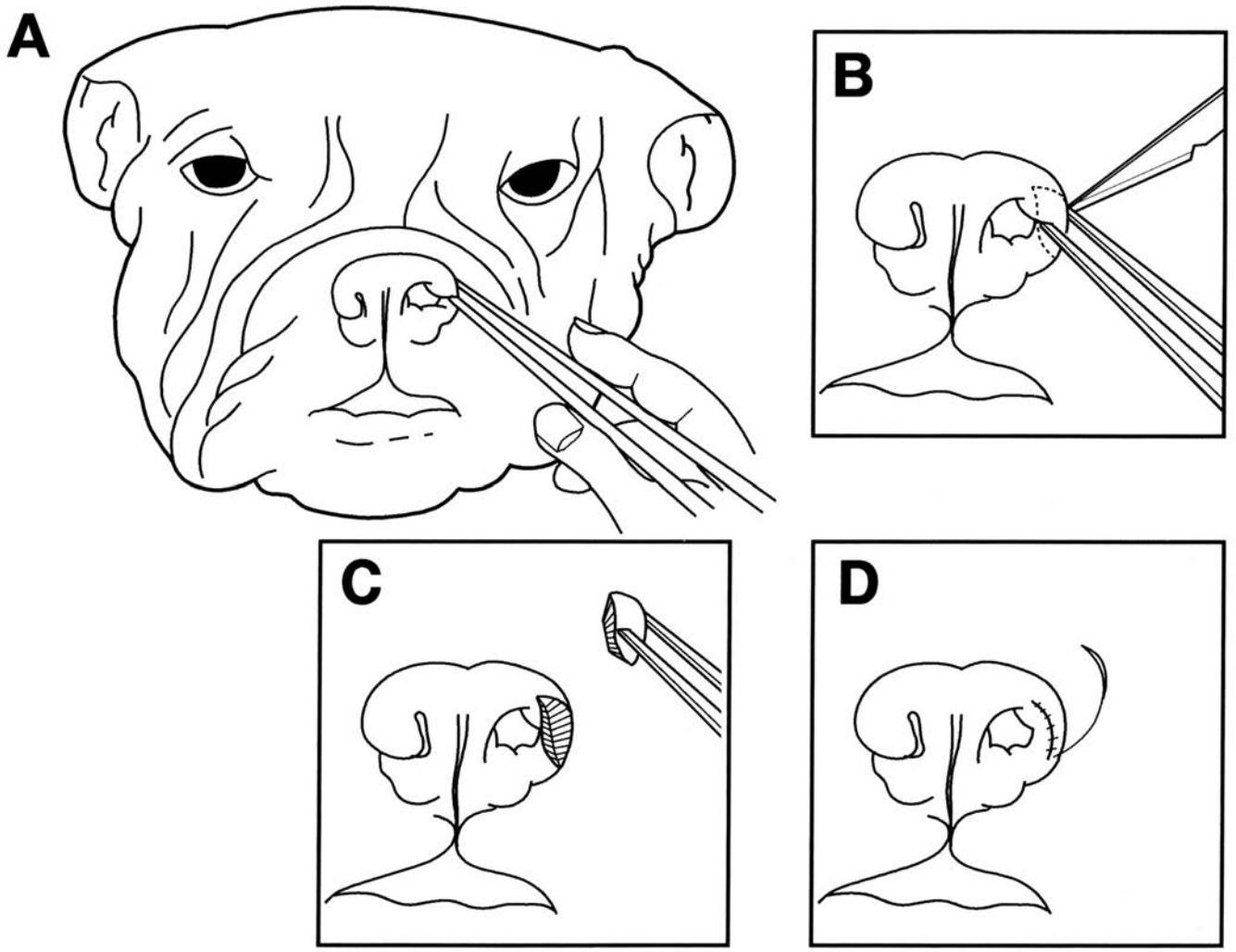


Figure 25-6. Stenotic nares resection. **A.** Resection of the nares begins by grasping the moveable margin of the nares to outline the wedge to be removed and to stabilize the tissue. **B.** Using a #11 scalpel blade a medial and the lateral incision are made adjacent to the tips of the forceps. **C.** The wedge is removed and discarded. **D.** The external nares are then widened by placing appositional sutures to appose the incised edges.

Aryepiglottic fold resection is occasionally performed in patients with aryepiglottic fold collapse. It is performed when other resection techniques have not adequately alleviated the patient's respiratory distress or concurrently with resection of palate, nares and saccules if respiratory distress is extreme and permanent tracheostomy is not acceptable to the client. Aryepiglottic fold resection is performed unilaterally through an oral approach. The fold is grasped and stabilized with thumb forceps and the fold and cuneiform process excised with Mayo scissors or uterine biopsy forceps. The tissue defect is allowed to heal by second intention.

Postoperative Management

The nasopharynx and larynx are aspirated and a nasal catheter placed for oxygen administration during recovery. Advance the catheter to the end of the soft palate if possible. Suture or glue the catheter to the skin and fit the animal with an appropriately sized Elizabethan collar to prevent the patient from removing the catheter. Keep the animal quiet and sedated to allow a slow quiet recovery with the endotracheal tube in place for as long as possible. Remove the tube with the cuff slightly inflated to withdraw any blood clots that may have entered the trachea. Begin supplemental oxygen through the nasal catheter (50 ml/kg/min) just before or after the endotracheal tube is removed. Continue nasal oxygen administration until the patient is fully recovered from anesthesia and breathing with minimal or no distress, usually 2 to 3 hours. Provide continuous monitoring during recovery and postoperatively for 24 to 72 hours as inflammation and edema may result in airway obstruction. The clinician should be prepared to reanesthetize and re-intubate or perform a tube tracheostomy in patients which experience severe dyspnea. Additional doses of corticosteroids may also be necessary and gastroprotectants are continued. Analgesics are continued for 48 to 72 hours. A weight reduction program should be instituted for obese animals.

Serious surgical complications include death due to glottic obstruction from inflammation and edema, and nasal regurgitation and rhinitis/sinusitis due to excessive soft palate resection. Inadequate resection of tissue results in persistent signs of upper airway obstruction. Excessive glottic manipulation may cause vagal induced bradycardia. Hemorrhage, gagging and coughing and aspiration may also occur in the early postoperative period.

Dehiscence of the nares may occur if the patient frequently licks or rubs its nose. Healing then occurs by second intention and may cause a pink scar. Scarring or stenosis following laryngeal saccule or aryepiglottic resection cause voice change, loss of bark, respiratory noise or progressive signs of upper airway obstruction.

Prognosis depends on the severity of the condition at the time of surgery. Partial resection of the soft palate, laryngeal saccules and nares is expected to relieve moderate to severe signs of respiratory distress in patients who do not have laryngeal collapse. Patients breathe with less effort and noise and are more tolerant of exercise and excitement. Some patients who have initially responded well to resection sometimes deteriorate and again show signs of severe respiratory distress months to years later. Laryngeal collapse has often become severe in these patients. Patients with advanced laryngeal collapse at the time of diagnosis and resection may respond unsatisfactorily to resection and require permanent tracheostomy to relieve their respiratory distress.

Suggested Readings

Bright RM, Wheaton LG: A modified surgical technique for elongated soft palate surgery. *J Am Anim Hosp Assoc* 19:288-292, 1983.

Clark GN, Sinibaldi KR: Use of a carbon dioxide laser for treatment of elongated soft palate in dogs. *J Am Anim Hosp Assoc* 204:1779-1785, 1994.

Ellison GW: Alapexy: An alternative technique for repair of stenotic nares in dogs. *J Am Anim Hosp Assoc* 40: 484-489, 2004.

Harvey CE: Upper airway obstruction surgery 1: Stenotic nares surgery in brachycephalic dogs. *J Am Anim Hosp Assoc* 18:535-537, 1982.

Harvey CE: Upper airway obstruction surgery 2: Soft palate resection in brachycephalic dogs. *J Am Anim Hosp Assoc* 18:538-544, 1982.

Harvey CE: Upper airway obstruction surgery 3: Everted laryngeal saccule surgery in brachycephalic dogs. *J Am Anim Hosp Assoc* 18:545-547, 1982.

Harvey CE: Upper airway obstruction surgery 4: Partial laryngectomy in brachycephalic dogs. *J Am Anim Hosp Assoc* 18:548-550, 1982.

Hendricks JC: Brachycephalic airway syndrome. *Vet Clinics North Am: Small Anim Pract* 22:1145-1153, 1992.

Poncet CM, Dupre GP, Freiche VG, Bouvy BM: Long-term results of upper respiratory syndrome surgery and gastrointestinal tract medical treatment in 51 brachycephalic dogs. *J Sm Anim Pract* 47: 137-142, 2006.

Rudorf H: Itrasonographic imaging of the tongue and larynx in normal dogs. *J Sm Anim Pract* 38: 439-444, 1997.

Wykes PM: Brachycephalic airway obstructive syndrome. *Problems in Veterinary Medicine: Head & Neck Surgery* 3:188-197, 1991.

Treatment of Laryngeal Paralysis with Unilateral Cricoarytenoid Laryngoplasty (A form of Arytenoid Lateralization)

Thomas R. LaHue

Introduction

Bilateral laryngeal paralysis is a common cause of upper airway obstruction in older dogs. Although the disease has been reported in many breeds of dogs and in cats the large sporting breeds (Labrador and Golden Retrievers) are most commonly affected. The disease is characterized by clinical signs of inspiratory stridor, exercise intolerance, and respiratory distress, which gradually worsen over a period of months. Severely affected dogs will often progress to cyanosis and collapse. Other signs include voice change and coughing or gagging. Clinical signs are usually not evident in dogs unless the disease is bilateral. The long-term prognosis for patients with laryngeal paralysis is usually poor unless the disease is managed surgically.[1]

The surgical technique described here is a form of arytenoid lateralization called unilateral cricoarytenoid laryngoplasty. This procedure or other forms of unilateral arytenoid lateralization have been successfully used by many surgeons to obtain consistently good results in the surgical treatment of laryngeal paralysis. Partial laryngectomy has been used successfully in the past but is not recommended for the treatment of laryngeal paralysis because of the high incidence of postoperative complications. Modified castellated laryngofissure has shown acceptable clinical results in dogs with laryngeal paralysis however the procedure is relatively complex, requires tracheostomy and is not widely used.

If proper surgical treatment is performed, the prognosis for affected dogs is good, however aspiration pneumonia remains a potential life-long risk.

Etiology

The most common form of laryngeal paralysis is the acquired, idiopathic form, which occurs primarily in older, large breed, male dogs. Congenital laryngeal paralysis is uncommon. A hereditary form has been reported in Bouviers des Flandres, with clinical signs observed at four to six months of age.[2] An association between laryngeal paralysis and generalized polyneuropathy has been reported in young Dalmatians.[3] A hereditary form of the disease has also been reported in Siberian huskies and husky cross breeds.[2] Direct injury to the recurrent laryngeal nerves due to trauma or surgery is an uncommon cause of laryngeal paralysis.

The primary cause of laryngeal paralysis is dysfunction of the recurrent laryngeal nerves. The specific etiology of this dysfunction in acquired laryngeal paralysis is unknown, although a demyelinating disease has been suggested.[4] This would preferentially affect longer nerve fibers such as the recurrent laryngeal nerve.[4] A possible association with hypothyroidism

has been reported.[1] The possibility of laryngeal paralysis being an early or initial clinical sign of a generalized polyneuropathy has been suggested.[5]

Neurogenic atrophy of intrinsic laryngeal muscles, particularly the cricoarytenoideus dorsalis muscle, causes failure of arytenoid cartilages and vocal folds to abduct, resulting in upper airway obstruction. The obstruction can worsen with exercise, excitement, or hot weather as increased oxygen demand causes greater inspiratory effort (greater negative pressure), which draws the arytenoid cartilages and vocal folds medially. This can become a vicious cycle, leading to cyanosis and collapse.

Diagnosis

The importance of an accurate diagnosis cannot be overemphasized. Laryngeal paralysis occurs primarily in older, larger breed dogs. It is rare in toy and small breed dogs. Other causes of respiratory distress such as upper airway obstruction caused by intraluminal or extraluminal (thyroid) neoplasia should be considered and ruled out before laryngeal paralysis is considered the primary cause. The most common clinical signs are respiratory distress, stridor, and exercise intolerance, often with a slow, insidious onset over a period of months to years. Other clinical signs observed less commonly include voice change and coughing or gagging. Although the onset of signs is gradual, it is not uncommon for patients to have acute, severe, life threatening episodes of upper airway obstruction, particularly during hot weather and when the dog is excited or exercising.

Physical examination of patients with suspected laryngeal paralysis should include auscultation of the laryngeal region with and without mild laryngeal compression both before and after exercise.[6] In dogs with laryngeal paralysis, auscultation usually reveals increased respiratory noise (stridor) over the laryngeal region, especially during inspiration. Dogs with normal laryngeal function should not have an appreciable change in upper airway noise with mild laryngeal compression. Dogs with laryngeal paralysis will exhibit a distinct worsening of the stridor as laryngeal compression is applied because they already have a fairly narrow, relatively fixed laryngeal glottis. This may be noted while listening as the dog is panting or upon auscultation of the laryngeal region. Thoracic auscultation will often only demonstrate referred upper airway sounds, but it is extremely important in order to evaluate the patient for possible concurrent disease. Aspiration pneumonia and/or bronchial disease can occur in patients with laryngeal paralysis because these patients are unable to fully close the glottis during swallowing.

Thoracic and cervical radiographs should be obtained to rule out other causes of respiratory compromise and to document concurrent disease. In addition to a CBC and chemistry profile, thyroid status is evaluated (T4 or TSH stimulation). There is an increased incidence of hypothyroidism in dogs with laryngeal paralysis, although there is not a proven cause and effect relationship. Hypothyroidism, like acquired laryngeal paralysis, tends to be a disease of older dogs. Hypothyroidism has been reported as a cause of generalized polyneuropathies.[7] Supplementation with thyroxine will not reverse the laryngeal paralysis, but it could help prevent or slow the progression of possible hypothyroid-induced generalized neuromuscular disease that may cause peripheral weakness.

Definitive diagnosis of laryngeal paralysis is made with laryngoscopy under very light anesthesia. In lightly anesthetized dogs with laryngeal paralysis, there is a failure of the arytenoid cartilages to abduct during inspiration. *The arytenoid cartilages can also fail to abduct if the level of anesthesia is too deep.* In order to make an accurate diagnosis, the patient must be under as light a plane of anesthesia as possible and the evaluation must be of adequate duration to be sure there is no effective arytenoid abduction during inspiration (at least 5 to 10 minutes). In some cases, paradoxical movement of the arytenoid cartilages may occur where the arytenoids are drawn medially due to the negative pressure created at inspiration.[8] Similarly, the arytenoids may appear to abduct weakly on expiration; this is caused by the arytenoids being moved from their paramedian position by passive expiratory efforts. *It is extremely important to correlate any laryngeal movement with the phase of respiration.* Various anesthetic protocols have been used effectively to assess arytenoids function. I currently use propofol (2 to 6 mg/kg, IV). After initial induction and arytenoid evaluation, I administer doxapram (1.0 to 2.2 mg/kg) and continue laryngoscopy. Use of doxapram is very useful in more clearly differentiating normal dogs from those with laryngeal paralysis. It increases respiratory effort and increases any intrinsic laryngeal motion (if present).[21] In dogs with bilateral laryngeal paralysis, use of doxapram may increase paradoxical arytenoid motion. Close monitoring of the patient's ventilatory status during laryngeal examination is important and the examiner should be prepared for patient intubation with the appropriate sized endotracheal tube. Laryngoscopy often reveals laryngeal (arytenoid) edema and inflammation, which may worsen the signs of laryngeal paralysis, and may change the character of dyspnea from primarily inspiratory to both inspiratory and expiratory.[8] If laryngeal paralysis is strongly suspected in patients with moderate to severe clinical signs, based upon history and physical examination, it is advantageous to schedule laryngoscopy so that surgery can be performed immediately following laryngoscopy if the diagnosis is confirmed.

Treatment

The recommended emergency medical treatment for an acute respiratory crisis due to laryngeal paralysis is sedation and endotracheal intubation, followed by gradual wakening of the animal.[6] These severely affected patients should be observed continuously and may need emergency surgery to relieve the upper airway obstruction. It is best to perform a definitive corrective procedure if possible rather than a temporary tracheostomy.

Alleviation of upper airway obstruction caused by laryngeal paralysis can be best achieved with surgery.[2] Medical therapy, including the use of tranquilizers, oxygen, and corticosteroids may be helpful in management of severely affected patients prior to surgery. Patients with preexisting aspiration pneumonia should be treated prior to surgery and may be more likely to develop

postoperative aspiration pneumonia. Patients with laryngeal paralysis and megaesophagus (or any cause of regurgitation) have a poor prognosis due to the extremely high likelihood of developing severe aspiration pneumonia after surgery.

The goal of surgery is to provide complete relief of upper airway obstruction while minimizing discomfort and postoperative complications. After surgery, patients should be able to breathe comfortably and have a normal activity level for their age.

Unilateral arytenoid lateralization in some form (cricoarytenoid laryngoplasty is described here) has been used successfully to achieve these goals in treating laryngeal paralysis and is the procedure of choice of many surgeons.[1,2,6,8-16] Other reported surgical techniques for treatment of laryngeal paralysis include partial laryngectomy (partial arytenoidectomy with vocal fold resection) using either an oral or ventral laryngotomy approach[17,18] and modified castellated laryngofissure with vocal fold resection.[19,20]

Surgical Technique

There are several variations of unilateral arytenoid lateralization. The procedure described here has been called cricoarytenoid laryngoplasty.[6,8] The procedure involves the placement of two sutures in the same location as the cricoarytenoideus dorsalis muscle, from the caudal dorsolateral aspect of the cricoid cartilage to the muscular process of the arytenoid cartilage (through the articular surface). Arytenoid lateralization has been used as a general term or to describe the procedure where sutures are placed from the caudal border of the thyroid cartilage to the muscular process of the arytenoid cartilage.[2,9,10,15,16] Regardless of the technique used, it is advisable to become familiar with the anatomy of the cervical and laryngeal region and the specific surgical procedure. The surgical technique should be observed prior to performing it and practiced on cadavers, or performed with an experienced surgeon present if possible.

Routine endotracheal intubation is performed following laryngoscopy. The unilateral cricoarytenoid laryngoplasty can be performed on either side. I perform the procedure on the left side for consistency only. Right handed surgeons usually prefer to perform left side lateralization because needle advancement through the cricoid is easier and less awkward. The patient is placed in right lateral recumbency with a slight rotation towards dorsal recumbency. It is helpful to place a small rolled towel under the neck at the level of the larynx. A ventrolateral approach to the larynx is made, beginning with a 5 to 8 cm long skin incision over the larynx, just ventral to the external jugular vein (Figure 25-7). It is helpful to palpate the caudal border of the cricoid cartilage and the wing of the thyroid cartilage as anatomic landmarks during the approach. Dissection is continued to the lateral and dorsal aspects of the larynx through the subcutaneous tissue and the superficial muscles of the neck, being careful to avoid the external jugular, linguofacial and maxillary veins.

The dorsal margin of the wing of the thyroid cartilage is palpated and retracted laterally by use of a "stay" suture or a hand-held retractor. The thyropharyngeus muscle is incised along the dorsal rim of the thyroid cartilage (Figure 25-8). Lateral retraction of the thyroid cartilage is important in order to avoid the esophagus. A layer of connective tissue is incised just medial and parallel to the rim of the thyroid cartilage and separated bluntly. The cricothyroid articulation at the caudal edge of the thyroid cartilage is separated with scissors and/or a Freer septum elevator (Figure 25-9A). This

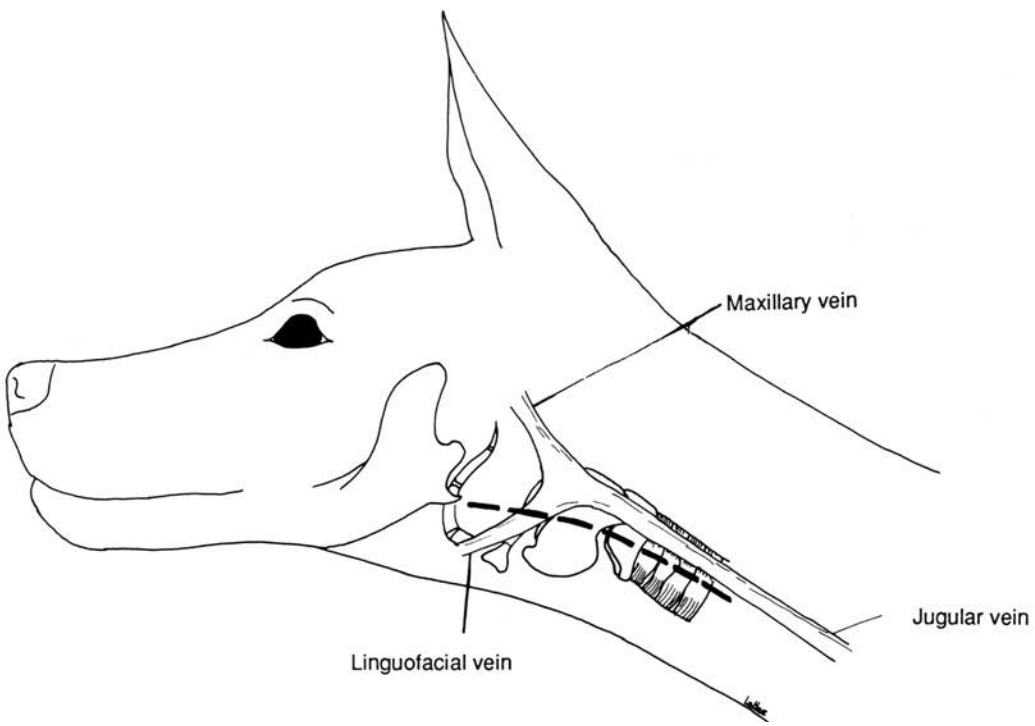


Figure 25-7. The site of the skin incision is shown by the dotted line. A ventrolateral approach to the larynx is made, beginning with an 8 to 10 cm long skin incision starting near the angle of the mandible and extending caudally just ventral to the external jugular vein. It is helpful to palpate the caudal border of the cricoid cartilage as a landmark during the approach.

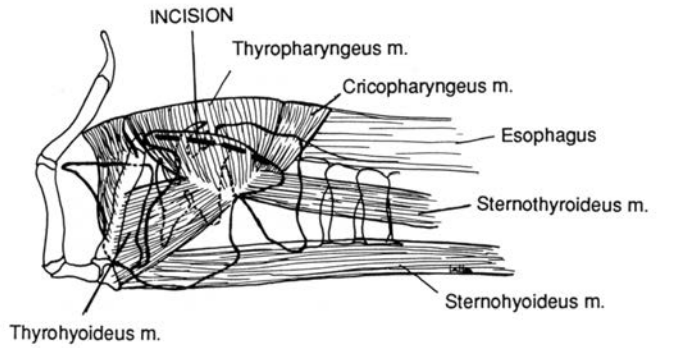


Figure 25-8. The dorsal margin of the wing of the thyroid cartilage is palpated and retracted laterally. The thyropharyngeus muscle is incised along that margin (dotted line).

disarticulation is necessary to provide adequate exposure. The cricoarytenoideus dorsalis muscle and muscular process of the arytenoid cartilage are identified. The cricoarytenoideus dorsalis muscle is undermined and incised close to the muscular process, leaving enough muscle on the muscular process to attach mosquito forceps to facilitate gentle manipulation (Figure 25-9B). The cricoarytenoid articulation is separated using blunt dissection with a Freer elevator, being careful not to damage the muscular process or penetrate the laryngeal mucosa (Figure 25-9C). The rostral aspect of the cricoarytenoid joint capsule is left intact, as this almost always allows adequate mobility of the arytenoid cartilage. The purpose of cricoarytenoid joint disarticulation is to gain mobility of the arytenoid cartilage in relation to the cricoid cartilage so the arytenoid cartilage can be adequately abducted. Laryngoplasty procedures have been described where cricoarytenoid disarticulation is not done.[13] However, some dogs have fibrosis and ankylosis of this joint. If disarticulation is not performed in these patients, adequate abduction of the arytenoid cartilage will not be achieved.

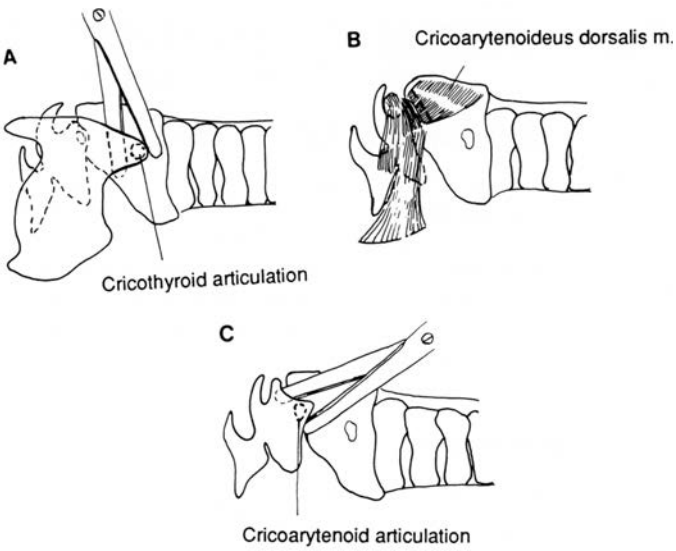


Figure 25-9. A. The cricothryroid articulation at the caudal edge of the thyroid cartilage is separated with scissors and/or a Freer septum elevator. **B.** The cricoarytenoideus muscle and muscular process of the arytenoid cartilage are identified. The muscle is undermined and incised close to the muscular process, leaving enough muscle on the muscular process to attach mosquito forceps for use in gentle manipulation. **C.** The cricoarytenoid articulation is separated using blunt dissection with fine scissors or a Freer elevator (preferred), being careful not to damage the muscular process or penetrate the laryngeal mucosa. The rostral aspect of the cricoarytenoid joint capsule is left intact as long as this allows mobility of the arytenoid cartilage to be attained. Thyroid cartilage is not pictured in **B** and **C**. It would be retracted laterally during these stages of the procedure.

When performing this procedure, I no longer incise and separate the sesamoid band that connects the two arytenoid cartilages because mobilization of the arytenoid cartilage and optimal abduction can be achieved without dissection of the described band.

The left arytenoid cartilage is now movable in relation to the cricoid cartilage. Two sutures of monofilament nylon or polypropylene (0 in large dogs, 2-0 in medium dogs) are passed closely under the caudal edge of the cricoid cartilage and directed cranially to penetrate through the cartilage on the dorsolateral aspect (approximately 5 to 8 mm from the caudal edge), being careful not to penetrate laryngeal mucosa (Figure 25-10A). These sutures are then passed from medial to lateral through the central portion of the articular surface of the muscular processs of the arytenoid cartilage at least 2 to 3 mm from the cartilage edge (Figures 25-10B and 25-10C). The sutures are tied separately (Figure 25-10D). The intact rostral portion of the cricoarytenoid joint capsule helps to prevent over-abduction of the arytenoid cartilage. Either at this point or following closure, the dog is extubated briefly while laryngoscopy is performed to confirm adequate abduction of the left arytenoid cartilage, followed by replacement of the endotracheal tube. Closure of the thyropharyngeus muscle is completed using fine (3-0 or 4-0) monofilament absorbable suture material in a simple continuous pattern. Subcutaneous tissues and skin are closed routinely.

Postoperative Management

Postoperative care includes continuous (24 hour) monitoring for dyspnea, intravenous fluid therapy, and withholding of food and water for 12 to 24 hours. Cefazolin (20 mg/kg, IV) is given at the time of anesthetic induction and repeated two hours later. Antibiotic therapy (ampicillin 20 mg/kg, PO, TID) is only continued if the laryngeal mucosa is penetrated. Patients most often do well postoperatively and are discharged from the hospital within 1 to 2 days of surgery. The most common serious complication that can occur postoperatively is aspiration and development of aspiration pneumonia. Depression, fever or coughing postoperatively should prompt the surgeon to take thoracic radiographs to rule out aspiration pneumonia. A soft, canned food consistency diet with no excess gravy or crumbs is recommended to minimize the risk of aspiration pneumonia. I also counsel owners to avoid any food that might result in vomiting, as that increases the risk of aspiration pneumonia. A voice change (similar to a debarked dog) is expected after cricoarytenoid laryngoplasty and other laryngoplasty techniques. Occasional coughing after drinking water occurs commonly in the postoperative period, but usually decreases after a short period of adaptation.[9]

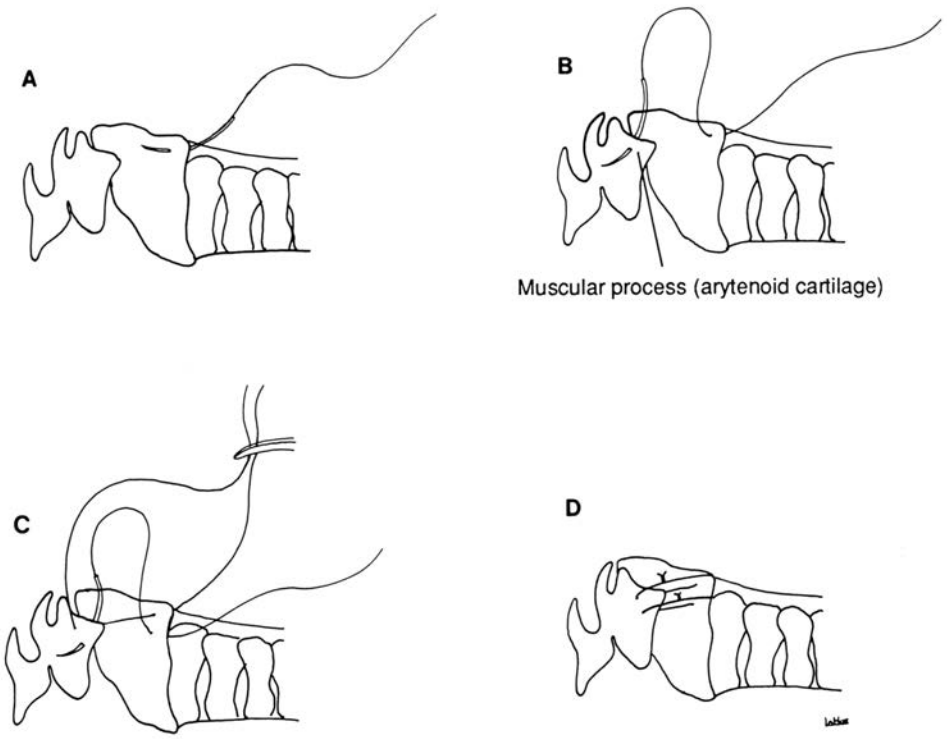


Figure 25-10. A. The first of two sutures is passed over the caudal edge of the cricoid cartilage and directed cranially to penetrate through the cartilage on the dorsolateral aspect (approximately 5 to 8 mm from the caudal edge), being careful not to penetrate laryngeal mucosa. **B.** Suture is then passed from medial to lateral through the articular surface and/or muscular process of the arytenoid cartilage at least 2 to 3 mm from the cartilage edge. **C.** The second suture is passed in a similar manner. **D.** Each suture is tied separately. The intact rostral portion of the cricoarytenoid joint capsule helps to prevent over-abduction of the arytenoid cartilage. Thyroid cartilage is not pictured. It would be retracted laterally during these stages of the procedure.

Surgical Results

Surgical techniques other than arytenoid cartilage lateralization techniques utilized in the treatment of laryngeal paralysis include partial laryngectomy and castellated laryngofissure. Partial laryngectomy usually involves partial arytenoidectomy with vocal fold resection using either an oral or ventral laryngotomy approach.

Arytenoid Lateralization/Cricoarytenoid Laryngoplasty

Unilateral cricoarytenoid laryngoplasty or some form of unilateral arytenoid lateralization has been shown to relieve signs of upper airway obstruction such as stridor, dyspnea and exercise intolerance in 82% to 100% of patients.[1,8,10-12,15,16,23] Lane reported a 97% overall success rate in surgical treatment of 167 cases of laryngeal paralysis using several modifications of arytenoid cartilage lateralization.[10] My success rate with unilateral cricoarytenoid laryngoplasty in over 500 dogs has been consistent with these results. White reported alleviation of exercise intolerance or stridor after arytenoid lateralization (with attachment of arytenoid cartilage to cricoid and/or thyroid cartilage) in 82% of dogs with laryngeal paralysis.[15] Greenfield and Venker-van Haagen reported alleviation of clinical signs of upper airway obstruction in 89% and 95% respectively with unilateral arytenoid lateralization.[2,11] Payne, et al reported results of abductor muscle prosthesis in 11 dogs, where placement of the sutures from cricoid cartilage to muscular process of the arytenoid cartilage is done without cricoarytenoid disarticulation.[13] Three of seven dogs where the procedure was done bilaterally died of aspiration pneumonia. There were no cases of aspiration pneumonia with unilateral procedures. In another study by Hammel, et al, the incidence of aspiration was reported in 7 dogs (18%).[22] Six of those dogs recovered with treatment. Snelling, et al reported 87.7% improvement in quality of life, with a 10.7% overall complication rate in 100 patients.[23]

Modified Castellated Laryngofissure

Modified castellated laryngofissure widens the glottic lumen by performing a stepped incision in the thyroid cartilage. The procedure also includes vocal fold resection and placement of mattress sutures through the arytenoid and thyroid cartilages to stabilize the arytenoid cartilages. In a report of four dogs treated with castellated laryngofissure,[19] two (50%) had no clinical signs of upper airway obstruction at 7 and 12 months postoperatively, and two (50%) had no clinical signs of upper airway obstruction at 10 and 12 months postoperatively. Another study evaluated a modified castellated laryngofissure in 12 dogs with laryngeal paralysis.[20] Signs of upper airway obstruction had either decreased in severity or disappeared in 11 of these dogs 15 to 452 days after surgery. One dog died immediately after surgery from hyperthermia, and three dogs died 1, 9, and 11 months postoperatively from non-related or unknown causes. Tracheotomy tubes were used during the operation and were maintained for a minimum of three days postoperatively in both

studies. Duration of postoperative hospitalization noted in only one case was eight days.

Modified castellated laryngofissure and arytenoid abduction techniques were evaluated using 30 canine postmortem specimens.[14] There was a greater change in cross-sectional area of the rima glottidis with modified castellated laryngofissure than with unilateral arytenoid lateralization techniques. The authors of this study suggested using modified castellated laryngofissure when subglottic luminal compromise, such as traumatic fibrosis, is present. They felt the procedure was technically more demanding, more time consuming, and more traumatic than arytenoid abduction (lateralization) techniques.

Partial Laryngectomy/Bilateral Ventriculocordectomy

Several studies have shown a high incidence of postoperative complications associated with partial laryngectomy for the treatment of laryngeal paralysis. Long term results of partial laryngectomy (oral approach) in 25 dogs with idiopathic laryngeal paralysis were as follows:[13] (52%) could breathe, eat and drink normally; four (16%) were considerably improved but still were noisy or had a cough, gag, or retch; six (24%) died of airway disease postoperatively; and two (8%) had initial improvement but were lost to follow-up.[17] Aspiration was the cause of death in three dogs. Tracheotomy tubes were placed prior to performing surgery in all cases. Duration of maintenance of the tracheotomy tube and length of postoperative hospitalization were not described. Granulation tissue or web formation across the glottic region causing airway obstruction has been reported after partial laryngectomy, particularly when a ventral laryngotomy approach was used.

Complications and long term results after partial laryngectomy for the treatment of idiopathic laryngeal paralysis were reported in 45 dogs.[18] Good or excellent results were obtained in 29 dogs (65%). Six dogs (13%) had some improvement, but residual respiratory compromise, exercise intolerance and consistent coughing. Ten dogs (22%) either showed no improvement over preoperative condition or developed fatal postoperative complications related to the partial laryngectomy. Death occurred in the immediate postoperative period (3 to 11 days) either because of pneumonia (8 dogs) or complete upper airway obstruction (1 dog). Nine dogs died of respiratory disease. Three dogs developed web stenosis across the glottis. The authors of this study did not recommend partial laryngectomy for the treatment of laryngeal paralysis because of the high incidence of postoperative complications. They felt that unilateral arytenoid lateralization may be a superior technique because unilateral lateralization provides relief from respiratory distress with a low complication rate.

Twenty four dogs with laryngeal paralysis treated with bilateral ventriculocordectomy through an oral approach at the University of Wisconsin-Madison were evaluated.[12] There was an unacceptably high incidence of postoperative complications after the bilateral ventriculocordectomy procedure. Complications occurred in 58% (14 of 24) of the dogs. The reported complications included increased respiratory stridor, exercise intolerance, and difficulty cooling off after exercise. Transverse laryngeal webbing occurred in nine of the 24 dogs (37.5%), requiring further surgery. The authors of this report recommended unilateral cricoarytenoid laryngoplasty for treatment of laryngeal paralysis in dogs.

Summary / Prognosis

It is important to recognize that while bilateral laryngeal paralysis is a significant cause of upper airway obstruction in older dogs, it is surgically treatable, with a good prognosis. Consistently good results have been obtained by many different surgeons with unilateral cricoarytenoid laryngoplasty or other forms of unilateral arytenoid lateralization. Familiarity with the laryngeal anatomy and the procedure is essential to a successful surgery. I recommend the unilateral cricoarytenoid laryngoplasty or other form of arytenoid lateralization because it achieves the goals of surgery in treating laryngeal paralysis, by relieving the respiratory distress, stridor, and exercise intolerance with a minimum of complications.

Editor's Note: Recent studies seem to confirm that dogs with laryngeal paralysis likely have a polyneuropathy. See references 24 and 25.

References

1. Gaber CE, Amis TC, LeCouteur RA: Laryngeal paralysis in dogs: A review of 23 cases. J Am Vet Med Assoc 186:377-380, 1985.

2. Harvey CE, Venker van Haagen AJ: Surgical management of pharyngeal and laryngeal airway obstruction in the dog. Vet Clin North Am (Small Anim Pract) 5:515-535, 1975.

3. Braund KG, Shores A, Cochrane S, et al: Laryngeal paralysis-polyneuropathy complex in young dalmatians. Am J Vet Res 55:534-542, 1994.

4. Smith MM, Child G, Cardinet GH, et al: Muscle and nerve abnormalities associated with canine laryngeal paralysis. Vet Surg 21:239, 1992 (abstr).

5. Braund KG, Steinberg HS, Shores A, et al: Laryngeal paralysis in immature and mature dogs as one sign of a more diffuse polyneuropathy. J Am Vet Med Assoc 194:1735-1740, 1989.

6. LaHue TR: Laryngeal surgery: Lateralization techniques: 1994 Scientific Proceedings, 22nd Annual Surgical Forum, Washington, D.C., American College of Veterinary Surgeons, 1994, pp 255-257.

7. Harvey HJ, Irby NL, Watrous BJ: Laryngeal paralysis in hypothyroid dogs,in Kirk RW, (ed): Current Veterinary therapy VIII, Small Animal Practice. Philadelphia, PA, Saunders, 1983, pp 694-697.

8. LaHue, TR: Treatment of laryngeal paralysis in dogs by unilateral cricoarytenoid laryngoplasty. JAAHA 25:317-324, 1989.

9. Lane JG: ENT and Oral Surgery of the Dog and Cat. Bristol, England, Wright, 1982, pp 113-118.

10. Lane JG: Diseases and surgery of the larynx, in: 1986 Scientific Proceedings, 53rd Annual Meeting of the American Animal Hospital Association, Denver CO, American Animal Hospital Association, 1986, pp 620-623.

11. Greenfield CL: Canine laryngeal paralysis. Comp Cont Ed 9:1011-1020, 1987.

12. Peterson SW, Rosin E, Bjorling DE: Surgical options for laryngeal paralysis in dogs: a consideration of partial laryngectomy. Comp Cont Ed 13:1531-1540, 1991.

13. Payne JT, Martin RA, Rigg DL: Abductor muscle prosthesis for correction of laryngeal paralysis in 10 dogs and one cat. JAAHA 26:599-604, 1990 .

14. Lozier S, Pope E: Effects of arytenoid abduction and modified castellated laryngofissure on the rima glottidis in canine cadavers. Vet Surg 21:195-200, 1992.

15. White RAS: Unilateral lateralization: an assessment of technique and long term results in 62 dogs with laryngeal paralysis. J Small Anim Pract 30:543-549, 1989.

16. Venker van Haagen AJ: Laryngeal diseases of dogs and cats, in Kirk RW, (ed): Current Veterinary therapy IX, Small Animal Practice. Philadelphia, PA, Saunders, 1986, pp 265-269.

17. Harvey CE, O'Brien JA: Treatment of laryngeal paralysis in dogs by partial laryngectomy. JAAHA 18:551-556, 1982.

18. Ross JT, Matthiesen DT, Noone KE, et al: Complications and long-term results after partial laryngectomy for the treatment of idiopathic laryngeal paralysis in 45 dogs. Vet Surg 20:169-173, 1991.

19. Gourley IM, Paul H, Gregory C: Castellated laryngofissure and vocal fold resection for the treatment of laryngeal paralysis in the dog. J Am Vet Med Assoc 182:1084-1086, 1983.

20. Smith MM, Gourley IM, Kurperschoek MS, et al: Evaluation of a modified castellated laryngofissure for alleviation of upper airway obstruction in dogs with laryngeal paralysis. J Am Vet Med Assoc 188:1279-1283, 1986.

21. Tobias KM, Jackson AM, Harvey RC: Effects of doxapram HCl on laryngeal function of normal dogs and dogs with naturally occurring laryngeal paralysis. Vet Anaesth Analg 31(4): 258-263, 2004.

22. Hammel SP, Hottinger HA, Novo RE: Postoperative results of unilateral arytenoid lateralization for treatment of idiopathic laryngeal paralysis in dogs: 39 cases (1996-2002). J Am Vet Med Assoc 228(8): 1215-20, 2006.

23. Snelling SR, Edwards GA: A retrospective study of unilateral arytenoid lateralisation in the treatment of laryngeal paralysis in 100 dogs (1992-2000). Aust Vet J 81(8):464-8, 20.

24. Stanley BJ, Hauptman JG, Fritz MC,et al: Esophageal dysfunction in dogs with idiopathic laryngeal paralysis: a controlled cohort study. Vet Surg 39:139, 2010

25. Thieman KM, Krahwinkel DJ, Sims MH, et al: Histopathological confirmation of polyneuropathy in 11 dogs with laryngeal paralysis J Am Anim Hops Assoc 46:161,2010

Chapter 26

Trachea

Treatment of Tracheal Collapse: Ring Prosthesis Technique

H. Phil Hobson

Introduction

The normal trachea is a dynamic organ composed of multiple hyaline cartilaginous rings, joined together laterally by fibroelastic annular ligaments, and across the tips of the cartilaginous rings dorsally by the tracheal membrane consisting of the trachealis muscle covered medially by ciliated epithelial mucosa. The fibroelastic annular ligaments allow for tracheal movement in any direction, whereas the trachealis muscle allows for expansion and contraction of the circumference and thus the diameter of the trachea and the volume of air that can move along the airway. Classic tracheal collapse occurs in a dorsoventral direction and results in patient symptoms varying in degree of severity from mild cough to total respiratory collapse. The canine patient is usually a middle-aged toy breed, but the age may vary, in my experience, from less than 1 year to 16 years of age.

Pathophysiology

The cause of tracheal collapse is unknown, but it is generally thought to be a congenitally predisposed, probably inherited, condition. Respiratory allergies and irritants (particularly tobacco smoke), obesity, chronic infections, trauma from collars, and endotracheal tube placement from general anesthesia have been reported to exacerbate the clinical signs. Lack of adequate innervation to the trachealis muscle is considered to be a possible cause. In a few cases, Dallman demonstrated an irregular hypocellular condition of the cartilage rings with less calcium and chondroitin sulfate present than normal. In some cases, the tracheal cartilage is softer than normal, with considerable loss of rigidity. However, occasionally the cartilage is more rigid than normal, resulting in difficulty in recontouring the cartilage during prosthetic ring placement. The cartilage rings may also be shorter than normal, especially at the thoracic inlet.

With disease chronicity, the ends of the tracheal rings become progressively further apart (Figure 26-1), allowing the tracheal membrane to sag into the tracheal lumen. Resonant vibration of the redundant tracheal membrane results in the classic honking cough. Increased negative pressure within the tracheal lumen during inspiration collapses the cervical trachea further and may balloon the thoracic trachea. Expiration results in collapse of the thoracic trachea and ballooning of the cervical trachea. Narrowing of the entire airway results in either event, especially on inhalation.

Tracheal collapse may extend into the mainstem bronchi, especially the left bronchus. Bronchial collapse may be accentuated because of compression by an enlarged left atrium. Heart

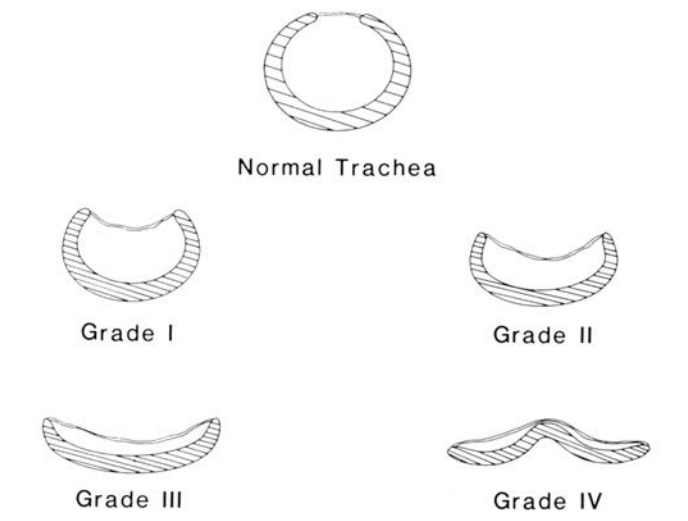


Figure 26-1. Classification of collapsed trachea. Grade I: The trachea is nearly normal. The trachealis muscle is slightly pendulous, and the tracheal cartilages maintain a circular shape. The tracheal lumen is reduced by approximately 25%. Grade II: The trachealis muscle is widened and pendulous. The tracheal cartilages are partially flattened, and the tracheal lumen is reduced by approximately 50%. Grade III: The trachealis muscle is almost in contact with the dorsal surface of the tracheal cartilages. The tracheal cartilages are nearly flat, and the ends may be palpated on physical examination. The tracheal lumen is reduced by approximately 75%. Grade IV: The trachealis muscle is lying on the dorsal surface of the tracheal cartilages. The tracheal cartilages are flattened and may invert dorsally. The tracheal lumen is essentially obliterated. (From Tangner CH, Hobson HP. A retrospective study of 20 surgically managed cases of collapsed trachea. Vet Surg 1982; 11:146.)

enlargement, especially right ventricular hypertrophy, secondary to chronic airway disease is common. Tracheal mucosal erosion or metaplasia may be seen as a result of chronic inflammation as well as from alveolar emphysema and mineralization.

Lateral collapse of the trachea or ventral collapse with minimal widening of the dorsal membrane associated with loss of cartilage rigidity is seen infrequently. Collapse caused by pressure from external masses is rare. Laryngeal function may be less than optimal.

Recently, the not infrequent occurrence of collapsed tracheas in miniature horses suggests to the author that there may be an association with the gene/s responsible for "dwarfism"/miniaturization, and bears further study.

Diagnosis

A presumptive diagnosis is often made on the presentation of a toy breed dog exhibiting a honking cough, with a history of chronic respiratory infections. Yorkshire Terriers, toy poodles, Pomeranians, Chihuahuas, and Maltese are most commonly affected. The condition has been seen rarely in mixed or larger breeds of dogs, cats, and miniature horses. The disorder has no sex predilection.

Most patients, probably those with a grade I collapse, respond to medical therapy consisting of antibiotics, cough suppressants, and corticosteroids, perhaps including bronchodilators and atropine, and these animals are not considered surgical candidates. Patients that fail to respond to conservative therapy should be evaluated thoroughly.

Collapsed tracheas can often be palpated readily in the dog with a long, thin neck, but palpation is difficult in the obese dog with a short, stocky neck. Lateral radiographs, although helpful, may yield false-negative results from ballooning of the trachea or false-positive results because of the esophagus and other tissues overlying the trachea. In the awake patient, fluoroscopic examination of the trachea provides the best evaluation of the airway, including the mainstem bronchi. However, I have seen a false-negative result. Patients in respiratory distress must be handled with care, with oxygen administered as needed. Diagnostic procedures can be life-threatening to the respiratory compromised patient.

Undoubtedly, the best evaluation of the trachea is accomplished by direct visualization, tracheoscopically. This evaluation requires general anesthesia and should be performed on those patients whose owners have agreed to allow surgical treatment if recommended or whose owners are available for consultation while the patients are still under anesthesia. Recovery of patients with severe collapse from anesthesia may be difficult, if surgical treatment is not performed.

Preoperative Considerations

The client should be well informed of the prognosis and possible complications at the outset. Dogs with less than a 50% collapse of the trachea are not considered surgical candidates. The clinical signs are not usually a result of inadequate airway diameter and are better managed medically. Early surgical intervention undoubtedly has advantages, but the degree of collapse may remain static in many patients over a prolonged period.

Periodic reevaluation is considered the best approach for these patients. Patients with a 50% or greater collapse of the trachea are likely to experience respiratory distress, especially during times of excitement, when oxygen demands are high or when respiratory infections are present. These patients are considered far less likely to respond to, or already have not responded to, conservative therapy, and thus surgery should be considered.

Postoperative infection with swelling of the mucosal lining, dorsal membrane, and surrounding tissue is always of concern, because the sutures used in prosthetic implant placement are likely to penetrate the unsterile lumen of the trachea. If infections are to occur, they are most likely during the first 2 weeks after the operation. Abscessation around a prosthetic ring when antibiotics are administered is rare. The mortality rate associated with surgery is in the range of 3% to 5% and is likely to be associated with impairment of air movement during the postsurgical recovery period.

The greatest concern during the surgery is injury to the recurrent laryngeal nerves with resulting laryngeal paralysis. The nerves lie in close approximation to the dorsal lateral aspect of the trachea just caudal to the larynx, to a more ventral medial position at the

thoracic inlet. The nerves are 1 mm or less in diameter in the toy breeds of dogs and are subject to injury during dissection of the trachea, tissue handling, prosthetic ring placement, or possibly even from the prosthetic ring itself if not placed properly.

Owners should be alerted to the potential need to perform a tracheostomy or laryngoplasty should laryngeal paralysis result. The patient's laryngeal function should be checked before leaving the operating room, and a tracheostomy should be performed if needed. A permanent tracheostomy is considered preferable by the author to laryngeal tie-backs or arytenoid cartilage resection in toy breeds of dogs with laryngeal paralysis.

Laryngeal function should be evaluated while the patient is under a light plane of anesthesia as part of the preoperative examination. Drugs with analgesic properties administered as preanesthetic agents make evaluation of laryngeal function on stimulation of the larynx more difficult and should be avoided when possible. Respiratory stimulants such as doxapram (0.5 to 1.0 mg/kg IV) may be of value in assessing the larynx for normal function. Aerobic cultures should be taken directly from the trachea, avoiding the pharyngeal area. Tracheoscopy should follow, with the patient under a surgical plane of anesthesia. Oxygen can be administered directly through the bronchoscope. Brush biopsies for cytologic evaluation should be taken of the caudal trachea at the completion of the visual examination. With proper preparation, the examination, culture, and biopsy can be completed expeditiously, thus keeping the use of intravenous anesthetic induction agents to a minimum.

Radiographs of the lungs should follow, with the intubated patient under general gaseous anesthesia. Compression of the rebreathing bag provides for deep inspiratory radiographs to be made and thus for optimal evaluation of the lungs by the radiologist. Most concurrent lung disease can be ruled in or out by these techniques. The final decision whether or not to proceed with surgery is made at this time.

When surgical treatment is to follow, antibiotics should be administered parenterally A broad-spectrum bactericidal antibiotic such as enrofloxacin that is effective against gram-negative organisms, should be used until the results of tracheal culture and sensitivity testing are available. The appropriate antibiotic should be continued for 2 weeks postoperatively.

Surgical Management

Various, surgical techniques have been proposed to treat tracheal collapse. Everting plication of the dorsal tracheal membrane has been effective in moderately affected animals with rigid cartilage rings. Chondrotomy of the ventral aspect of every other tracheal ring has also been effective in some moderately affected patients with rigid cartilage rings. Resection and anastomosis are effective when few rings are collapsed, usually by trauma. Intraluminal prosthetic dilators have been useful for the short term, but they can erode the tracheal wall, stimulate granuloma formation, or interfere with mucus clearance over the longer term. Intraluminal stents have been used and may prove very effective in the future, especially when tracheal collapse is primarily within the thorax and for collapsing principal bronchi. Problems experienced with intraluminal stents include collapse when subjected to too much flexion, failure to anchor well resulting in expulsion when coughing occurs, pulmonary edema, availability of inappropriate sizes, and uneven contact between the stent and the airway wall. Granulation tissue proliferation caused by stents may result in intraluminal obstruction.

Currently, the surgical techniques most universally accepted are those that support the trachea, including the dorsal tracheal membrane, with extraluminal prosthetic devices to which the trachea is sutured. Earlier use of long sections of extraluminal prosthetic devices restricted needed flexion of the trachea, and shorter sections applied only to the ventral aspect of the trachea failed to support the sagging dorsal membrane. Current prosthetic devices provide that support. Support is reinforced by connective tissue proliferation around the prosthesis and through the holes in the prosthesis when individual ring prostheses are used. The individual ring technique consists of the placement of four to seven individual prosthetic rings around the trachea with spacing between the rings, whereas the spiral technique is essentially a continuous spiral prosthesis.

Total Ring Prosthesis

Prosthetic rings are made from 3-mL polypropylene syringe cases by cutting the syringe case into 7-to 10-mm sections with a pipe cutter over a wood dowel rod or by sawing the syringe case into sections and drilling approximately 3-mm diameter holes with either a hand drill or with a No. 11 Bard-Parker scalpel blade, or a leather punch can be used. Five holes are usually drilled, with the syringe case ring cut at the location of the sixth equally spaced hole. Angled serrated wire-cutting scissors work well for cutting the ring to decrease its size if necessary and facilitate placement of the ring around the trachea. The ends of the ring are rounded and smoothed, as are the edges of the ring and the edges of the holes, to minimize irritation after placement. The polypropylene rings can be autoclaved or sterilized by other methods. The rings can be made larger if necessary by simply spreading the ends of the rings before suturing them to the trachea. Conversely, they can be made smaller by trimming the ends of the rings, squeezing the rings, and placing a figure-of-eight suture across the cut ends of the rings through the adjacent holes after placement, but before suturing to the trachea. Polypropylene rings may break if too much pressure is applied in either expansion or compression during alteration for size and contour at the time of surgery.

The patient is positioned in dorsal recumbency with the forelegs secured caudally. A towel roll is positioned under the neck near the shoulders. A ventral midline incision is made from the larynx to just caudal to the manubrium (Figure 26-2). The sternohyoideus and sternocephalicus muscles are separated to expose the trachea; the surgeon should avoid the thyroid vein as much as possible. The thyroid vein lies between the sternocephalicus muscles in fascia on the ventral surface of the trachea. The trachea is surrounded by loose areolar tissue and receives its primary blood supply segmentally from the thyroid arteries and its nerve supply segmentally from the recurrent laryngeal nerves. Preservation of as much of the blood supply and innervation to the trachea as possible is desirable. The recurrent laryngeal

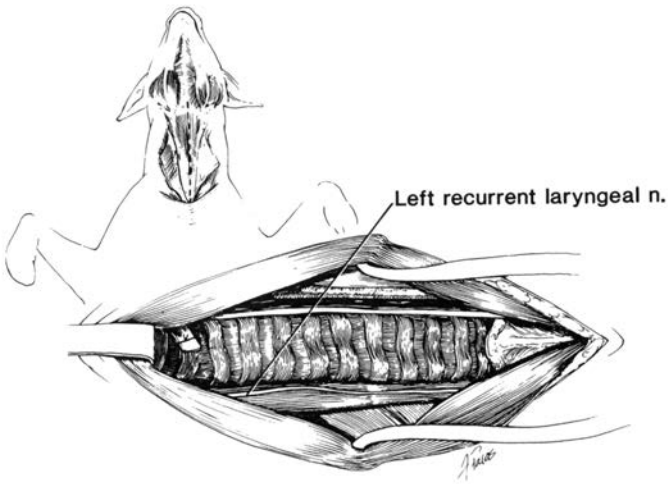


Figure 26-2. Ventral cervical midline approach to the cervical trachea. The skin incision extends from the larynx to the manubrium.

nerves lie in close approximation to the dorsal lateral aspect of the trachea near the larynx coursing more ventral medially as the thoracic inlet is approached. These nerves must be handled carefully during dissection and ring placement. No tissue should be cut without knowing that the nerves are protected. The nerves should be retracted gently by grasping adjacent tissue, not the nerve itself, during dissection.

Curved hemostats are used to bluntly dissect a tunnel dorsally around the trachea (Figure 26-3). Care is taken to dissect between the recurrent laryngeal nerves and the trachea and to gently support the nerves as one end of the ring is grasped with the tip of the curved hemostat and gently delivered through the tunnel around the trachea. The cut end of the ring is positioned ventrally. The prosthetic ring is sutured in place with 3-0 or 4-0 polydioxanone sutures passed around a tracheal ring, up through a hole in the prosthesis, and tied. The prosthesis is grasped with forceps, and the trachea is rotated in either direction to facilitate placement of the more dorsal sutures, including at least one in the dorsal tracheal membrane.

In the occasional severe case, multiple small chondrotomies must be made through the rigid cartilage to facilitate recontouring the tracheal rings to the prostheses. These tracheal cartilages may be in the shape of an opened W. Care should be exercised to cut only the cartilage and not the tracheal mucosa.

Placement of the rings is begun just caudal to the larynx and is continued caudally with approximately the width of the prosthetic ring left between each ring placed. The neurovascular supply to the trachea is carefully left intact between the rings. Movement of the endotracheal tube during surgery is essential to prevent suture from passing through the cuff of the endotracheal tube. In addition, movement of the endotracheal tube is performed after each prosthetic ring is sutured into place to prevent inadvertent suturing of the endotracheal tube to the trachea.

Rings can be placed around the trachea deep within the thoracic inlet by gentle but strong rostral traction on the trachea. This is facilitated by grasping a distal prosthetic ring that has been

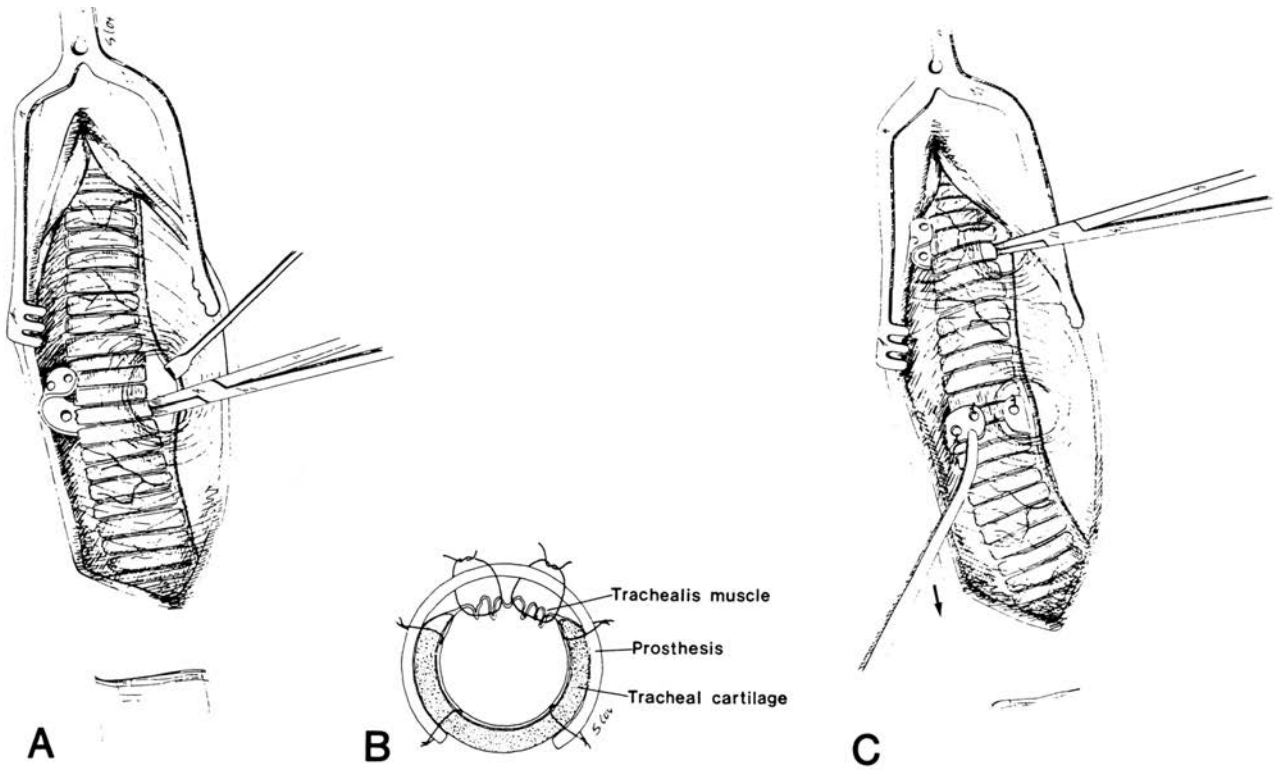


Figure 26-3. Implantation of total ring prosthesis. **A**. A small section of trachea is isolated by blunt dissection with a curved hemostat. The hemostat is then used to direct the prosthesis around the trachea. The recurrent laryngeal nerves are carefully retracted. **B.** Suture placement. **C.** Cranial retraction on the cervical trachea facilitates placement of total ring prostheses to the thoracic inlet portion of the trachea. (From Walker TL, Hobson HP. Tracheal collapse. In: Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

sutured to the trachea (See Figure 26-3). Lateral ventra retraction of the tissue from the trachea at the thoracic inlet, including the recurrent laryngeal nerves, vagosympathetic trunk, and carotid arteries, aids in placement of these rings. With some effort, these rings can be placed far enough into the thoracic inlet that, when the patient is standing in a normal upright position after surgery, the caudal prosthetic ring will be located at the second intercostal space.

Severe tracheal collapse within the thoracic cavity can be approached, preferably through a right third intercostal space, for further ring placement. This is rarely done, however, because only about one additional ring can be applied rostral to the carina. No external support can be applied to a collapsed principal bronchus. When the rings can be placed as far caudally as the second intercostal space, even in patients with severe intrathoracic tracheal collapse, inspiratory efforts should result in adequate air movement to maintain normal oxygenation as the thoracic airways balloon on inspiration. The patient, however, may still cough, even to the point of exhibiting the honking cough, and is predisposed to infections and secondary changes because of the narrow airway.

Postoperative Considerations

Laryngeal function is of prime concern. It is usually evaluated before removal of the patient from the operating room. A tracheostomy is performed if deemed necessary.

Most patients do not require further surgery, nor do they require postoperative oxygen. Most are recovered in the postoperative recovery room. Analgesics are administered as indicated. Prednisolone is often given at the end of the operation to minimize effects of irritation to the airway and the recurrent laryngeal nerves. Appropriate antibiotics are continued for 2 weeks postoperatively. Antitussives and bronchial dilators are given rarely, but they are administered if deemed necessary. Any concurrent medical problems are treated as indicated because many of these patients are older dogs with other maladies.

Editor's Note: Dr. Hobson has likely performed more tracheal ring prosthetic placements than any surgeon in the world. The surgery described here continues to be regarded as extremely valuable in the management of tracheal collapse. Some surgeons elect to place extraluminal prosthetic rings on the cervical trachea and place intraluminal stents within the thoracic trachea when indicated.

When laryngeal paralysis occurs following surgery, arytenoid tie-backs are preferred by most surgeons as the treatment of choice for the condition.

Prosthetic rings manufactured by New Generation Devices, Glen Rock, NJ, www.newgenerationdevices.com are thinner and more easily placed around the trachea than those made from syringe cases however they are more costly. The rings are currently available in 4 different diameters.

Suggested Readings

Anderson GR. Surgical correction of tracheal collapse using Teflon rings. Okia Vet 1971; 23:6.

Buback JL, Boothe HW, Hobson HP. Surgical treatment of tracheal collapse in dogs: 90 cases (1983-1993). J Am Vet Med Assoc 1996; 208:308.

Dallman MJ, Brown EM. Structural considerations in tracheal disease. Am J Vet Res 1979; 40:555.

Dallman MJ, McClure RC, Brown EM. Histochemical study of normal and collapsed trachea in dogs. Am J Vet Res 1988; 49:2l17.

Delehanty DD, Georgi JR. A tracheal deformity in a pony. J Am Vet Med Assoc 1954;125:42.

Fingland RB , Dehoff WD, Birchard SJ. Surgical management of cervical and thoracic tracheal collapse in dogs using extraluminal spiral prosthesis: results in seven cases. J Am Anim Hosp Assoc 1987;23:163.

Hobson HP. Total ring prosthesis for the surgical correction of collapsed trachea. J Am Anim Hosp Assoc 1976; 12:822

Knowles RP, Snyder CC. Chondrotomy for congenital tracheal stenosis. In: Proceedings of the American Animal Hospital Association. 1967:246.

Leonard HC. Surgical correction of collapsed trachea in dogs. J Am Vet Med Assoc 1971; 158:598.

Leonard HC, Wright JJ. An intraluminal prosthetic dilator for tracheal collapse in the dog. J Am Anim Hosp Assoc 1978;14:464.

Radlinsky MG, Fossum TW Walken MA. Evaluation of Palmaz stents in the trachea and bronchi of normal dogs. In: Proceedings of the American College of Veterinary Surgery. Chicago, IL 1995:19.

Rubin GJ, Neal TM, Bojrab MJ. Surgical reconstruction for collapsed tracheal rings. J Sm Anim Pract 1973; 14:607.

Schiller AG, Helper LC, Small E. Treatment of tracheal collapse in the dog. J Am Vet Med Assoc 1964; 145:669.

Slatter DH. A surgical method for correction of collapsed trachea in the dog. Aust Vet 1974; 50:41.

Tangner CH, Hobson HP. A retrospective study of 20 surgically managed cases of collapsed trachea. Vet Surg 1992-11-146.

Reference

1. Fingland RB, DeHoff WD, Birchard SJ. Surgical management of cervical and thoracic tracheal collapse in dogs using extraluminal spiral prostheses. J Am Anim Hosp Assoc 1987;23:163

Intra-Luminal Tracheal Stenting

Chick Weisse

Introduction

Tracheal collapse is a progressive, degenerative disease of the cartilage rings of predominantly older small and toy-breed dogs in which hypocellularity and decreased glycosaminoglycan and calcium contents lead to dynamic airway collapse during respiration. Affected animals present with signs ranging from a mild, intermittent "honking" cough to severe respiratory distress from dynamic upper-airway obstruction. Various combinations of anti-inflammatories, anti-tussives, sedatives/tranquilizers, and/or bronchodilators are typically effective in alleviating the initial respiratory problems associated with tracheal collapse. In addition, weight loss, restricted exercise, and removal of

second-hand smoke or inhaled allergens can further palliate clinical signs. Careful, regular monitoring of co-morbidities such as cardiac disease or pulmonary disease may help reduce the incidence of respiratory crisis episodes. Those patients that have failed aggressive medical and environmental management, and have had other potential causes of respiratory disease either treated or ruled out, become candidates for surgical or interventional treatment.

The most commonly performed surgery for animals with extra-thoracic tracheal collapse is the placement of extra-luminal ring prostheses. Using a ventral midline cervical approach, extra-luminal support rings are carefully placed around the trachea. This technique has a reported 75% to 85% overall success rate in one report of 90 dogs for reducing clinical signs, however there is significant associated morbidity.[1] In the same study, 5% of animals died peri-operatively, 11% developed laryngeal paralysis from the surgery, 19% required permanent tracheostomies (half within 24 hours), and ~23% died of respiratory problems with a median survival of 25 months. In addition, only 11% of the dogs in this study had intra-thoracic tracheal collapse (all dogs had extra-thoracic tracheal collapse) and the authors advised against this technique in patients with intra-thoracic tracheal collapse as the resulting morbidity was unacceptably high.

The combination of surgical risk and the inability to adequately treat intra-thoracic tracheal collapse led to the evaluation of minimally-invasive surgical techniques used in humans for potential treatment options. Interventional radiology involves the use of contemporary imaging modalities such as fluoroscopy to gain access to different structures in order to deliver materials for therapeutic purposes. Specially designed intra-luminal metallic stents have been placed within the human tracheobronchial system using these techniques to treat chondromalacia, malignant obstruction, or strictures and stenoses. A number of stents have been previously evaluated in the canine trachea, including both balloon-expandable stents (Palmaz) and self-expanding (Stainless steel, Laser-cut nitinol, Knitted nitinol) stents.[2-4] The vastly superior flexibility makes the use of self-expanding metallic stents (SEMS) particularly appealing for tracheal use. Clinical improvement rates in 75% to 90% of animals treated with intra-luminal SEMS have been reported.[3,4] Immediate complications were typically minor although there was a reported peri-operative mortality rate of approximately 10%, a rather high figure compared to the author's experience. Late complications included stent shortening, excessive granulation tissue forming within the trachea, progressive tracheal collapse, and stent fracture.

Neither surgery nor stenting are cures for tracheal collapse, and to the author's knowledge, neither has been shown to slow the progression of the disease. When used appropriately in the proper patients, both can significantly improve the patients' quality of life when medications alone are no longer adequate. Below are this author's criteria for patient selection, method of stent selection, and technique for placing intra-luminal tracheal stents. It should be noted that the majority of the following information is based solely on experience as veterinary research on this subject is currently in its infancy.

Patient Selection

The diagnosis of tracheal collapse and other forms of respiratory dysfunction have been described elsewhere. The readers are referred to other materials for a complete discussion of respiratory system evaluation and related diagnostic procedures. Due to the relatively high morbidity and mortality rates associated with surgery or stenting of the trachea, these procedures are avoided when possible. Other primary or secondary respiratory disorders must be evaluated concurrently or addressed prior to more invasive therapies for tracheal collapse. Animals with concurrent cardiac and/or pulmonary disease can often benefit substantially from medical treatment such that more invasive tracheal collapse treatments can be avoided or postponed.

Whether considering surgical rings or intra-luminal stenting it is imperative that aggressive medical management has been attempted and has failed to provide a "reasonable quality of life" for the patient. In the author's opinion, this includes anti-inflammatory doses of corticosteroids, anti-tussives, and the general management considerations described above. An exception to this rule is the emergent, intubated patient which has failed attempts at extubation. An owner's inability to administer medication is not a valid reason to perform one of these invasive procedures as the majority of patients will still require medication following treatment. In addition, while the "grade" of tracheal collapse (Grades I, II, III, or IV) has been described in the literature, the author will not treat based upon the grade of collapse alone. The success of either of these procedures must be evaluated in light of the owners' expectations. It is the veterinarian's responsibility to properly inform the owner that these are largely palliative procedures and the disease is likely to progress.

Rings or Stent?

Whether to perform surgery versus stenting is a complex, controversial and unresolved question. Decisions must be made on an individual case basis, however some basic guidelines can be used. In my opinion, if significant intra-thoracic tracheal collapse is present then surgery is either unlikely to resolve the problem or be associated with excessive morbidity and therefore an intra-luminal stent should be considered. If only cervical tracheal collapse is present, then extra-luminal surgical rings may be considered. An exception may be in a geriatric patient or one with excessive co-morbidities (extensive cardiac or pulmonary disease, endocrinopathies, etc.) in which prolonged anesthesia or healing associated with surgery may present more of a concern. In addition, the author would prefer to avoid intra-luminal stent placement in younger animals as long-term follow-up (> 5 years) in tracheal stented animals has not yet been performed.

The patient with diffuse cervical and intra-thoracic tracheal collapse is an even greater dilemma. One can argue that an intra-luminal stent for the intra-thoracic collapse and surgical rings for cervical collapse might avoid some of the potential complications associated with very long tracheal stents spanning the thoracic inlet, however the alternative view would be that this approach would combine the potential complications associated

with both procedures. In these cases, the author is currently placing a single, long stent to span both the intra- and extra-thoracic trachea. Others are placing stents intra-thoracically and surgical rings on the cervical trachea.[5]

Bronchial Collapse

There remains much debate concerning the use of intra-luminal stents in patients with mainstem bronchial collapse. Unfortunately, there is currently no data available to recommend or oppose the routine use of intra-luminal stents in these patients, and therefore, regrettably, the author can only offer an opinion. The questions raised are two-fold:

(1) *Should stents be placed within collapsing mainstem bronchi?* I do not recommend stenting of collapsing mainstem bronchi. Not only will bronchial stents "cage-off" other bronchi and consequently prevent drainage from affected lung lobes, but secondary and tertiary bronchi will continue to collapse and therefore the benefit achieved will likely be minimal, and temporary, when compared to the risks. Theoretically, there may be animals in which focal mainstem bronchial collapse has been diagnosed in which placement of short bronchial stents could provide some benefit.

(2) *Should tracheal stents be placed in patients with concurrent tracheal and mainstem bronchial collapse?* Certain patients will benefit from tracheal stenting, even when concurrent mainstem bronchial collapse is present. The patient should be carefully evaluated to determine the animal's primary clinical signs. Tracheal collapse can lead to dyspnea, coughing/honking, or both. Bronchial collapse will usually manifest as a cough, expiratory dyspnea, or both. When both tracheal and bronchial collapse are present, the results following tracheal stent placement become less predictable. If dyspnea is the major clinical sign and intra-thoracic tracheal collapse is present, a tracheal stent can help relieve the dynamic obstruction. If the patient's primary problem is coughing, then it becomes difficult to determine if the coughing is secondary to the tracheal collapse or bronchial collapse. In these patients, the author always warns the owner that continued coughing will likely be present as the bronchial collapse will continue. In addition, in the author's experience, it appears that continued, intractable coughing will cause repeated cycling of the stent and may increase the risk of subsequent fracture, or predispose to the formation of excessive granulation tissue. Persistent coughing must be treated aggressively to minimize the risk of these complications.

Expectations/Risks/Discussion with the Owner

An in-depth discussion with the owner concerning the risks and expectations should take place once the decision has been made to consider tracheal stenting. Neither surgery nor stenting has been demonstrated to slow the progression of tracheal collapse and both techniques are considered palliative. Clinical improvement rates in 75% to 90% of animals treated with intra-luminal SEMS have been reported, and immediate complications were mostly minor although there was a peri-operative mortality rate of approximately 10% in one report.[3,4] Late complications can include stent shortening, excessive granulation tissue, progressive tracheal collapse, and stent fracture. Continued coughing should be anticipated in patients with concurrent bronchial collapse and these patients may have a worse prognosis. In addition, the vast majority of patients will require continued medical therapy.

Stent Selection

A general review of stents is beyond the scope of this chapter, but a brief discussion of certain stent characteristics is necessary to understand how one selects an appropriate stent type and size. This discussion will not include balloon-expandable metallic stents (BEMS) as SEMS are exclusively being used to treat tracheal collapse in animals. In their resting state (deployed, or outside of the delivery system), SEMS are expanded to their stated, pre-determined dimensions. For example, a 10 mm diameter x 70 mm long SEMS will be 10 mm wide and 70 mm long if deployed from the delivery system. Following manufacturing, an SEMS is compressed and mounted onto a delivery system using a number of different techniques. The relatively small delivery system (compared to the expanded stent diameter) allows introduction through very small holes (vascular sheath or endotracheal tubes, for instance). During placement, as the delivery system sheath is retracted, the stent expands back to its original dimensions.

Stent Material

The majority of stents being manufactured today are made of nitinol, a nickel ("Ni")-titanium ("Ti") alloy developed by the Naval Ordinance Laboratory ("NOL") which is classified as a shape-memory metal. This characteristic means that nitinol assumes a weakened, deformable state (Martensite phase) at low temperatures but it will return to, and maintain, its original shape at body temperature (Austenite phase). Laser-cut nitinol stents are cut from hollow tubes of nitinol and at cooled temperatures, the metal's properties change allowing compression of the stent onto a delivery system. Upon returning to ambient temperature, the stent favors its original design which is achieved upon deployment from the delivery system. Laser-cut nitinol SEMS are currently not recommended by the author for the treatment of diffuse cervical and intra-thoracic tracheal collapse in veterinary patients due to an unacceptably high occurrence of stent fracture (personal experience). However, others have had success placing shorter laser-cut nitinol stents in the intra-thoracic trachea only.[5] Woven, knitted, or mesh stents are designed to be compressed onto a delivery system at normal temperatures through specific design modifications. While the design of these stents facilitates placement onto a delivery system, there is a wide range of foreshortening that occurs from the design changes as well. Examples of more commonly used nitinol stents in veterinary patients currently include mesh stents (Vet Stent-Trachea, Infiniti Medical) or knitted stents (Ultraflex, Boston Scientific). Other commercially available stents used for tracheal collapse are made of stainless steel or similar alloys (Wallstent, Boston Scientific) (Figure 26-4).

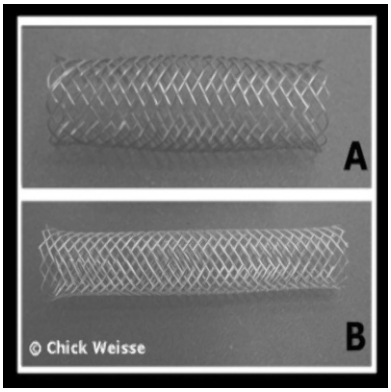


Figure 26-4. A. Mesh nitinol stent; Vet Stent – Trachea™ (Infiniti Medical). Note the rounded edges of this stent chosen to reduce potential granulation tissue development. **B.** Mesh stainless steel stent; Wallstent™ (Boston Scientific).

Foreshortening

The vast majority of tracheal stents currently placed in veterinary patients are mesh or knitted SEMS. One important characteristic of these stents which must be anticipated is the subsequent "foreshortening" that will occur during deployment. "Foreshortening" refers to the shortening of the stent that is encountered as it is released from the delivery system. The stent size, as indicated on the packaging, refers to the diameter and length at complete expansion. If the stent does not achieve complete expansion (i.e. the lumen in which it is placed prevents complete radial expansion to its original diameter), the stent will be longer than expected. In other words, the stents are significantly longer when viewed in the compressed state on the delivery system. As the stent expands radially it shortens, and as such, the ultimate length of the stent is inversely proportional to the degree of expansion (The less the stent expands, the longer it will be). This is an extremely important property of knitted and mesh stents which must be recognized and accounted for during the stent selection process. For example, the more oversized the stent chosen (diameters over 10% to 15% greater than the diameter of the trachea), the longer the stent will be when initially deployed, and the greater the tendency for the stent to shorten over time as it gradually expands to its original, predetermined diameter. This gradual shortening must be accounted for when choosing the appropriate stent length; Over-sized stents should span additional length of normal trachea beyond the area of collapse as future shortening is anticipated. In the author's experience, stent shortening typically occurs at the cranial end of the stent in a caudal direction over time, most likely due to the fact that the cervical trachea is usually larger in diameter than the intra-thoracic trachea. This difference in diameter seems to facilitate greater radial expansion of the stent in the cervical trachea. As a result, the cranial aspect of the stent slowly migrates in a caudal direction. When collapse extends to the larynx, the stent is placed to extend as far cranially as possible without contacting the cricoid cartilage. If the over-sized stent gradually shortens over time, a single extraluminal ring can be placed surgically if tracheal collapse rostral to the stent recurs and clinical signs redevelop.

Reconstrainability

While foreshortening can complicate the process of choosing the appropriate SEMS for tracheal collapse, another characteristic of some of these stents is "reconstrainability". This feature allows the operator to re-sheath a partially deployed stent in order to reposition the stent and deploy it elsewhere or remove it completely if necessary. Generally, the mesh stents (Vet Stents-Trachea™ [nitinol], Wallstents™ [Stainless steel]) are reconstrainable to varying degrees, while the knitted stents (Ultraflex™ [nitinol]) are not reconstrainable. Obviously, it is important to know beforehand whether the stent is reconstrainable. In addition, although a stent may be considered "reconstrainable", that does not mean that the stent can be removed once fully deployed. While some stents can be removed following placement, most stents currently used for tracheal collapse in veterinary patients are designed to remain in place, and as such removal would be very difficult.

Stent Sizing

In order to choose an appropriately sized stent, it is important to determine (1) the length of the collapse, and (2) the diameter of the trachea. The single most effective way to minimize peri-operative stent placement complications when learning this procedure is to appropriately determine these tracheal dimensions.

Stent Length: Simple radiography is not adequate in identifying the length of collapse as different areas of collapse will be apparent during different phases of respiration (Figure 26-5). While tracheoscopy has been historically regarded as the "gold standard" for identifying tracheal collapse, this procedure requires general anesthesia which can add significant risk in these often debilitated patients. The author prefers to identify the length of collapse in a fully awake animal using real-time fluoroscopy. In addition, it is important to induce coughing when possible as the extreme airway pressures subsequently generated will often reveal more extensive collapse than identified during more relaxed breathing (Figure 26-6). Anatomical landmarks are then identified to record the cranial-most and caudal-most extent of the collapse. In addition, mainstem bronchial collapse can often be identified during fluoroscopy and should be noted when present.

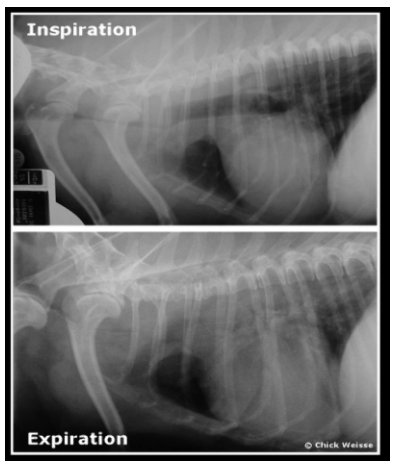


Figure 26-5. Inspiratory and expiratory lateral thoracic radiographs of a dog demonstrating cervical tracheal collapse most apparent during inspiration (top image) and intra-thoracic tracheal collapse most apparent during expiration (bottom image).

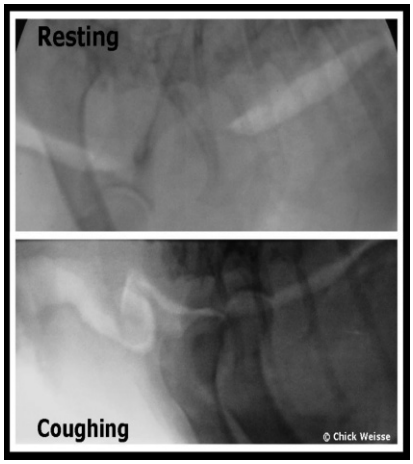


Figure 26-6. Fluoroscopic images demonstrating dramatic differences in determination of the location of tracheal collapse present during passive respiration (top image with thoracic inlet tracheal collapse) and a coughing episode (bottom image). Note the extensive collapse, and apparent folding of the caudal cervical trachea, that occurs during coughing.

On occasion, a previously well-managed patient will present that is unable to be extubated following general anesthesia for an unrelated procedure. Under these circumstances, the awake fluoroscopy technique described above will not be possible. For these rare cases, the author uses a home-made "negative-pressure ventilation device" (Figure 26-7). Following adequate pre-oxygenation with manual positive pressure ventilations, this apparatus is connected to the endotracheal tube and the dosing syringe plunger is withdrawn to 10 to 15 cm H_2O on the sphygmomanometer as a radiograph is taken to document the location of collapse (Figure 26-8).

Once the length of the collapse has been determined, the stent length is chosen to extend approximately 1 cm beyond the cranial and caudal extents of collapse. If the entire length of the trachea is affected, the stent length is usually chosen to extend from approximately 1 cm cranial to the carina to 1 cm caudal to the cricoid cartilage of the larynx. Alternatively, one could choose to place an intra-thoracic tracheal stent alone and place surgical rings on the cervical trachea.

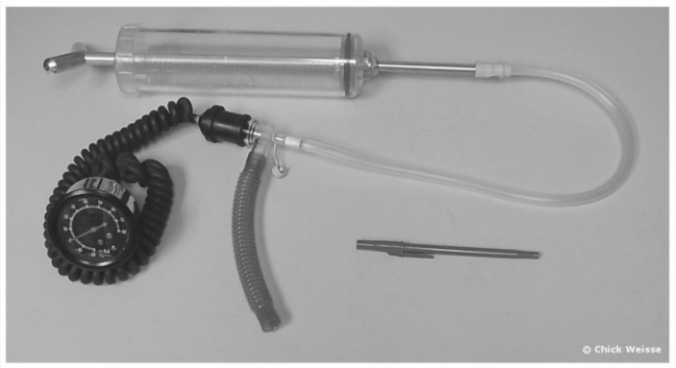


Figure 26-7. Negative pressure ventilation device that can be attached to an endotracheal tube and subsequently used to identify the location of tracheal collapse in an anesthetized animal in which awake fluoroscopy is not possible.

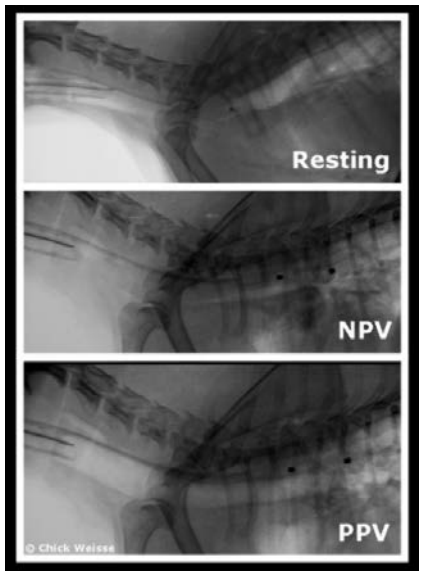


Figure 26-8. Serial fluoroscopic images of an individual dog under normal resting ventilation, negative pressure ventilation (NPV) and positive pressure ventilation (PPV). Note the extensive tracheal collapse apparent under NPV but less clear under resting respiration. Under PPV, maximal dilation of the entire trachea is apparent.

For shorter lengths of collapse, one must decide whether the animal will benefit from complete tracheal stenting versus covering just the shorter affected segment. One study identified a potential increased risk of complications in animals receiving longer Wallstents, however this finding was not corroborated in another study.[3,4] A correlation between stent length and complication rate has not yet been apparent in this author's experience and, as such, if progression of the disease is expected, the patient will generally receive stenting of the majority of the trachea. In general, the author avoids complete tracheal stenting in younger patients when possible. In older patients, or those cases in which the client can only afford a single procedure, a discussion concerning the risks and benefits of complete tracheal stenting is necessary. In general, the price of a stent is not determined by its dimensions (a 40 mm long stent is usually the same price as a 90 mm stent). Therefore, there is no financial benefit to placing a shorter stent.

Stent Diameter: The maximal tracheal diameter is typically determined at the time of stent placement to avoid having to repeat general anesthesia. It is therefore necessary to have a number of different stent sizes available. Alternatively, the stent sizing process can take place during a separate general anesthetic episode and the appropriate stent size subsequently ordered. It is the veterinarian's judgment as to whether an additional anesthetic episode places the patient at significant risk. **It is imperative that the stent diameter is not chosen based upon resting survey radiographs.** Otherwise, the stent diameter will typically be under-sized, resulting in subsequent stent migration. In addition, the author avoids using standard "magnification" values assigned to different radiographic units. These values tend to be "estimations" and are not sufficiently accurate for the fine measurements necessary in these cases.

The author places a measuring catheter within the esophagus

in order to account for radiographic magnification. Alternatively, some other measuring device can be placed externally and included in the radiograph, although placement within the esophagus is ideally located directly beside the trachea. With the esophageal marker catheter technique, the patient is placed in lateral recumbency following intubation. A wet hydrophilic guidewire[a] and flushed marker catheter[b] combination are advanced into the mouth. Using fluoroscopic guidance, the guidewire is gently advanced down the esophagus and the marker catheter is advanced over-the-wire. The soft guidewire is always advanced first to avoid damage to the esophagus by the relatively stiffer marker catheter. The marker catheter is placed within the esophagus such that the radio-opaque marks extend along the location of the tracheal collapse. The guidewire can then be withdrawn. Under fluoroscopic guidance, the endotracheal (ET) tube is withdrawn until the distal-most aspect is just beyond the larynx and the cuff is gently re-inflated. Positive pressure ventilation of 20 cm H_2O is temporarily performed to achieve maximal tracheal expansion as a radiograph is taken. The radio-opaque marks on the marker catheter are 10 mm apart; this distance is measured on the radiograph and used to determine the radiographic magnification that is then used to extrapolate the actual maximal diameters of both the intra-thoracic and cervical trachea (Figure 26-9A). It is important to take maximal measurements of BOTH the cervical and intra-thoracic trachea as these measurements can vary dramatically.

The stent diameter is usually chosen to be 10% to 20% greater than the maximal tracheal diameter to minimize chances of subsequent stent migration. The author generally inventories stents in 2 mm diameter increments (i.e., 8 mm, 10 mm, 12 mm, and 14 mm diameter) and in the most commonly used lengths. The cervical trachea is routinely larger in diameter than the intra-thoracic trachea. Stent sizing can be complicated when the difference in these two measurements varies dramatically. When the two diameters are similar (within 2 mm), the stent diameter chosen is at a minimum equal to the maximal tracheal diameter and typically no more than 10% to 20% larger than the maximal diameter.

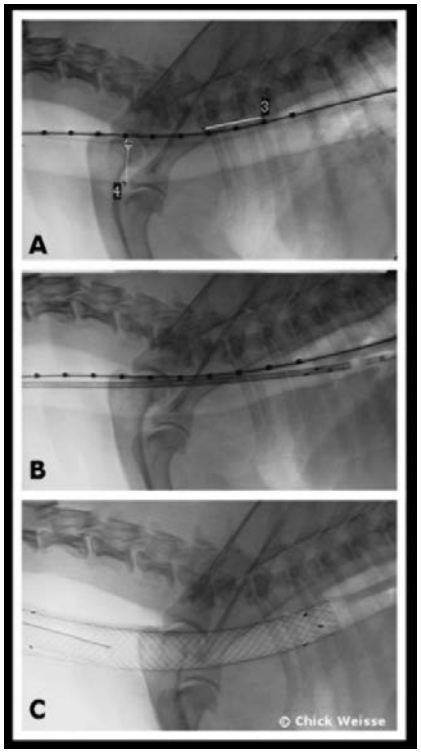


Figure 26-9. Serial fluoroscopic images during tracheal sizing and stent placement. **A.** Using PPV and an esophageal marker catheter, measurements are taken to establish the maximal tracheal diameter. **B.** The stent delivery system is advanced into the trachea. Note that the cervical and intra-thoracic trachea and in-line to facilitate atraumatic passage of the stent. **C.** Restoration of a patent trachea immediately following stent deployment.

Example 1: A dog with maximal intra-thoracic tracheal diameter of 8mm and maximal cervical tracheal diameter of 10mm would likely receive a 12 mm diameter stent. When the discrepancy between the cervical and intra-thoracic trachea is 3 mm or greater, a stent diameter that is at least 10% to 20% larger than the intra-thoracic tracheal diameter or the average of the two measurements is chosen as long as the stent will be well seated within the intra-thoracic trachea to prevent cranial migration.

Example 2: A dog with a maximal intra-thoracic tracheal diameter of 8 mm and maximal cervical tracheal diameter of 12 mm would likely receive a 12 mm (or 10 mm) diameter stent. However, one must also consider the relative length of the stent that will be located in the smaller diameter trachea. If only about 20% of the stent will be located in the 8 mm diameter portion of the trachea, adequate tracheal wall contact may not be achieved with the 10 mm stent. Alternatively, if 80% of the stent will be within the 8 mm diameter portion of the trachea, a 10 mm diameter stent may be sufficiently seated within this location to prevent migration. The advantage of the 10 mm diameter stent is that the length will be easier to determine as it will more closely achieve full expansion and therefore the length will be closer to its predetermined length.

In both examples above, if a 12 mm diameter stent was chosen, a shorter length stent would be required as the stent would not reach its full diameter and therefore the stent length would be longer than anticipated had full expansion been achieved. **These calculations are intended as guidelines and cannot be used for every case.**

Stent Placement Technique

The following description applies to placement of mesh SEMS (Vet Stents-Trachea™, Wallstents™). For information regarding placement of knitted SEMS, the readers are referred to alternate resources.

General Anesthesia and Preparation

Anesthesia protocols differ among institutions, however the author prefers a rapid induction and recovery. An anti-tussive/tranquilization combination such as butorphanol (0.2 to 0.3 mg/kg) and acepromazine (0.01 mg/kg) can be an effective premedication when necessary, however premedications are routinely avoided unless intravenous catheterization creates excessive anxiety and respiratory distress. Pre-oxygenation of the patient before handling is routinely performed. Unless contraindicated,

[a]Weasel Wire, Infiniti Medical, Haverford, PA. [b]Marker Catheter, Infiniti Medical, Haverford, PA.

a combination of intravenous propofol and diazepam are used with minimal inhalant anesthesia concentrations. Propofol CRIs are occasionally used. The use of peri-operative antibiotics is debatable and chosen on an individual case basis. Unless contraindicated, these patients typically receive one perioperative dose of dexamethasone SP (0.1 to 0.25 mg/kg IV).

The largest diameter ET tube possible should be selected (at least 4 mm inner diameter) to facilitate unrestricted passage of the stent delivery system through the tube while permitting simultaneous oxygen delivery and ventilation during the procedure. An ET tube with a radio-opaque line or markers should always be used when possible to help avoid inadvertent deployment of the stent within the tube. The use of sterile ET tubes is debatable and not routinely required by the author. Following intubation, the patient is placed in lateral recumbency. Subsequent measurements are used to determine the tracheal stent diameter as described above. The radiographic landmarks previously obtained during awake fluoroscopy identifying the length of the collapse are compared with those of the esophageal marker catheter to determine the length of stent necessary.

Stent Placement

Once the appropriately sized stent is chosen, it is removed from its packaging using sterile technique. The stent is prepared and saline flushed according to manufacturer recommendations. The operator is encouraged to practice these techniques outside of the patient before introducing the delivery system into the ET tube. **ALL MANIPULATIONS SHOULD BE PERFORMED UNDER DIRECT FLUORSCOPIC GUIDANCE.** A right-angle bronchoscope adapter (Figure 26-10) is attached to the ET tube to facilitate passage of the stent delivery system through the tube while maintaining the anesthesia circuit system. The delivery system must pass easily and without friction. Occasionally it is necessary to remove the diaphragm on the bronchoscope adapter to permit unrestricted passage of the delivery system. Before passing the stent, the patient should be positioned such that the cervical and intrathoracic trachea lie in a straight line to facilitate unrestricted passage of the relatively inflexible delivery system (Figure 26-9B). This position will minimize trauma to the tracheal wall during advancement of the delivery system. The author always places tracheal stents under fluoroscopic guidance although some have performed these techniques using endoscopic assistance alone. In addition, passage of the delivery system and stent placement can induce a coughing reflex. The animal should be sufficiently anesthetized to avoid a coughing episode during stent deployment.

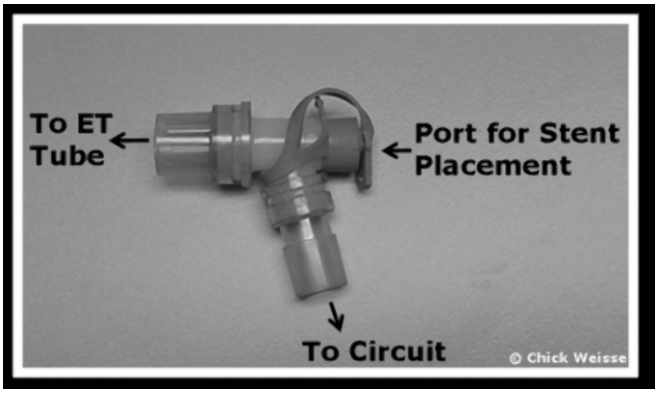


Figure 26-10. Bronchoscope adapter used to maintain a complete anesthesia circuit while passing the stent delivery system through the bronchoscope opening and down the endotracheal tube.

The radio-opaque stent is easily visualized under fluoroscopy, even when constrained within the delivery system. Once the distal end of the stent has been positioned appropriately, stent deployment can proceed. During deployment, the entire stent and delivery system combination can be gently pulled craniad if the stent is initially placed too caudally, however the entire system cannot be advanced caudally if placement is inappropriately cranial. For this reason, some prefer initially to place the distal aspect of the stent slightly (~0.5 to 1cm) caudal to the desired final location. To initiate stent deployment, with one hand on the hub (or the cannula), and the other hand on the Y-piece (sheath), gently withdraw the Y-piece (sheath) while simultaneously advancing the hub (cannula) in equal proportions (Figure 26-11). If done appropriately, as stent deployment proceeds, the distal end of the stent will remain in the same location throughout deployment. Under no circumstances should the cannula (hub) be advanced while the sheath remains stationary. This will force the stent caudally and traumatize the tracheal mucosa. These same circumstances apply to the process of stent reconstrainment. If the operator is unhappy with the location of the partially deployed stent, reconstrainment should be performed via simultaneous withdrawal of the cannula and advancement of the sheath in order to avoid dragging the stent across the tracheal mucosa. The operator should read the manufacturer's instructions to determine the degree to which stent deployment can occur before stent reconstrainment is no longer possible.

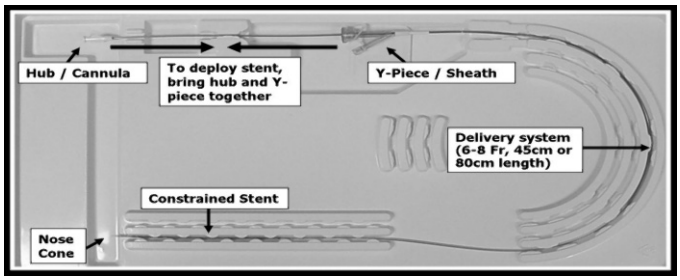


Figure 26-11. Tracheal stent mounted on delivery system within packaging.

Following complete stent deployment, carefully remove the delivery system. This should be performed under fluoroscopic guidance to ensure the delivery system nose-cone does not engage the distal end of the stent upon removal. Radiographs are taken to document the final position of the stent within the trachea (Figure 26-9C). The patient is recovered immediately, typically in an intensive care unit setting, and often within an oxygen cage. The use of butorphanol (0.1 to 0.2 mg/kg IV) and/or acepromazine (0.005 to 0.01 mg/kg IV) can be useful to facilitate smooth recovery from general anesthesia.

Post-Operative Care and Follow-Up

Patients are routinely discharged one or two days post-stenting with a 3 to 6 week tapering dose of prednisone (initial dose of 1 to 2 mg/kg/day PO), continued anti-tussive therapy (Hydrocodone 0.25 mg/kg PO q6 to 12 hours or higher doses if tolerated), and 10 to 14 days of broad-spectrum oral antibiotics. Patients with bronchial collapse and/or an observed "expiratory push" during exhalation may benefit from bronchodilator therapy as well.

Owners should be warned to anticipate an initial dry cough that should improve over the following 3 to 4 weeks. If the patient has documented bronchial collapse, the owners should expect continued coughing in the future. Aggressive medical management of coughing is imperative for a good long-term outcome. It is the author's anecdotal experience that continued coughing increases the risk of both granulation tissue formation and stent fatigue/fracture. High doses of anti-tussive medications and inhalation steroids have been useful when routine therapy is inadequate. The majority of patients will require life-long medication following tracheal stenting. The initial recheck examination is approximately two weeks post-stenting or sooner if problems arise. Repeat examinations are performed regularly (every 3 to 6 months if possible) or sooner if the patient's clinical signs worsen.

Disclosure: The author is a consultant for Infiniti Medical, LLC and has been involved in the specifications chosen for the Vet Stent-TracheaTM and Delivery System.

References

1. Buback JL, Boothe HW, and Hobson HP. Surgical treatment of tracheal collapse in dogs: 90 cases (1983-1993) Journal of the American Veterinary Medical Association 1996; 208(3):380-384.

2. Radlinsky MG, Fossum TW, Waler MA, et al. Evaluation of the palmaz stent in the trachea and mainstem bronchi of normal dogs. Veterinary Surgery 1997; 26(2):99-107.

3. Norris JL, Boulay JP, Beck KA, et al. Intraluminal self-expanding stent placement for the treatment of tracheal collapse in dogs (abstr), in Proceedings, 10th Annual Meeting of the American College of Veterinary Surgeons 2000.

4. Moritz A, Schneider M, and Bauer N. Management of advanced tracheal collapse in dogs using intraluminal self-expanding biliary wallstents. Journal of Veterinary Internal Medicine 2004; 18:31-42.

5. Krahwinkel DJ. Tracheal collapse: Is surgery an option?, in Proceedings, 15th Annual Meeting of the American College of Veterinary Surgeons, San Diego, CA, 2005.

Tracheal Resection and Anastomosis

Roger B. Fingland

Tracheal anastomosis is indicated for management of benign and malignant tracheal stenoses, traumatic tracheal disruption, and segmental tracheomalacia. Important preoperative considerations include localization of the lesion, determination of the proximal and distal margins of the lesion, and, in the case of malignant lesions, evaluation of the animal for distant metastases. Plain film radiography, tracheoscopy, and computed tomography are helpful in localization of tracheal lesions.

Tracheal anastomosis in veterinary patients typically is accomplished by apposition of circumferentially divided tracheal cartilages with sutures placed in simple interrupted fashion (split-ring technique).[1] Alternative techniques such as overriding segments, creation of mucosal flaps, and apposition of annular ligaments are less desirable because these techniques are technically more difficult or result in critical anastomotic stenosis.[1,2] In one study, simple continuous and simple interrupted suture techniques for tracheal anastomosis after large-segment tracheal resection were compared in dogs. Differences in surgical time and anastomotic stenosis were not clinically significant.[3]

Tension has a profound effect on anastomotic healing and is the major factor limiting the extent of tracheal resection. Tracheal anastomoses consistently are successful in mature dogs when tension on the anastomosis is less than 1750 g.[4] Unfortunately, attempts to correlate grams of tension with number of tracheal cartilages have produced widely disparate results.[5] In general, 25% of the trachea (8 to 10 tracheal cartilages) can be resected in a mature dog with consistently satisfactory results. In young animals and in animals with primary tracheal disease, this number may be significantly lower.[6]

Surgical Techniques

Cervical Trachea

Preoperative planning is imperative. An endotracheal tube with a high-volume, low-pressure cuff should be used. Ideally, the endotracheal tube should be positioned proximal to the affected tracheal segment, and the entire procedure should be performed "over" the endotracheal tube. In patients with significant luminal compromise, the endotracheal tube should be positioned distal (orad) to the lesion for the surgical approach and the initial tracheal dissection. Tracheal anastomosis necessitates intraoperative manipulation of the endotracheal tube and, on occasion, direct intubation of the distal segment of the trachea. A sterile endotracheal tube should be available for intraoperative intubation of the distal segment of the trachea. The endotracheal tube cuff must be deflated when the tube is repositioned within the trachea and then reinflated before the procedure continues. Prophylactic administration of a broad-spectrum antibiotic is recommended.

The patient is positioned in dorsal recumbency, and the ventral cervical region is prepared for aseptic surgery. The skin and subcutaneous tissues are incised from the larynx to the manubrium. The trachea is exposed by midline separation of the paired sternocephalicus and sternohyoideus muscles. The segment of trachea to be resected is determined based on preoperative evaluation and intraoperative inspection and palpation. The lateral pedicles are dissected from the trachea along a segment that includes two cartilage rings proximal and two cartilage rings distal to the proposed margins of the excision. Carrying the lateral pedicle dissection beyond the proposed margins of excision facilitates manipulation of the proximal and distal tracheal segments and placement of primary anastomotic

and tension sutures. Traction sutures (3-0 polydioxanone, SH-1 taper needle, 70 cm) are placed around the right and left lateral aspects of the second tracheal cartilage proximal to the cartilage to be incised. The swaged-on needle is left in place, and the suture is looped but not tied. These traction sutures facilitate manipulation of the proximal tracheal segment and are used as tension sutures after the primary anastomosis is completed.

The segment of trachea is excised by circumferentially incising one tracheal cartilage at each end of the segment (Figure 26-12). Care is taken to incise the tracheal cartilages circumferentially in two equal halves. If the endotracheal tube was initially positioned distal to the lesion, the cuff is deflated, the endotracheal tube is directed into the proximal tracheal segment, and the endotracheal tube cuff is reinflated. On both sides of the trachea, the swaged-on arm of the lateral traction suture is passed around the second complete tracheal cartilage distal to the incised tracheal cartilage. These sutures are used to approximate and maintain apposition of tracheal segments and to facilitate rotation of the trachea for placement of primary anastomotic sutures (Figure 26-13).

The proximal and distal circumferentially incised tracheal cartilages are approximated using the pre-placed lateral tension sutures (Figure 26-14). Accurate alignment of the two split cartilages is important. The primary anastomosis is created using 4-0 polydioxa-none suture placed in a simple interrupted pattern approximately 3 mm apart (Figure 26-15). Each suture incorporates the split proximal and distal tracheal cartilages. All sutures enter the lumen of the trachea.

The dorsal tracheal membrane is exposed by rotating the trachea with the preplaced lateral tension sutures (Figure 26-16). Anastomotic sutures are placed in the dorsal tracheal membrane in a manner that ensures accurate apposition and an airtight seal.

The lateral tension sutures are tied after the primary anastomosis is complete (Figure 26-17). A third tension suture is placed on the ventral aspect of the trachea. The tension sutures should be tight enough to relieve tension from the primary anastomotic sutures, but they should not cause deviation or overlapping of the apposed ends of the proximal and distal segments of the trachea.

Thoracic Trachea

The thoracic segment of the trachea is approached through a right third intercostal thoracotomy. The technique for resection and anastomosis of the thoracic segment is similar to the technique described for the cervical segment of the trachea. Direct intubation of the proximal segment of the trachea intraoperatively usually is necessary. Direct intubation of an isolated primary bronchus may be necessary to maintain ventilation. Preoperative planning and technical expertise are necessary to ensure success.

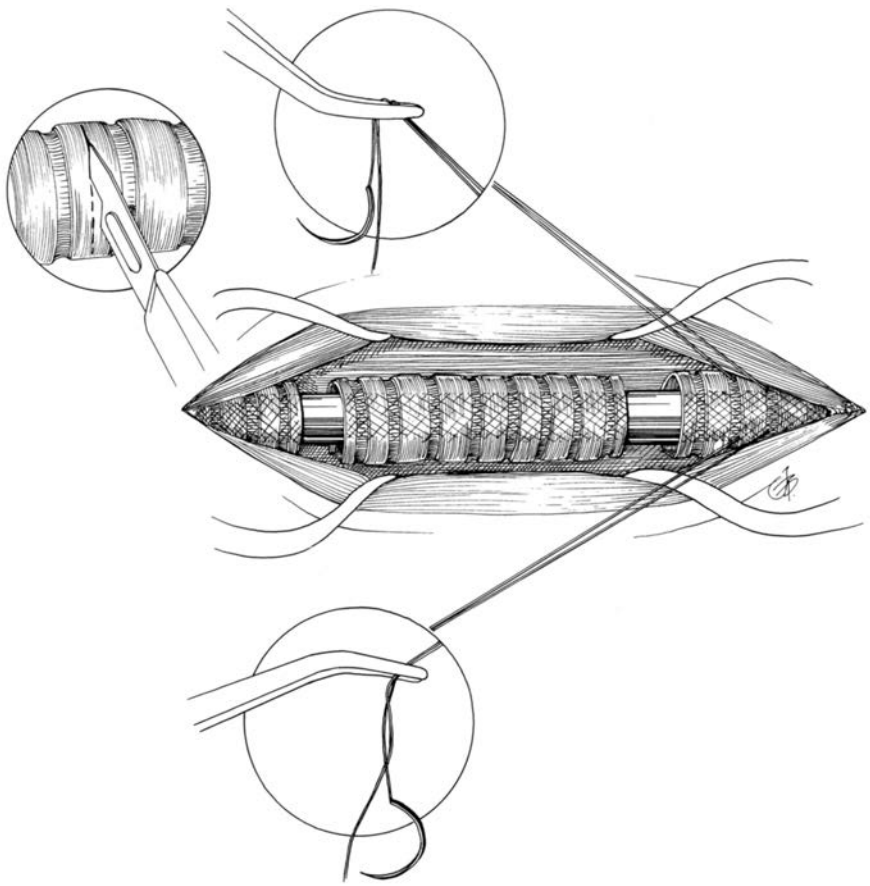


Figure 26-12. Ventral view of the exposed cervical trachea showing placement of traction sutures. The segment to be removed has been excised by circumferentially incising (*inset*) the proximal and distal tracheal cartilages.

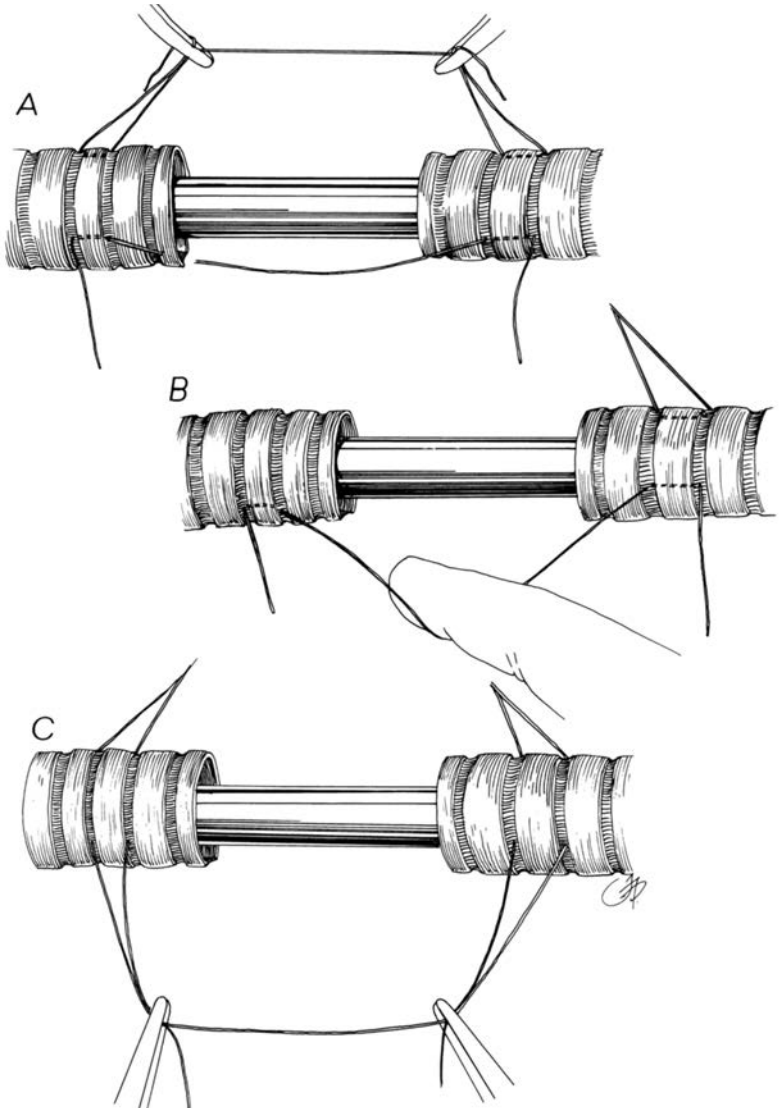


Figure 26-13. The tracheal segment has been excised. **A.** The proximal and distal segments of the trachea are joined by tension sutures. The tension sutures are drawn through the tracheal wall **B.** and are tagged to facilitate manipulation of the trachea for primary anastomosis.

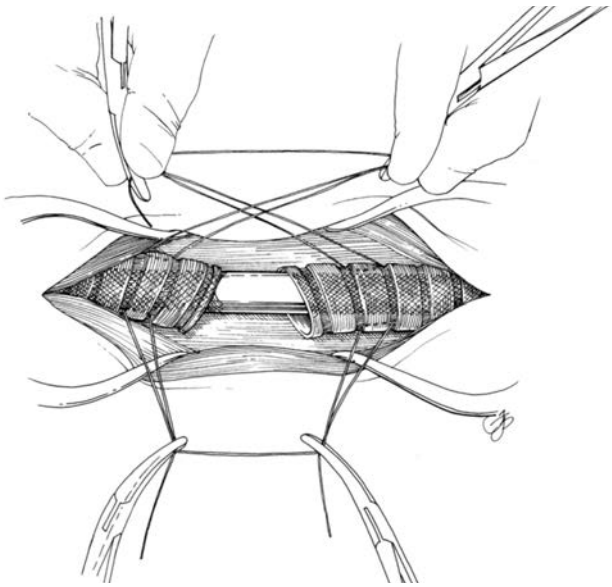


Figure 26-14. The tagged tension sutures are used to approximate the proximal and distal segments of the trachea for primary anastomosis.

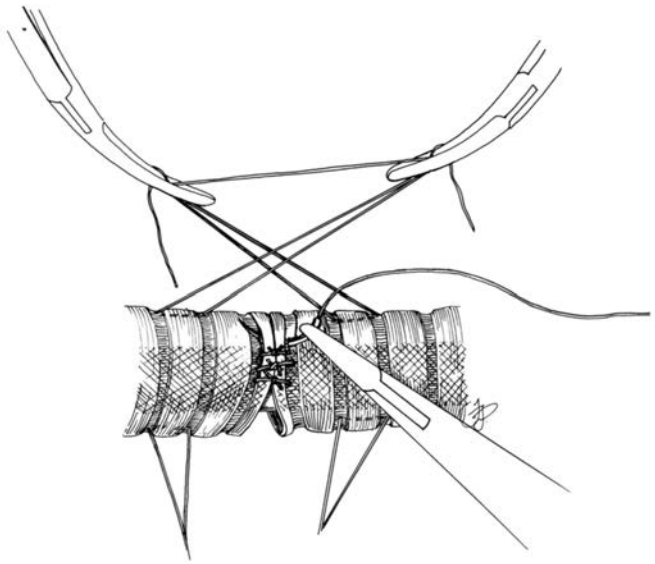


Figure 26-15. The primary anastomosis begins on the ventral aspect of the trachea by placing simple interrupted sutures around the split proximal and distal tracheal cartilages.

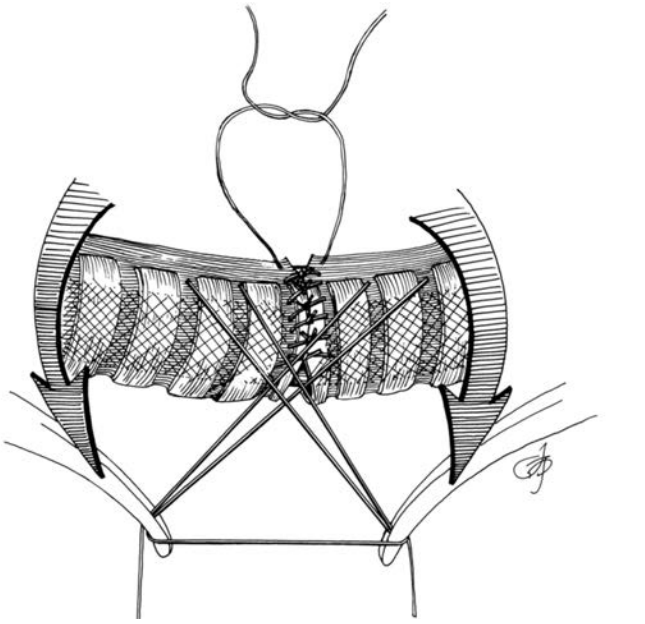


Figure 26-16. A tagged tension suture is used to rotate the trachea for exposure of the left lateral and dorsal aspects. Simple interrupted anastomotic sutures are placed approximately 3 mm apart.

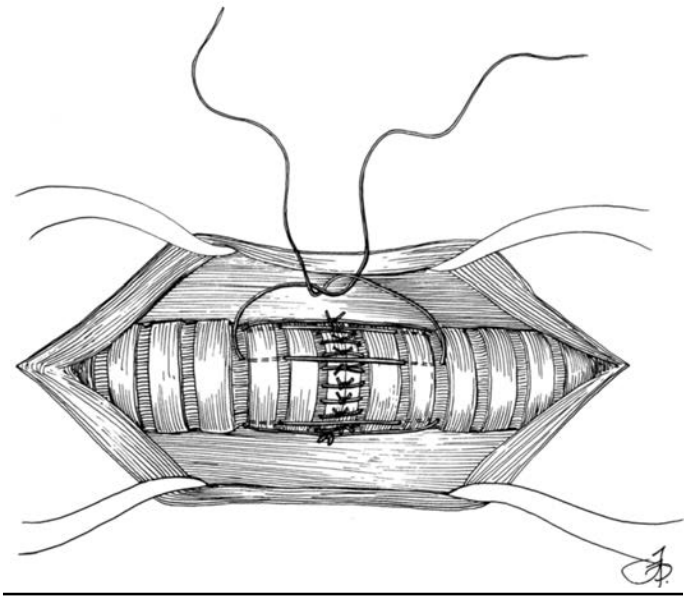


Figure 26-17. The primary anastomosis is completed, and the tension sutures are knotted. A third tension suture is placed on the ventral aspect of the trachea. The tension sutures should relieve tension from the primary anastomosis, but they should not result in deviation or overlapping of the tracheal segments.

Postoperative Considerations

Brief, atraumatic tracheal suctioning after extubation is helpful to remove clotted blood from the lumen of the trachea. The patient should be observed closely for respiratory distress for 12 to 24 hours after surgery. Postoperative respiratory distress can result from laryngeal or pharyngeal edema, occlusion of the tracheal lumen at the anastomotic site, or iatrogenic laryngeal paralysis from intraoperative recurrent laryngeal nerve injury. Antitussives and glucocorticoids are administered as needed to reduce inflammation and to suppress coughing.

The nature of tracheal wound healing ensures some degree of anastomotic stenosis. Periodic endoscopic examination of the trachea after anastomosis is helpful to evaluate wound healing and anastomotic stenosis. Anastomotic stenosis usually is not clinically significant in sedentary patients until the tracheal lumen is compromised by 50 to 75%.[7] Meticulous, atraumatic surgical technique and elimination of tension on the anastomosis usually result in a successful outcome.

References

1. Hedlund CS. Tracheal anastomosis in the dog: comparison of two end-to-end techniques. Vet Surg 1984;13:135.

2. Lau RE, Schwartz A, Buergelt CD. Tracheal resection and anastomosis in dogs. J Am Vet Med Assoc 1980; 176:134.

3. Fingland RB, Layton CE, Kennedy GA, et al. A comparison of simple continuous versus simple interrupted suture patterns for tracheal anastomosis after large-segment tracheal resection in dogs. Vet Surg 1995,24:320.

4. Cantrell JR, Folse JR. The repair of circumferential defects of the trachea by direct anastomosis: experimental evaluation. J Thorac Cardiovasc Surg 1961,42:589.

5. Vasseur PB, Morgan JP. The trachea. In: Gourley IM, Vasseur PB, eds. General small animal surgery. Philadelphia: JB Lippin-cott, 1985.

6. Maeda M, Grillo HC. Effects of tension on tracheal growth after resection and anastomosis in puppies. J Thorac Cardiovasc Surg 1973;65:658.

7. McKeown PP, Tsuboi H, Togo T, et al. Growth of tracheal anastomoses: advantages of absorbable interrupted sutures. Ann Thorac Surg 1991;51:636.

Permanent Tracheostomy

Cheryl S. Hedlund

Introduction

A permanent tracheostomy is a stoma in the ventral tracheal wall created by suturing tracheal mucosa to skin. Tracheostomy tubes are not needed to maintain lumen patency following this procedure. Tracheostomas are maintained for life or until the stoma is surgically closed. Permanent tracheostomies are recommended for animals with upper respiratory obstructions causing moderate to severe respiratory distress that cannot be successfully managed by other methods. Dogs and cats with cyanosis or severe dyspnea at rest or with minimal exertion are candidates. Respiratory distress is commonly associated with laryngeal dysfunction secondary to laryngeal collapse or neoplasia, and sometimes nasopharyngeal or proximal tracheal obstruction. Before creating a tracheostoma, it is important to establish the clients willingness and ability to provide postoperative care. Although most patients requiring a permanent tracheostomy function much better after surgery, some clients will refuse the procedure and elect less beneficial surgical procedures or euthanasia.

Surgical Technique

A permanent tracheostomy is performed with the anesthetized patient in dorsal recumbency.[1-3] The skin of the ventral and lateral neck is clipped and aseptically prepared for surgery. On the operating table, the patient's forelegs are positioned caudally along the chest, and then the animal's neck is elevated and extended with a dorsal cervical pad. The proximal cervical trachea is exposed with a ventral cervical midline incision beginning at the distal larynx and extending caudally 8 to 10 cm. The paired sternohyoid muscles are separated and are retracted laterally to visualize the trachea. The endotracheal tube cuff is advanced distal to the proposed tracheostomy site. The surgeon creates a tunnel dorsal to the trachea from the third to sixth tracheal cartilages and, using this tunnel, apposes the sternohyoid muscles dorsal to the trachea with horizontal mattress sutures to create a muscle sling (Figure 26-18). The muscle sling serves to deviate the trachea ventrally reducing tension on the mucosa-to-skin sutures. Beginning with the second or third tracheal cartilages, a rectangular segment of tracheal wall three to four cartilage widths long and one-third the circumference of the trachea in width is outlined. (See Figure 26-18) Using a #11 scalpel blade, the cartilage and annular ligaments are incised to the depth of the tracheal mucosa. The surgeon elevates a cartilage edge with thumb forceps and dissects the cartilage segment from the mucosa using the blunt edge of the scalpel blade. If tracheal cartilages show any weakness or tendency to collapse, place one or two prosthetic tracheal rings cranial and caudal to the stoma. A similar segment of skin is excised adjacent to the stoma. If the patient has loose skin folds or abundant subcutaneous fat, larger segments of skin are excised to help prevent skin fold occlusion of the stoma. Excess fat is excised in obese patients to allow direct contact of the skin and peritracheal fascia. The surgeon sutures the skin directly to the peritracheal fascia laterally and the annular ligaments proximal and distal to the stoma with a series of interrupted intradermal sutures (3-0 or 4-0 polydioxanone or poliglicaprone 25) without entering the tracheal lumen. These skin-peritracheal sutures promote adhesion of the skin to the trachea and are important in reducing postoperative skin fold problems, seroma formation, and tension on the stomal sutures. An "I" or "H" shaped incision is made through through the mucosa. The mucosa is folded over the cartilage edges and sutured to the edges of the skin with approximating sutures (4-0 monofilament absorbable) (Figure 26-19). Simple interrupted sutures are placed at the corners and a simple continuous pattern is used along the sides of the stoma. Sutures are spaced approximately 2 mm apart. Precise apposition is important to minimize tracheostomal stenosis but is not always possible. Precise apposition is not possible if the tracheal mucosa is disrupted during dissection or previous tube tracheostomy, or of poor quality due to disease. If the patient does not have enough mucosa to cover the incised cartilage edges and annular ligaments, the surgeon should appose as much mucosa to the skin as possible and allow the exposed areas to heal by second intention. If necessary, sutures are passed around or through adjacent cartilages or annular ligaments. Skin edges are apposed proximal and distal to the stoma with simple interrupted or cruciate sutures. Blood and mucus are suctioned from the stoma before the animal recovers from anesthesia.

Permanent tracheostomy following total laryngectomy requires the creation of a tracheostoma after the transected end of the trachea is closed or deviated to the skin.[3,5] Closure of the transected trachea is accomplished by preserving a flap of dorsal tracheal membrane from the more proximal trachea that can be folded over the exposed lumen of the distal trachea and then sutured. Alternatively, the transected distal trachea is closed by placing a series of interrupted horizontal mattress sutures to appose the dorsal tracheal membrane to the cartilage. After using either of these closure techniques a permanent tracheostomy is performed as described previously.

Another option after total laryngectomy is to incorporate the distal tracheal end into the tracheostoma. This is accomplished by apposing the sternohyoid muscles dorsal to the distal tracheal end. Then, beginning at the distal tracheal transection site, the surgeon removes segments of four to six tracheal cartilages from the ventral aspect of the tracheal wall, while preserving as much mucosa as possible (Figure 26-20). At the most proximal aspect of the proposed stoma, the dorsal tracheal membrane is apposed directly to the skin with simple interrupted sutures. Excess skin is excised as necessary to prevent skinfolds at the site, and then the skin is sutured directly to the peritracheal fascia and annular ligaments with intradermal sutures. The tracheostoma is completed by apposing the tracheal mucosa at the lateral and distal cartilage margins to the skin with simple continuous sutures (Figure 26-21).

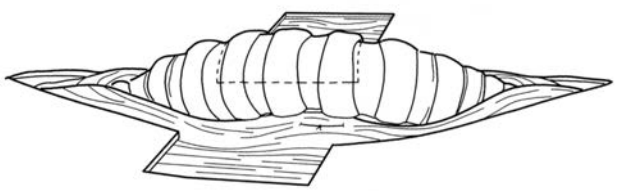


Figure 26-18. The trachea is deviated ventrally by apposing the sternohyoid muscles dorsal to the trachea creating a muscle sling. A rectangular segment of ventral tracheal wall, approximately one third the tracheal circumference and three to four cartilages long, is excised without penetrating the mucosa. Loose skin adjacent to the tracheal incisions is excised. (Reprinted with permission from: Hedlund CS: Tracheostomies in the management of canine and feline upper respiratory disease. Veterinary Clinics of North America: Small Animal Practice 24: 873-886, 1994.)

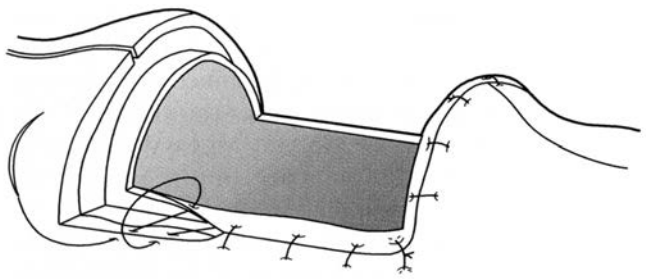


Figure 26-19. After placing skin-peritracheal fascial sutures and incising the tracheal mucosa, the mucosa is rolled over the cartilage edges and apposed to the skin edges. Simple interrupted sutures are placed in the corners and apposition is completed with a simple continuous pattern. (Reprinted with permission from: Hedlund CS: Tracheostomies in the management of canine and feline upper respiratory disease. Veterinary Clinics of North America: Small Animal Practice 24: 873-886, 1994.)

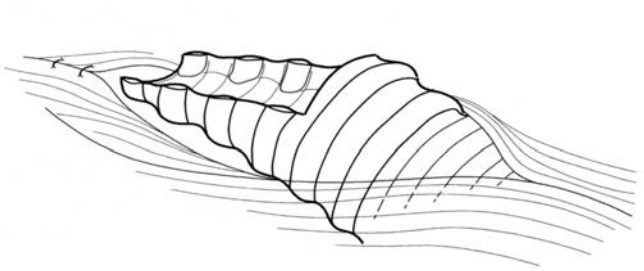


Figure 26-20. Permanent tracheostomy following complete laryngectomy can be accomplished by apposing the sternohyoid muscles dorsal to the trachea and then removing a segment of tracheal wall four to six cartilages long. The mucosa is preserved as with the standard permanent tracheostomy technique. (Reprinted with permission from: Hedlund CS: Tracheostomies in the management of canine and feline upper respiratory disease. Veterinary Clinics of North America: Small Animal Practice 24: 873-886, 1994.)

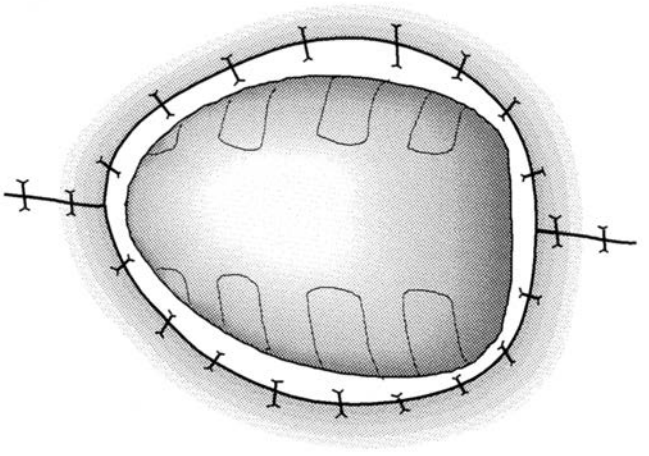


Figure 26-21. The dorsal tracheal membrane is apposed to the proximal skin edges with simple interrupted sutures. The tracheostoma is completed by apposing skin to mucosa with a simple continuous pattern. (Reprinted with permission from: Hedlund CS: Tracheostomies in the management of canine and feline upper respiratory disease. Veterinary Clinics of North America: Small Animal Practice 24: 873-886, 1994.)

Postoperative Care

Patients that have undergone permanent tracheostomy are monitored in the intensive care unit for 24 to 48 hours after surgery to observe for dyspnea and to care for the tracheostoma. Obstruction of the tracheostoma can result in death by asphyxiation. The stoma is inspected every 1 to 3 hours. The stoma is cleaned aseptically when mucus begins to occlude the tracheostoma or when respiratory effort increases. Mucus accumulating around the tracheostoma is carefully removed with moistened gauze sponges or cotton tipped applicators. Mucus accumulating in the tracheal lumen is removed with a moistened sterile cotton swab or suction tip. Cleaning must be performed carefully to avoid disrupting the suture line or irritating the tracheal mucosa. A water-impermeable ointment (petrolatum or boric acid ointment) or cyanoacrylate skin protectant is applied around the tracheostoma to discourage tracheal secretions from adhering and crusting. Low humidity during the first four to six days seems to reduce the amount of exudation and also promotes healing.

Initially, most animals secrete a moderate amount of mucus, with cleaning needed every 1 to 3 hours, but the interval gradually increases to every 4 to 6 hours by 7 days and twice daily by 30 days after surgery.[3,4] Patients are usually ready for discharge within 7 days of surgery; at this time, the stomas should be inspected every 4 to 6 hours and mucus removed as needed. Animals with severe tracheal irritation, secretory diseases, or those exposed to mucosal irritants (smoke, fragrances, dust, pollens, etc) may require more frequent cleaning. Most animals learn to expel mucus forcefully from their stoma in a self-cleaning manner. Hair is clipped from around the tracheostoma once or twice a month to prevent matting with mucus. Exercise and housing should be limited to clean areas free of smoke and unnecessary fragrances. Swimming is prohibited, and the stoma should be protected when sprays are used near the pet.

Owners are usually satisfied with their pet's response after permanent tracheostomy.[3,4] Most pets have improved breathing, less noisy breathing, and increased activity. Approximately 60% of dogs and cats with permanent tracheostomy (without laryngectomy) lose their ability to vocalize normally.

Complications of permanent tracheostomy include stomal occlusion by skinfolds or mucus, dehiscence, and stenosis.[3,4,6-7] Skinfold occlusion is the most common long-term complication. It may be intermittent, related to the animal's posture or continuous. Skinfold problems can be minimized by carefully assessing and excising larger amounts of skin from animals with loose skin folds during initial permanent tracheostomy surgery. Adhesions created by skin-peritracheal sutures are important in preventing skin fold problems. When skinfolds do interfere with tracheostomal airflow, skin lateral and dorsal to the stoma is excised without disturbing the mucosa-to-skin junction. Obstruction of the stoma by mucus is prevented by diligent patient observation and management. Dehiscence occurs if there is tension or irritation at the mucosa-to-skin junction.[4,6] It is prevented by using good surgical and management techniques. Dehiscence leads to a greater degree of stomal stenosis. Some stenosis occurs at all tracheostomal sites but it may progress to nearly complete stomal obstruction with dehiscence or trauma. If dyspnea recurs secondary to stenosis, it may be necessary to revise the tracheostoma surgically. Revision is best accomplished by making a skin incision from each corner of the stoma, removing an appropriate segment of skin and advancing the skin flap laterally.to evert the mucocuteanous junction thus widening the stoma (Figure 26-22).

Mortality associated with kinking of the trachea is likely (57%) to occur if the tracheostoma is created below the twelfth cartilage.[6] Defense mechanisms in the bronchi, bronchioles, and lungs are adequate in most cases to prevent pulmonary infections in animals with permanent tracheostomies. Permanent tracheostomy does not affect breathing pattern or reflexes.[7]

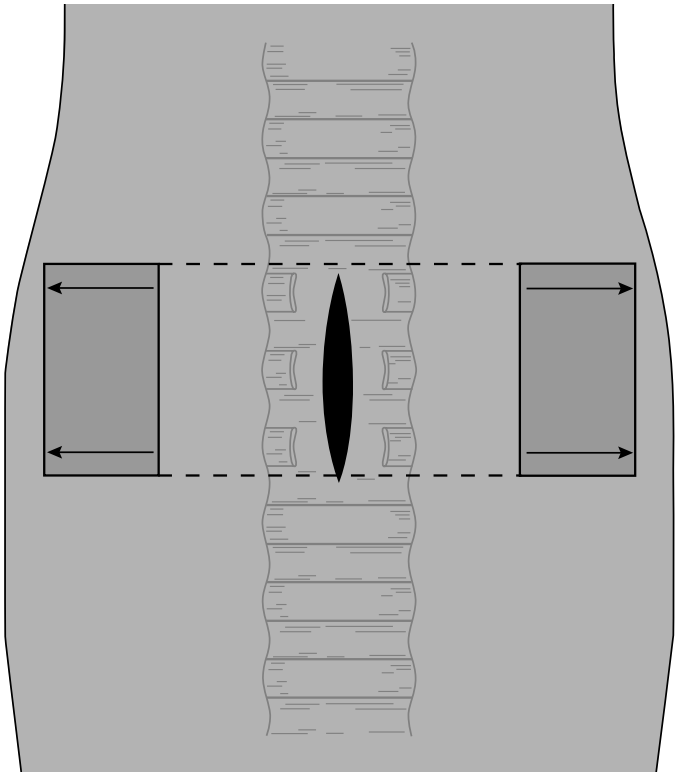


Figure 26-22. Revision of a stenosed stoma is accomplished by minimally interrupting the mucocutaneous junction. First make a skin incision extending laterally from each corner of the stoma. Then resect an appropriate segment of skin connecting the incisions on each side. Finally, apply traction to the skin flaps to evert the mucocutaneous junction and appose the incised skin edges.

References

1. Hedlund CS, Tangner CH, Montgomery DL, et al: A procedure for permanent tracheostomy and its effects on tracheal mucosa. *Vet Surg* 11:13, 1982.

2. Dalgard DW, Marshall PM, Fitzgerald GH, et al: Surgical technique for permanent tracheostomy in Beagle dogs. *Lab Anim Sci* 29: 367, 1979.

3. Hedlund CS: Tracheostomies in the management of canine and feline upper respiratory disease. *Vet Clin North Am Small Anim Pract* 24:873, 1994.

4. Hedlund CS, Tangner CH, Waldron DR, et al: Permanent tracheostomy: Perioperative and long-term data from 34 cases. *J Am Anim Hosp Assoc* 24:585, 1988.

5. Block G, Clarke K, Salisbury SK, et al: Total laryngectomy and permanent tracheostomy for treatment of laryngeal rhabdomyosarcoma in a dog. *J Am Anim Hosp Assoc* 31:510-513, 1995.

6. Dahm JD, Paniello C: Tracheostomy for long-term laryngeal experimentation. *Otolaryngol Head Neck Surg* 118:376-380, 1998.

7. Mutoh T, Kanamaru A, Suzuki H, et al: Effects of permanent tracheostomy on respiratory reflexes to lung inflation and casaicin in sevoflurane anaesthetized dogs. *J Vet Med A* 46:335-343, 1999.

Chapter 27

Lung and Thoracic Cavity

Thoracic Approaches

Dianne Dunning

Introduction

Intercostal thoracotomy and median sternotomy are the most commonly used thoracic approaches in small animals. The choice of a thoracic approach depends upon the type of access to the thoracic cavity that is needed. Intercostal thoracotomy is easy to perform and does not require special surgical instrumentation, but it permits only limited access within the thoracic cavity. Median sternotomy allows wide access to the thoracic cavity, except for the structures in the dorsal mediastinum such as the esophagus and bronchial hilus. However, median sternotomy requires access to an oscillating saw or sternal splitter. Nevertheless, median sternotomy is the thoracic approach that allows the most complete exploration of the thoracic cavity.

Surgical Technique

Intercostal Thoracotomy

Intercostal thoracotomy is chosen to provide access to a defined area of interest within one hemisphere of the thoracic cavity. Approximately one-third of one hemisphere of the thoracic cavity and its associated mediastinal structures are visible with this approach. The intercostal space chosen depends on the thoracic structures of interest (Table 27-1). In general, the cardiac structures are approached best through the fourth or fifth intercostal space. The cranial lung lobes are accessed through the fourth or fifth intercostal space, whereas the caudal lung lobes are best accessed through the fifth or sixth intercostal space. The right middle lung lobe is accessed through the right fifth intercostal space. The cranial esophagus can be accessed from either the third or the fourth intercostal space on the right or left side. The caudal esophagus is accessed on either the right or left side between the seventh and eighth intercostal space. The thoracic duct in the dog is best accessed between the eighth and tenth spaces. These are general guidelines only, as thoracic radiographs or CT should be reviewed prior to any surgical procedure to identify the most appropriate intercostal space for entry to the thoracic cavity. In addition, up to three ribs may be partially excised to improve access to the thoracic hemisphere without destabilizing the thoracic wall and compromising chest wall excursion.

To perform an intercostal thoracotomy, the patient is placed in lateral recumbency with a rolled pad placed under the thorax. An incision is made with a scalpel through the skin, subcutaneous tissues, and cutaneous trunci muscle. The latissimus dorsi and pectoralis muscles are incised parallel to the skin incision. The fifth rib is easily identified as the caudal insertion of the scalenus muscle and the cranial origin of the external abdominal oblique muscle (Figure 27-1). Depending on the intercostal space entered, either the scalenus or the external abdominal oblique muscle is incised. The serratus ventralis muscle is separated to expose the

desired intercostal space (Figure 27-2). The intercostal muscles are incised midway between the ribs to avoid lacerating the intercostal vessels, coursing on the caudal aspect of each rib (Figure 27-3). The pleura is punctured, and the incision is extended with scissors dorsally to the tubercle of the rib and ventrally past the costochondral arch to the internal thoracic vessels. A Finochietto retractor is used to expose the thoracic structures and a thoracic exploratory is performed prior to any surgical intervention.

Prior to closure of the thoracotomy, a thoracostomy tube is placed through the caudodorsal thoracic wall (Figure 27-4). The thoracostomy tube should remain open to the atmosphere during closure of the thoracotomy site to prevent inadvertent tension pneumothorax. Once the soft tissues are apposed and the closure is airtight, the pleural space is evacuated, and the thoracostomy tube is closed. Before thoracotomy closure, a local selective intercostal nerve block of the adjacent intercostal spaces is performed with 0.75% bupivacaine to decrease postoperative pain and to improve ventilation.

The thoracotomy is closed by preplacing five to eight heavy-gauge sutures around the adjacent ribs. The preplaced circumcostal sutures are used by an assistant to approximate the ribs while the surgeon ties each suture (Figure 27-5A,B). Transcostal sutures that are placed through holes drilled in adjacent ribs has

Table 27-1. General Recommendations for Intercostal Thoracic Approaches

Anatomic Structure	Intercostal Space
Heart	
Patent Ductus Arteriosus	Left 4th or 5th
Persistent Right Aortic Arch	Right 4th
Pulmonic Valve	Right 4th
Pericardium (pericardectomy)	Left or Right 5th
Thoracic Duct	
Dog	Right 8th, 9th, or 10th
Cat	Left 8th, 9th, or 10th
Lung Lobes	
Left Cranial	Left 4th, 5th, or 6th
Left Caudal	Left 5th or 6th
Right Cranial	Right 4th, 5th, or 6th
Right Middle	Right 5th
Right Caudal	Right 5th or 6th
Esophagus	
Cranial	Left 3rd or 4th
Heartbase	Right 5th
Caudal	Left or Right 7th, 8th, or 9th
Vena cava	
Cranial	Right 4th
Caudal	Right 6th, 7th, or 8th

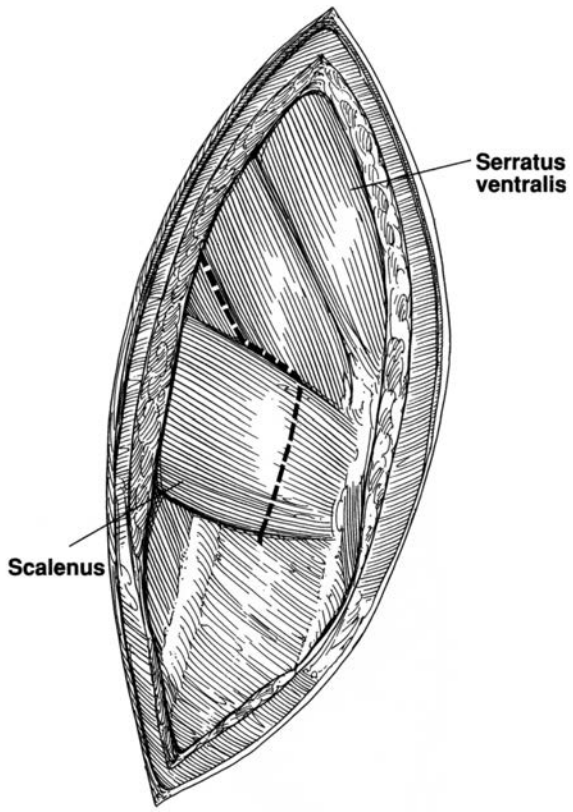


Figure 27-1. Intercostal thoracotomy. Incision of the latissimus dorsi muscle. The fifth rib is identified by the caudal insertion of the scalenus muscle and the cranial origin of the external abdominal oblique muscle. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:57.)

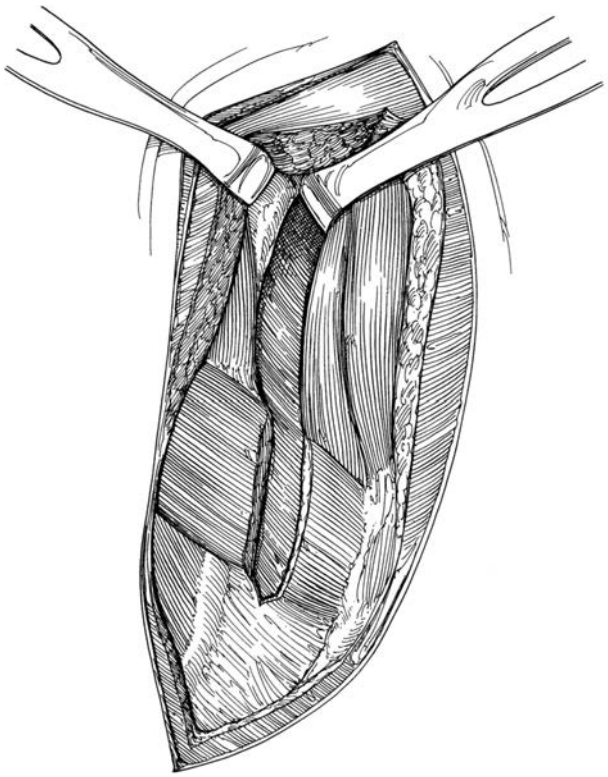


Figure 27-2. Intercostal thoracotomy. Incision of the scalenus muscle and the serratus ventralis muscle. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:57.)

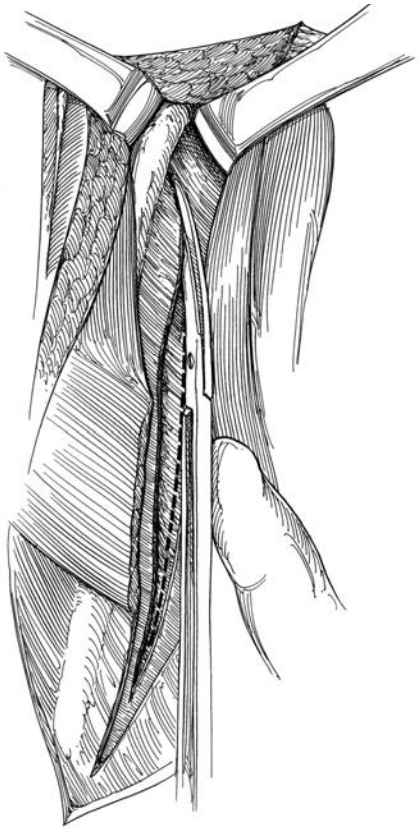


Figure 27-3. Intercostal thoracotomy. Incision of the intercostal muscles midway between the ribs to avoid damaging the intercostal vessels. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:58.)

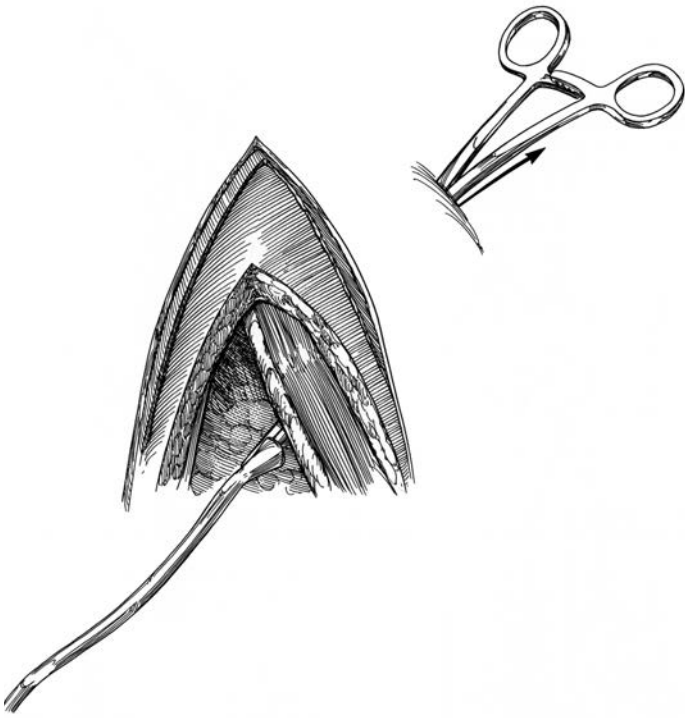


Figure 27-4. Intercostal thoracotomy. Placement of a thoracostomy tube in the caudodorsal thorax before closure. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:60.)

been suggested as a less painful method of closure. The serratus ventralis or external abdominal oblique and scalenus muscles are closed in a single layer with a simple continuous suture pattern. The latissimus dorsi muscle, cutaneus trunci muscle, subcutaneous tissues, and skin are closed in separate layers with a simple continuous suture pattern (Figure 27-6).

Median Sternotomy

Median sternotomy is indicated when exploratory surgery of the thoracic cavity is necessary. Median sternotomy should not be avoided because of a belief that it is associated with higher postoperative pain and complication rates than intercostal thoracotomy. Complication rates associated with median sternotomy are no higher than those associated with thoracotomy.

Median sternotomy is performed with the animal in dorsal recumbency. The skin and subcutaneous tissues are incised with a scalpel over the midline on the sternum (Figure 27-7). The pectoral musculature is incised and is elevated from the sternebrae with electrocautery. The sternum is then cut on its midline with an oscillating saw or sternal splitter (Figure 27-8). Care is taken to limit the penetration of the saw or osteotome to avoid injury to internal thoracic structures. Either the manubrium or the xiphoid is left intact to achieve a stable closure of the sternum. Finochietto retractors are used to expose thoracic structures. A caudal median sternotomy can be combined with a ventral midline celiotomy to gain further exposure of caudal thoracic and cranial abdominal structures (Figure 27-9). A partial incision of the diaphragm can be made to facilitate wider retraction. A midline cervical incision can be combined with a sternotomy through the manubrium to expose the structures of the thoracic inlet.

Before closure, a thoracostomy tube is placed subcostally and lateral to the midline (Figure 27-10). The sternotomy is closed with alternating figure-of-eight 20 to 22gauge orthopedic wires (Figure 27-11). The pectoralis muscles, subcutaneous tissues, and skin are closed in separate layers with a simple continuous suture pattern.

Postoperative Care

Hypoventilation, hypoxemia, hypothermia, acid-base imbalance, hypotension, pain and hemorrhage are among the problems that may arise in the first 12 to 24 hours after thoracotomy. Median sternotomy and intercostal thoracotomy are both associated with alterations in normal pulmonary function that may be attributed to several factors including pain. These changes may inhibit deep inspiration and may promote small airway collapse, resulting in ventilation-perfusion mismatch. Measurement of arterial blood gases after surgery provides information about ventilation and pulmonary gas exchange. Additional postoperative monitoring should include frequent assessment of drainage from the thoracic cavity, temperature, pulse rate, respiratory rate, and mucous membrane color.

Analgesia is indicated in all animals after thoracotomy. Parenteral opioids, epidural morphine, intrapleural anesthetics, and selective intercostal nerve blocks using 0.75% bupivacaine may be used alone or in combination to provide postoperative analgesia (Table 27-2).

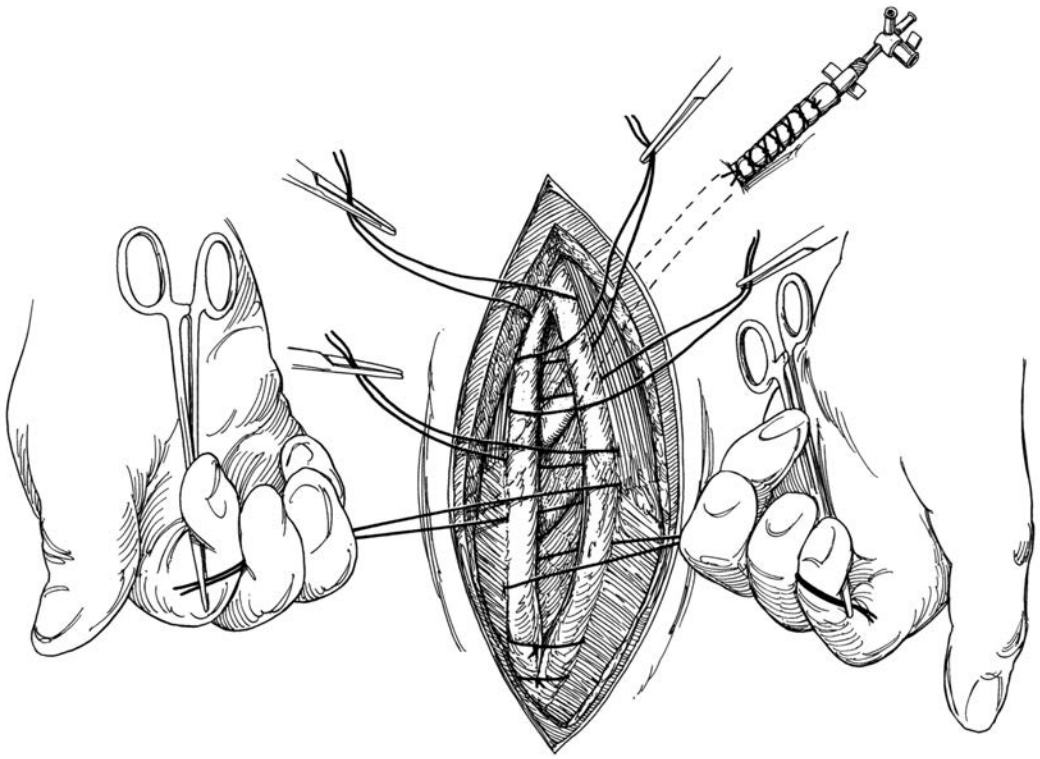


Figure 27-5A. Intercostal thoracotomy closure. Approximation of the ribs by an assistant using the preplaced circumcostal sutures while the surgeon ties each suture. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:60.)

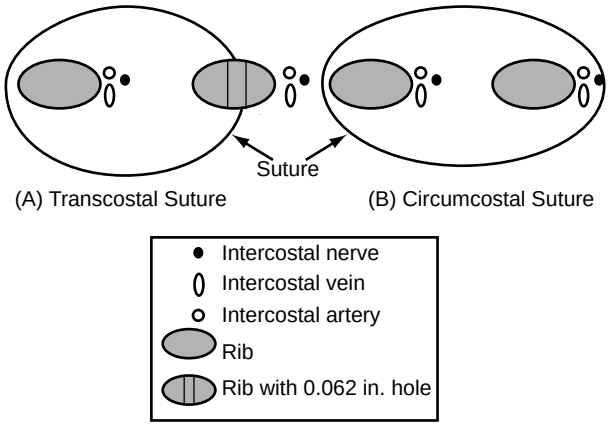


Figure 27-5B. Schematic of transcostal suture placement. A 0.062 Steiman pin is used to drill the holes in the 5th rib. The suture is passed around the cranial aspect of the cranial rib and through the caudal rib and tied securely, thus avoiding the neurovascular bundle. (From Rooney MB, Mehl M, Monnet E. Intercostal thoracotomy closure: transcostal sutures as a less painful alternative to circumcostal suture placement. Vet Surg 2004;33:209-213.)

Suggested Readings

Burton CA, White RN. Review of the technique and complications of median sternotomy in the dog and cat. J Small Anim Pract 1996;37:516-522.

Pelsue DH, Monnet E, Gaynor JS, et al. Closure of median sternotomy in dogs: suture versus wire. J Am Anim Hosp Assoc 2002;38:569-576.

Rooney MB, Mehl M, Monnet E. Intercostal thoracotomy closure: transcostal sutures as a less painful alternative to circumcostal suture placement. Vet Surg 2004;33:209-213.

Berg RJ, Orton EC. Pulmonary function in dogs after intercostal thoracotomy: comparison of morphine, oxymorphone, and selective intercostal nerve block. Am J Vet Res 1986;47:471-474.

Conzemius MG, Brockman DJ, King LG, et al. Analgesia in dogs after intercostal thoracotomy: a clinical trial comparing intravenous buprenorphine and interpleural bupivacaine. Vet Surg 1994;23:291-298.

Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:33-40, 55-72.

Pascoe PJ, Dyson DH. Analgesia after lateral thoracotomy in dogs: epidural morphine vs. intercostal bupivacaine. Vet Surg 1993;22:141-147.

Stobie D, Caywood DD, Rozanski EA, et al. Evaluation of pulmonary function and analgesia in dogs after intercostal thoracotomy and use of morphine administered intramuscularly or intrapleurally and bupivacaine administered intrapleurally. Am J Vet Res 1995;56:1098-1109.

Thompson SE, Johnson JM. Analgesia in dogs after intercostal thoracotomy: a comparison of morphine, selective intercostal nerve block, and interpleural regional analgesia with bupivacaine. Vet Surg 1991;20:73-77.

Walsh PJ, Remedios AM, Ferguson JF, et al. Thoracoscopic versus open partial pericardectomy in dogs: comparison of postoperative pain and morbidity. Vet Surg 1999;28:472-479.

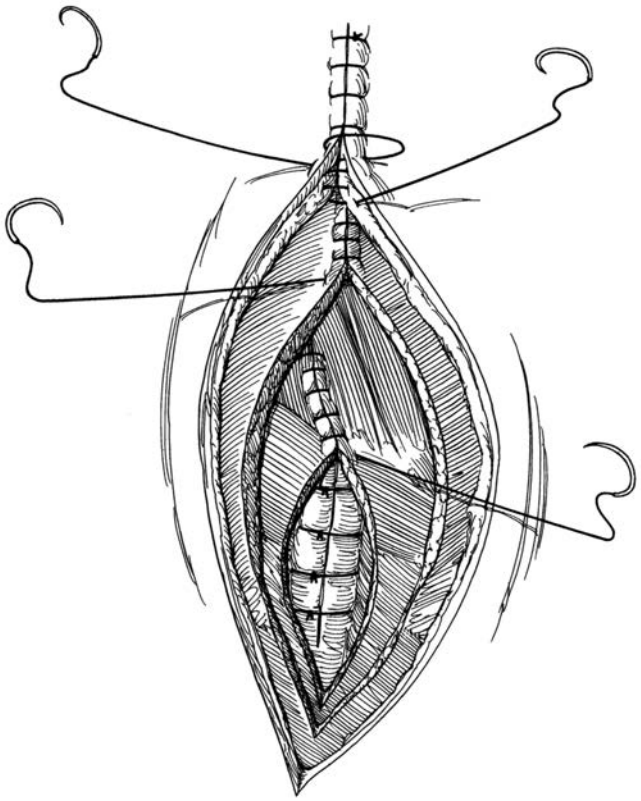


Figure 27-6. Intercostal thoracotomy closure. Closure of the muscle and skin in separate layers with a simple continuous suture pattern. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:62.)

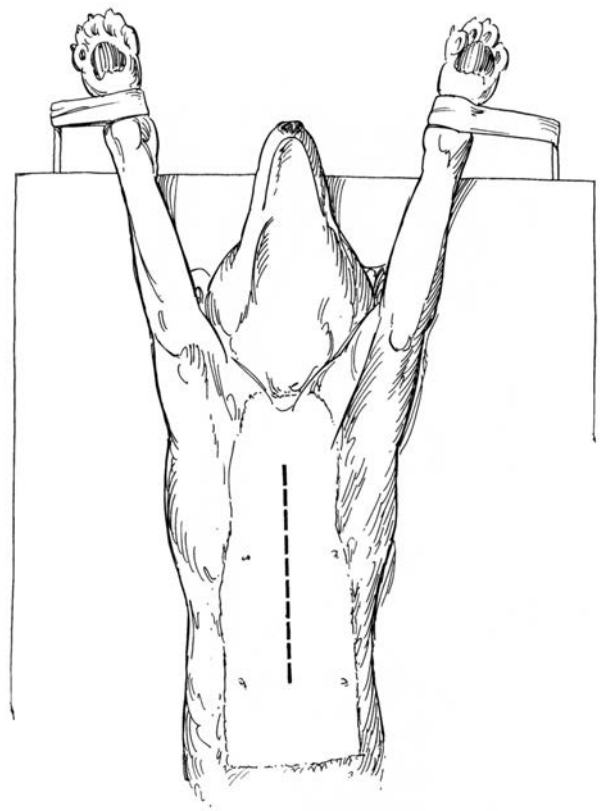


Figure 27-7. Median sternotomy. Median sternotomy is performed with the animal in dorsal recumbency. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:65.)

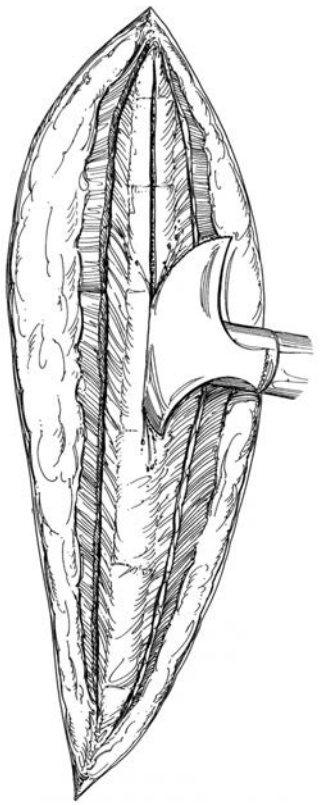


Figure 27-8. Median sternotomy. The sternum is cut on midline with an oscillating saw. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:66.)

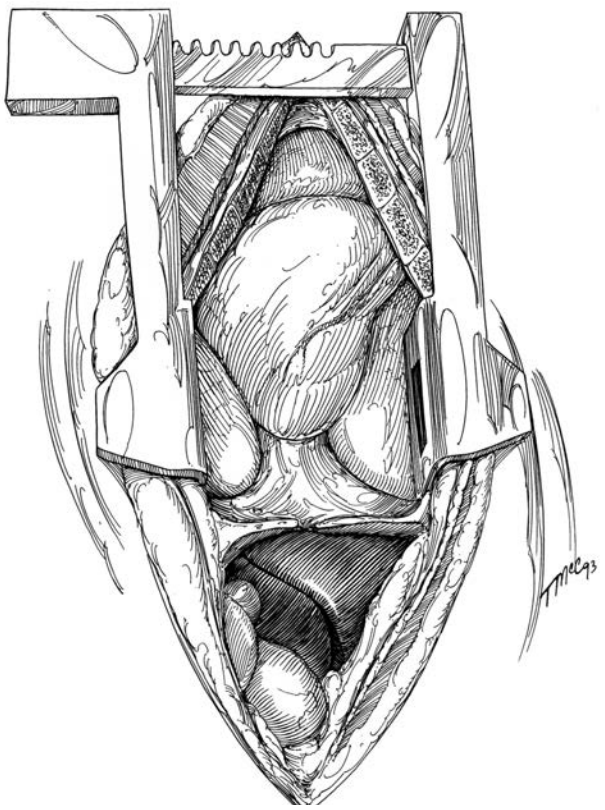


Figure 27-9. Median sternotomy. A caudal median sternotomy combined with a ventral midline celiotomy to gain exposure to the caudal thoracic and cranial abdominal organs. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:67.)



Figure 27-10. Median sternotomy. Placement of a thoracostomy tube paramedially and subcostally before closure. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:69.)

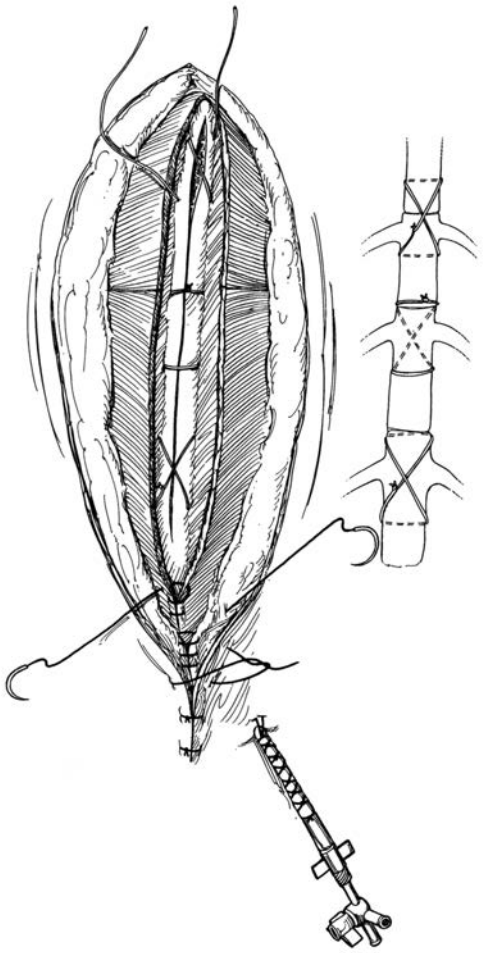


Figure 27-11. Median sternotomy closure. Stable closure of the sternotomy is achieved by preplaced alternating figure-of-eight orthopedic wire around each sternebra. The muscle, subcutaneous tissues, and skin are closed in separate layers in a simple continuous suture pattern. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:67.)

Table 27-2. Commonly Used Drugs for Postoperative Calming and Alleviation of Postoperative Pain.

Key Drug	Route	Dose Range (dog) (mg/kg)	Frequency (hr)
Morphine	IV	0.5-1.0	Q 1-2
Morphine	IM, SQ	0.2-2.0	Q 2-6
Morphine	IV	0.3-0.5 IV loading dose followed by 0.10.3	CRI
Fentanyl	IV	0.002-0.003 IV loading dose followed by 0.001-0.005	CRI
Hydromorphone	IV, SQ, IM	0.05-0.2	Q 4-6
Oxymorphone	IV	0.02-0.1	q 1-2
Oxymorphone	IM, SQ	0.05-0.2	q 2-4
Carprofen	SQ PO	4.4 followed by 2.4/4.4	Pre-emptive injectable BID/qd
Deracoxib	PO	3-4	qd for 7 days
Ketoprofen	IV, SC, IM	2.0	One time dose
Meloxicam	IV, SQ	0.2	qd
Tepoxalin	PO	10	qd

Pulmonary Surgical Techniques

Dianne Dunning

Partial and complete lung lobectomies are occasionally indicated in small animal practice. Although the surgical techniques are not difficult, they require a familiarity with thoracic anatomy and pulmonary physiology, as well as a support staff to monitor the animal both during and after surgery to ensure a successful outcome.

Surgical Anatomy

The trachea of dogs and cats divides into two principal bronchi, which in turn subdivide into lobar bronchi that supply each lung lobe (Figure 27-12). The left and right lungs are separated by a thin but complete mediastinum. The left lung is divided into cranial and caudal lobes by a deep fissure. The left cranial lung lobe is further divided by an incomplete fissure into cranial and caudal parts, but they share a common lobar bronchus. The right lung is divided into cranial, middle, caudal, and accessory lobes. The accessory lobe passes dorsal to the caudal vena cava and lies medial to the plica vena cava, a fold of pleura that extends around the caudal vena cava. These structures should be identified during manipulation of the right caudal and accessory lung lobes. The pulmonary vessels closely follow the lobar distribution of the bronchi. Pulmonary arteries are located on the craniodorsal aspect of each bronchi, whereas pulmonary veins are located on the caudoventral aspect. Partial or complete lung lobectomy may be performed through a standard intercostal thoracotomy in the fourth through sixth intercostal space or through a median sternotomy.

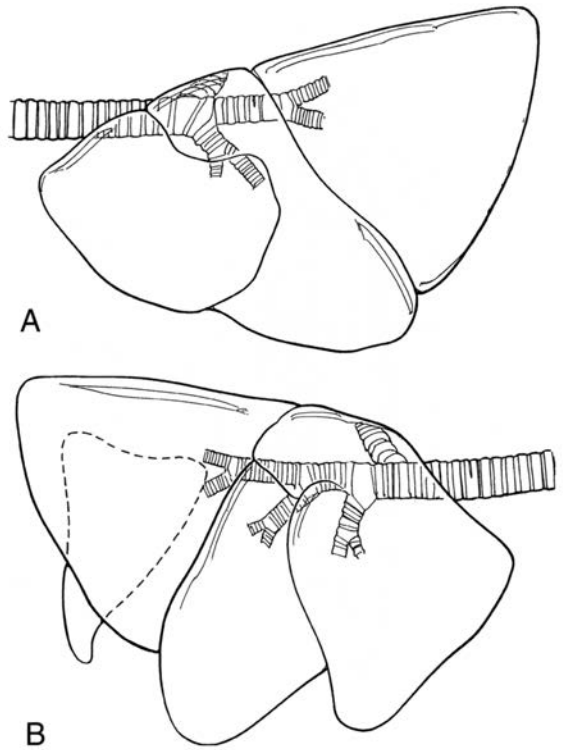


Figure 27-12. Lung lobe anatomy. **A.** Left. **B.** Right. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:162.)

Surgical Techniques

Partial Lung Lobectomy

Partial lung lobectomy is used to obtain a biopsy or excise localized marginal lesions of the distal two thirds of the lung. Partial lung lobectomy may be performed by freehand suturing or with a stapling device. To perform a partial lobectomy by hand, the lung is clamped with noncrushing vascular or intestinal clamps proximal to the isolated lesion (Figure 27-13). The lung is excised distal to the clamps. A continuous horizontal mattress pattern of 4-0 monofilament suture is placed proximal to the clamps (Figure 27-14). Delicate swaged-on taper-point needles should be used. Smooth fluid movements that follow the curvature of the needle should be used when driving the needle through the tissue to minimize air leaks at the suture line. The ends of the suture are tied and "tagged" with hemostatic forceps to facilitate manipulation of the lung. The clamps are removed, and the lung incision is oversewn in a simple continuous pattern (Figure 27-15). The incision is then checked for air leaks by submerging the lung in saline during positive-pressure ventilation of 20 to 30 cm of H_2O. Additional sutures may be placed as necessary. Some leakage of air after this technique may be expected, but this usually resolves within a few hours after surgery.

Stapling devices are now commonly available to veterinary surgeons. The advantages of stapling equipment for partial lobectomy are shortened surgical and anesthetic time, decreased blood loss, and reduction of the incidence of bronchopleural fistulas after lung lobe resection. The most useful device for pulmonary procedures is the thoracoabdominal (TA) stapler. This instrument places two staggered rows of stainless steel staples that form a B shape when compressed. The 3.5 mm (blue)

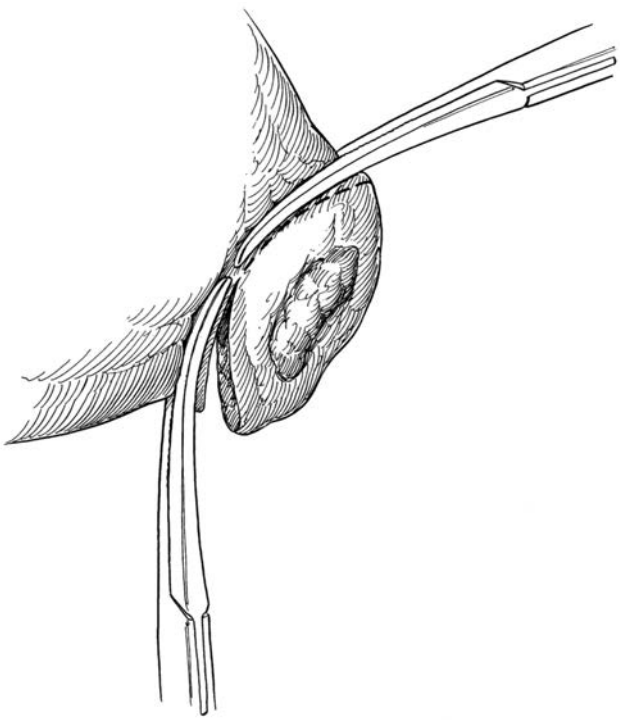


Figure 27-13. Partial lung lobectomy. The lung is clamped proximal to the isolated lesion. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:165.)

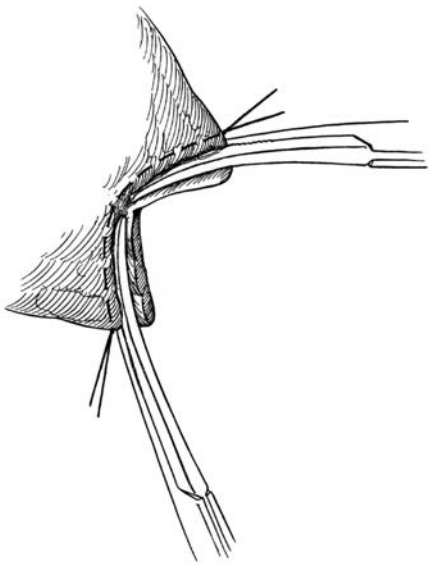


Figure 27-14. Partial lung lobectomy. A continuous horizontal mattress pattern is placed proximal to the clamps. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:165.)



Figure 27-15. Partial lung lobectomy. The clamps are removed, and the incision is oversewn with a simple continuous pattern. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:165.)

or the 2.5 mm (white, V or V3) staple cartridges may be used for pulmonary procedures. A gastrointestinal anastomosis stapler also may be used for longer staple lines. The stapler is placed across the lung and is clamped proximal to the lesion (Figure 27-16). The staple device is fired and the lung is transected utilizing the edge of the TA stapling device as a cutting edge. After the removal of the stapling device, the lung is checked for air leaks in the manner described previously.

Complete Lung Lobectomy

Excision of an entire lung lobe is indicated for severe trauma, neoplasia, lobe torsion, abscesses, or refractory infections. The affected lung lobes should be manipulated gently to minimize

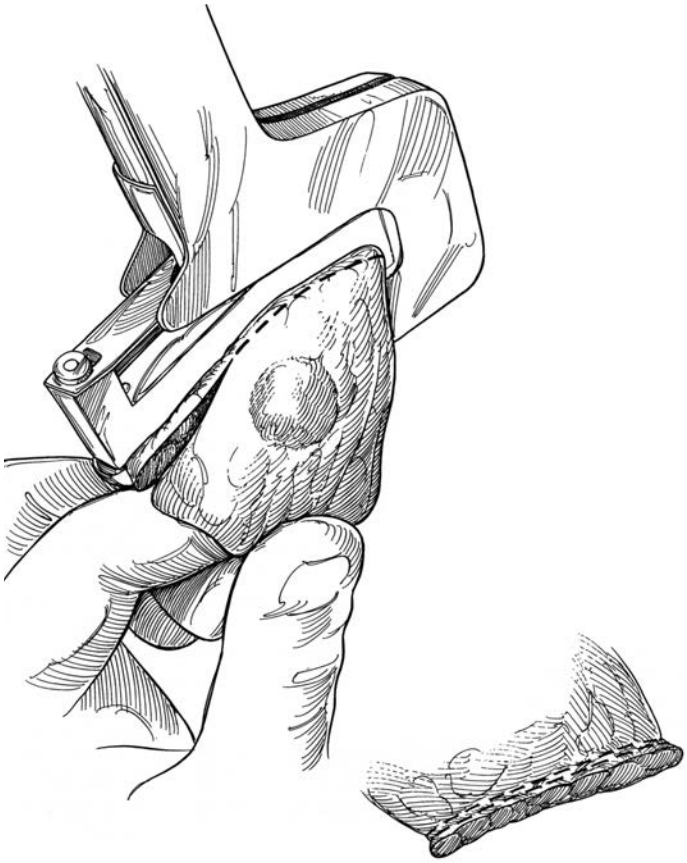


Figure 27-16. Partial lung lobectomy with staples. The stapler is placed across the lung and is clamped proximal to the lesion. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:166.)

embolization of neoplastic cells or extrusion of purulent material into adjacent airways. Dogs and cats can survive removal of up to 50% of lung lobe mass. Removal of more than 75% of the lung is invariably fatal. Because the right lung constitutes more than 50% of the lung capacity, removal of the entire right lung is contraindicated. Excision of the entire left lung is tolerated in the dog, assuming the right lung is normal.

Lung lobectomy should follow the anatomic distribution of the bronchi. The left cranial and caudal lung lobes may be removed individually. The cranial, middle, and caudal right lobes may be removed individually because they each have separate bronchi. The accessory lung lobe usually is removed with the left caudal lung lobe. Before removal of the caudal and accessory lobes, the pulmonary ligaments must be divided from the mediastinum with Metzenbaum scissors.

The pulmonary artery is accessed first by ventral and caudal retraction of the lung lobe. The lobe may be grasped gently with a dry gauze sponge. The artery is isolated by blunt dissection with right-angle forceps parallel to the long axis of the vessel (Figure 27-17). The artery is triple ligated and is divided between the middle and distal ligature. The pulmonary vein is accessed by dorsal and cranial retraction of the lung lobe. The vein is isolated, ligated, and divided in a similar manner to the artery. The lobar bronchus is then clamped with a noncrushing tangential clamp and is divided 3 mm distal to the clamp. The bronchial stump is

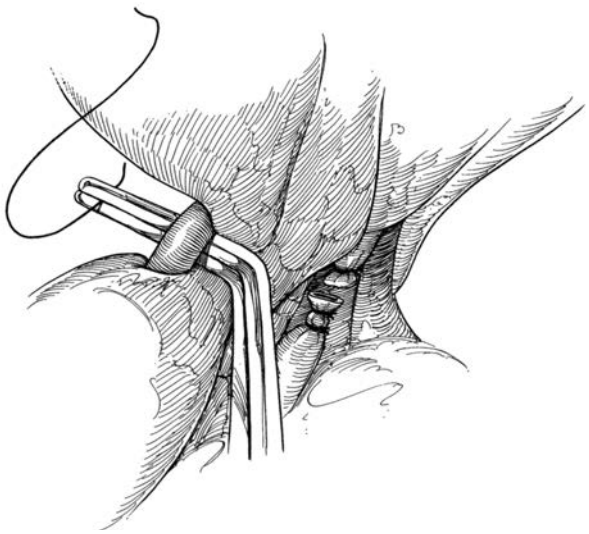


Figure 27-17. Complete lung lobectomy. Dissection of the ligatures around the pulmonary vessels is accomplished with right-angle forceps parallel to the long axis of the vessel. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:164.)

closed with 4-0 suture in a continuous mattress pattern (Figure 27-18). The tangential clamp is removed, and the bronchial stump is oversewn with a continuous pattern (Figure 27-19). The bronchus is then checked for air leaks by saline immersion.

En bloc stapling of the hilus may be used to remove large lung lobe abscesses or tumors when minimal handling of the affected lung is desired. When using 2.5-mm staples (TA 30 V or V3, white), it is rarely necessary to separately ligate and divide the pulmonary vessels. Dissection of the lung lobe from the mediastinum is performed if needed to exteriorize the lobe. The stapler is placed across the hilus of the lobe and is clamped. A clamp is placed distal to the TA stapler across the lobe to prevent spillage of material from the lobe. The staple device is fired, and the lobe is transected, using the edge of the TA stapling device as a cutting edge. After the removal of the stapling device, the hilus is inspected for leaks in the same manner as described previously.

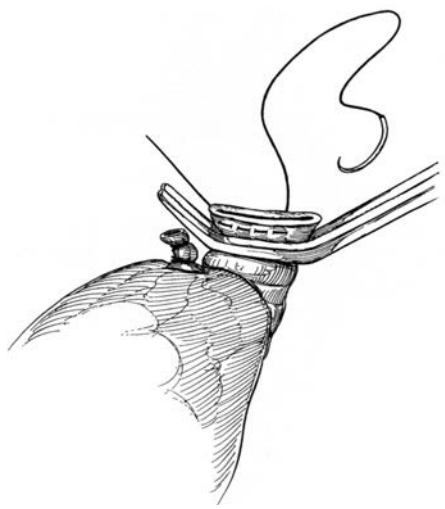


Figure 27-18. Complete lung lobectomy. The lobar bronchus is clamped and divided, and the bronchial stump is closed in a continuous mattress pattern. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:164.)

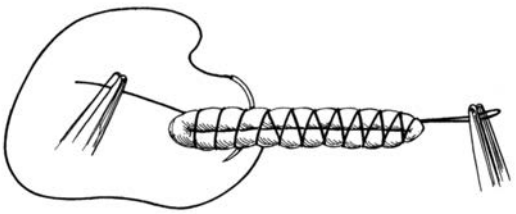


Figure 27-19. Complete lung lobectomy. The bronchial stump is oversewn with a continuous pattern. (From Orton EC. Small animal thoracic surgery. Baltimore: Williams & Wilkins, 1995:164.)

Postoperative Care

Placement of a thoracostomy tube is always recommended before closure of the thoracotomy. If the thoracostomy tube is nonproductive, it may be removed soon after the surgical procedure (see the earlier section of this chapter on thoracic approaches). Animals should be monitored frequently for pneumothorax or hemorrhage after pulmonary surgery. Pneumothorax usually resolves spontaneously after pulmonary surgery. High-volume air leaks can be managed by continuous suction until they resolve.

Suggested Readings

Garcia F, Prandi D, Pena T, et al. Examination of the thoracic cavity and lung lobectomy by means of thoracoscopy in dogs. Can Vet J 1998;39:285-291.

Lansdowne JL, Monnet E, Twedt DC, et al. Thoracoscopic lung lobectomy for treatment of lung tumors in dogs. Vet Surg 2005;34:530-535.

Lipscomb VJ, Hardie RJ, Dubielzig RR. Spontaneous pneumothorax caused by pulmonary blebs and bullae in 12 dogs. J Am Anim Hosp Assoc 2003;39:435-445.

McNiel EA, Ogilvie GK, Powers BE, et al. Evaluation of prognostic factors for dogs with primary lung tumors: 67 cases (1985-1992). J Am Vet Med Assoc 1997;211:1422-1427.

Murphy ST, Ellison GW, McKiernan BC, et al. Pulmonary lobectomy in the management of pneumonia in dogs: 59 cases (1972-1994). J Am Vet Med Assoc 1997;210:235-239.

Orton EC. Small animal thoracic surgery Baltimore: Williams & Wilkins, 1995:161-167. Walshaw R. Stapling techniques in pulmonary surgery. Vet Clin North Am Small Anim Pract 1994;24:335-366.

Thoracic Drainage

Dennis T. Crowe and Jennifer J. Devey

The ability to recognize and manage the dog or cat with various types of fluid (blood, chylous effusion, suppurative effusion, transudate) or air accumulation in the pleural cavity is vital. Although small accumulations of fluid or air in the pleural space may be easily tolerated and hence go undetected, larger amounts prevent normal lung expansion during the inspiratory phase of the ventilatory cycle and can cause a significant increase in ventilatory effort. If significant air or fluid accumulations are present, the animal may display signs of respiratory distress, orthopnea, polypnea, and poor tolerance for exercise or stress. Immediate thoracentesis of fluid or air can be accomplished with a minimal stress to the patient and may provide enough drainage to be lifesaving. Although mild conditions may

require treatment only by thoracentesis, more severe conditions require the placement of a chest tube (tube thoracostomy) and either intermittent or continuous pleural evacuation. If suppurative or infected fluids are retained in the pleural space, the patient is at an increased risk of systemic infection or sepsis. Retention of chylous effusions can lead to fibrosing pleuritis and atelectasis. This discussion reviews the common methods of pleural drainage used in small animal practice.

Needle Thoracentesis

Procedure

If the patient has any evidence of respiratory distress, oxygen should be provided immediately. This can be administered by flow-by oxygen at high flow rates (10 to 15 L/minute), oxygen mask, human nasal cannulas, nasal oxygen tubes, or oxygen hoods. Oxygen cages are not recommended because of the inability to monitor and treat the patient (See Chapter 6).

Before performing needle thoracentesis in the conscious and aware patient, a local anesthetic block is recommended. Using a 22- to 25-gauge needle 1% lidocaine is infiltrated into all layers from the skin down to and including the pleura, with a small amount of anesthetic deposited into the pleural space. The lidocaine should be buffered with sodium bicarbonate. A suggested ratio is two-thirds 1% lidocaine to one-third sodium bicarbonate. Systemic analgesia is not generally required for needle thoracentesis; however, when the patient is in pain, parenteral analgesics may also be used.

Emergency and diagnostic needle thoracentesis can be performed with various needles and catheters, including an 18- to 20-gauge hypodermic needle, a short plastic intravenous catheter, or a bovine teat cannula (Figure 27-20). In extremely small patients, an 18- to 20-gauge butterfly catheter can also be used. A three-way stopcock and a 35- or 60-mL syringe are attached to the needle either directly or by a 20-inch section of intravenous extension tubing. The intravenous tubing, three-way stopcock, syringe should be assembled and capped to maintain sterility and stored in a crash cart for emergencies. A second section of tubing, attached to the sidearm of the stopcock, is useful in directing aspirated fluids into a collection jar. This assembled apparatus can be operated by one person.

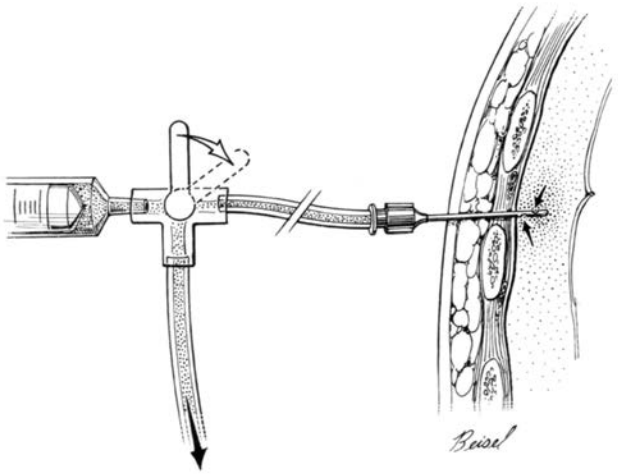


Figure 27-20. Apparatus for thoracentesis: an indwelling intravenous catheter or a bovine teat cannula, a three-way stopcock, a large syringe, and tubing from an intravenous administration set. Plastic catheters and blunt teat cannulas can remain perpendicular to the chest wall because of the low likelihood of causing lung injury. (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

Thoracentesis is usually performed at the seventh or eighth intercostal space (Figure 27-21). The animal should be allowed to rest in the position providing the least stress. Usually, this is standing, sitting, or in sternal recumbency. The lateral recumbent position is only acceptable if the patient is unconscious, intubated, and being ventilated. The dorsoventral location of the puncture site within the intercostal space is influenced by whether air or fluid is to be aspirated. If air is to be aspirated, the midthoracic region is preferred, with the animal in lateral recumbency. If the animal is standing or is in sternal recumbency, air is aspirated at the junction of the dorsal and middle thirds. Fluid is best removed from the middle third of the seventh intercostal space, when the animal is standing or is in sternal recumbency. More caudal placement of a needle may lead to penetration of the dome of the diaphragm and or liver injury.

Inadvertent injury to the lung parenchyma with the tip of the needle may lead to pneumothorax, particularly if the lung is lacerated in the process. This complication can be avoided by the use of the following technique: An 18- or 20-gauge needle is placed through the skin with the bevel facing caudally. A drop of saline is placed on the needle hub, and the needle is then slowly advanced into the pleural space (Figure 27-22A). Once the pleural space is entered, the negative pressure within the thorax causes the fluid in the hub to be pulled into the chest. In cases of tension pneumothorax, the pressure causes the fluid to be pushed out of the needle hub (Figure 27-22B). The surgeon must stop advancing the needle at this point, to avoid lung injury. The needle is then tilted in a caudal direction. At this time, the bevel of the needle should be directed parallel to the chest wall, with the opening directed away from the chest wall (Figure 27-22C).

Indications

Thoracentesis used as a diagnostic procedure can provide a fluid sample for laboratory evaluation. Thoracentesis is ideal for the initial treatment of acute pneumothorax and pleural effusions and as a method of intermittent drainage of the pleural cavity for treatment of slow accumulations of fluid or air. The surgical placement of a chest drainage tube (tube thoracostomy), however, is preferred for the removal of large volumes of fluid or continuing accumulation of air in the pleural space. Clinical experience has also suggested that it is impossible to drain the pleural space adequately with simple thoracenteses when accumulations of blood, chylous effusion, or pus are present.

Complications

Inadvertent trauma to the lung from overpenetration and movement of the needle leading to lung laceration is the most common complication. This is best prevented using the foregoing technique. The intercostal vessels can be lacerated during the

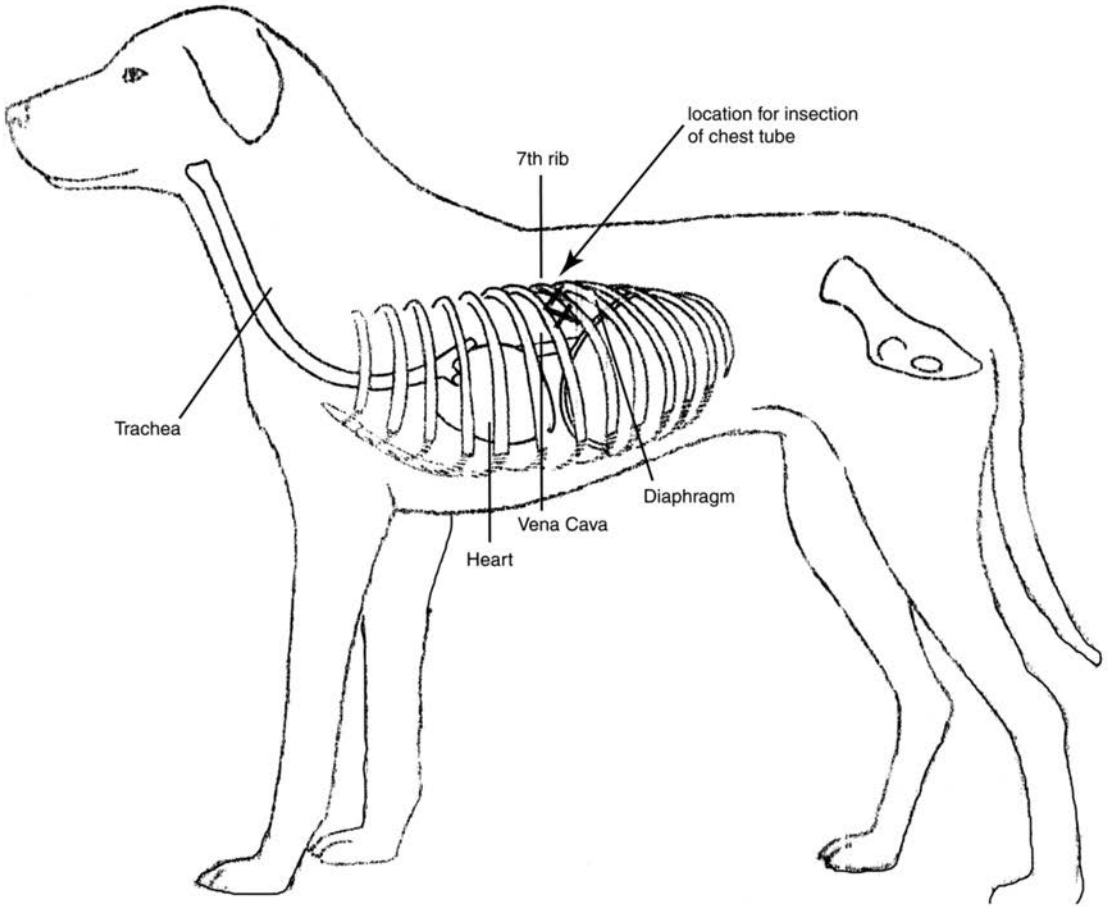


Figure 27-21. The seventh intercostal space is the ideal location for thoracentesis and chest tube insertion in most patients because of safety. Here at the junction of the dorsal third and ventral third of the space is the least danger of causing injury to vascular structures, the large airway, and the diaphragm.

procedure if the needle is introduced immediately adjacent to the ribs. A minor laceration is likely to be self-limiting; however, if an expanding hematoma is noted over the thoracentesis site, this area should be surgically explored and the vessel ligated or cauterized. Rarely, tangential laceration of an intercostal artery can cause serious hemothorax.

Minithoracostomy

Indications and Tube Selection

Various commercial thoracentesis and minithoracostomy tube kits are available (Argyle Turkel Safety Thoracentesis System, Sherwood Medical Products, St. Louis, MO; Pneumothorax Sets, Cook Critical Care, Bloomington, IN). These kits contain a medium-bore multiholed catheter (8 to 10 French) for pleural drainage. These catheters can be used for temporary drainage and may be valuable for short-term indwelling chest tubes for cats and small dogs.

Procedure

If a minithoracostomy tube is selected for insertion, the lateral chest wall at the level of the seventh to ninth intercostal spaces is aseptically prepared. A local anesthetic block using 1 to 2% lidocaine is placed. On rare occasions, the animal may require minor sedation or short-acting neuroleptanalgesia. If sedation or neuroleptanalgesia is required, it should be provided intravenously to effect, and ventilation should be monitored. A small skin incision (large enough to allow passage of the thoracostomy tube) is made. The needle and catheter system are slowly introduced into the pleural space, and suction is applied. If an indwelling system is required, the catheter assembly is advanced, the needle assembly is removed, and the tube is secured. Some systems (Argyle Turkel Safety Thoracentesis System, Sherwood Medical Products) have color indicators to detect when the pleural space has been entered. After placement, the catheter is fixed in place by suturing the tube to the fascia, and a bandage is applied. A radiograph is taken to assess tube location.

Complications

The short length of these minithoracostomy catheters may lead to dislodgment, particularly in larger dogs (A Mann, unpublished data). The catheter may also be too small to achieve adequate pleural drainage in big dogs or in those animals with rapid reaccumulations of fluid or air. Kinking can also be a problem with these catheters.

Tube Thoracostomy

Tube Selection

Tube thoracostomy involves the surgical placement of flexible sterile red rubber (Sovereign, Sherwood Medical Products), polyvinyl chloride (Argyle Straight Thoracic Catheter, Sherwood

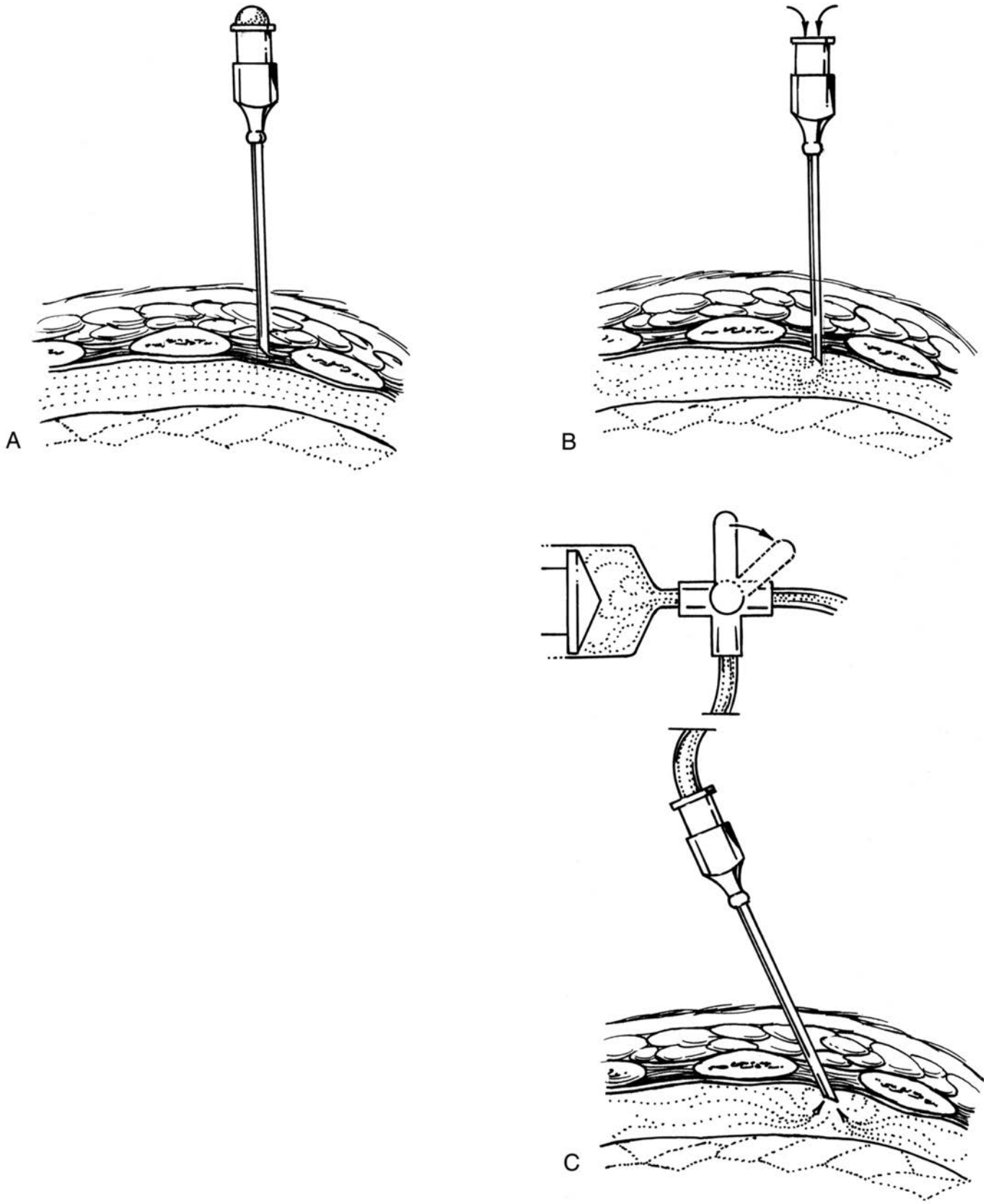


Figure 27-22. A-C. A hypodermic needle is used to evacuate air or fluid from the pleural space. A drop of saline added to the hub of the needle is used to indicate when the tip of the needle is in the pleural space. The drop of fluid is aspirated into the pleural space if the fluid is still under negative pressure. If it is under positive pressure, the fluid moves outward; if it moves outward under force, a tension pneumothorax is present. The needle is then angled to allow the bevel of the needle to face the open pleural space and is held there while aspiration is performed. (The syringe depicted in the drawing is too small for the job.)

Medical Products; Cook Critical Care), or silicone (Cook Critical Care) tube into the pleural space. Sterile endotracheal tubes can also be used if they are modified by knotting the cuff inflation mechanism, cutting the valve off, and removing the cuff. The tubing should be flexible, but not collapsible. The internal diameter of the tube should be at least one-half to two-thirds the width of one of the larger intercostal spaces (approximate diameter of a mainstem bronchus). This is important if tension pneumothorax is being treated and to help prevent occlusion by clots or viscous fluids.

The number and size of the holes placed in the catheter also influence the flow rate and effectiveness of the tube. Experimental flow studies on catheters indicate that, when three side holes are present, each additional hole increases the flow rate by only 6%. Most commercially available chest tubes contain an end hole and five or six side holes. If a noncommercial tube is used, side holes can be created using a pair of scissors or a No. 15 scalpel blade. The recommended size of the hole is approximately one-fourth the circumference of the tube. Diameters exceeding one-third the circumference of the tube cause considerable weakness and predispose the tube to kinking.

Commercially available chest tubes contain a marker strip throughout their length to allow radiographic confirmation of placement. The end of a chest tube should be placed on the ventral floor of the patient's thorax and cranial to or adjacent to the heart. In this location, both air and fluid can be drained efficiently from the pleural cavity where the tube is located. All holes must be located within the chest cavity. This placement can be verified radiographically with tubes that have a "sentinel eye," that is, an interruption in the radiopaque marker where the last hole is located. For best function, the tube should be placed no farther cranially than the level of the second rib; more cranial placement may obstruct the flow of air or fluid and may cause phrenic nerve irritation and dysfunction (Figure 27-23). In tubes where holes have been created, the last hole should be placed through the radiopaque marker for identification purposes. In some cases, because the mediastinum is intact, two chest tubes are required, one for each side of the pleural space.

Chest Tube Placement During Thoracotomy

To place a chest tube at the time of a thoracotomy, the tip of a curved hemostat is bluntly forced through intercostal muscle and parietal pleura at the seventh or eighth intercostal space or two spaces caudal to the thoracotomy incision. A subcutaneous tunnel is made in a caudal direction from the inside of the thorax to the outside for a distance of two to three intercostal spaces. A small skin incision is made at the ninth or tenth intercostal space over the tips of the hemostats. The proximal part of the chest tube is grasped, and the tube is pulled into the thoracic cavity and positioned. The tube can also be placed by advancing a curved hemostat through the incision into the pleural cavity, by grasping the distal part of the tube and pulling the tube out of the chest cavity in a reverse fashion (Figure 27-24). Cutting the distal part of the tube on an oblique angle creates a pointed end that facilitates its movement through the thoracic wall if it is placed in a reverse fashion. The tip of the tube is positioned cranial and ventral. In all cases, radiographs should be taken after the tube is placed to ensure that the tube is in a proper location and is not kinked or twisted (Figure 27-25).

Anchoring the Chest Tube

The tube is secured by passing a heavy suture on a taper needle through the skin next to the tube and into the periosteum of the rib adjacent to the tube. A hinge is created by tying 6 to 10 knots and then the suture is passed around the tube in a simple criss-cross fashion and tied with 2 knots. This criss-cross "friction knot" is repeated 2 to 3 times, and then 3 to 5 more knots are tied (Figure 27-26). The use of this friction knot avoids the need for tape, which is not sterile and can slip. A second hinge is created on the other side of the tube with the same suture, and the suture is anchored again through the skin and into the periosteum. In small patients, the suture can be passed around the rib. If this is done, care is taken to ensure that the needle does not lacerate the lung. If the suture is not anchored to the periosteum, the tube may migrate as the patient breathes and moves, and the tip may exit the pleural space. The thoracotomy is then closed.

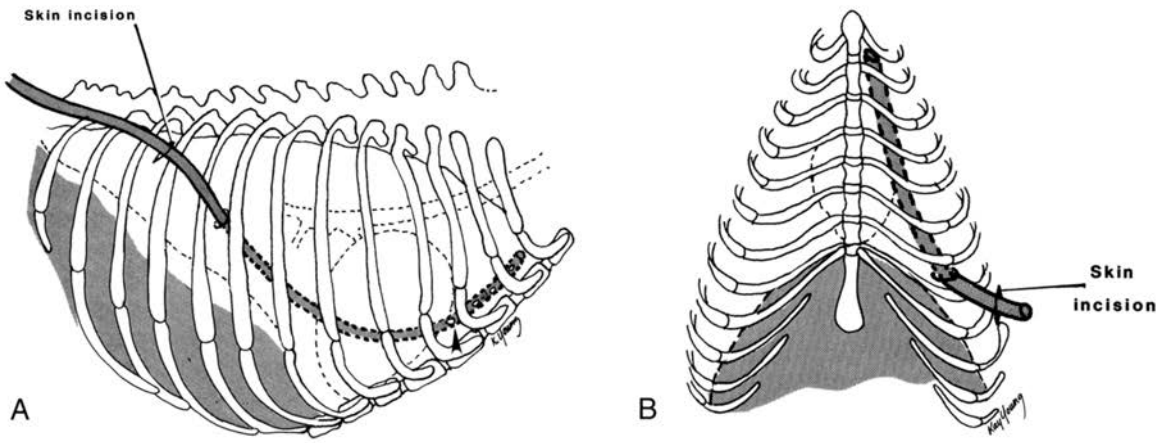


Figure 27-23. Drawings from lateral **A.** and ventrodorsal **B.** radiographs demonstrate proper intrathoracic location of the chest drain. The *arrowhead* in A indicates the location of the last side hole in the catheter as seen on the radiograph (where the radiopaque line is interrupted). (For best function, the tube should be placed no farther cranially than the level of the second rib; more cranial placement may obstruct the flow of air or fluid.) (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

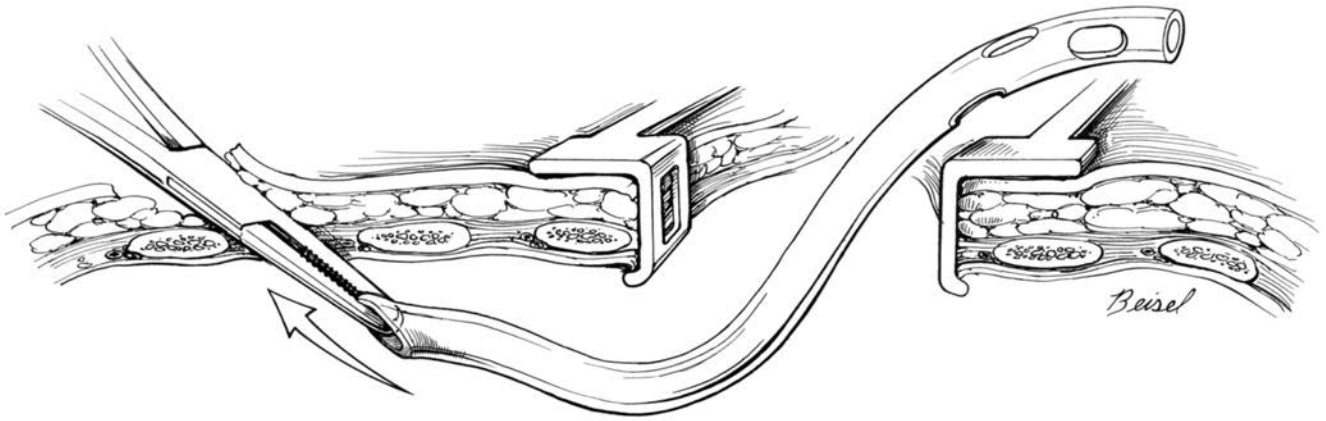


Figure 27-24. In pulling the chest drain out through the seventh or eighth intercostal space, cutting the end of the tube on an oblique angle facilitates its movement through the thoracic wall. (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

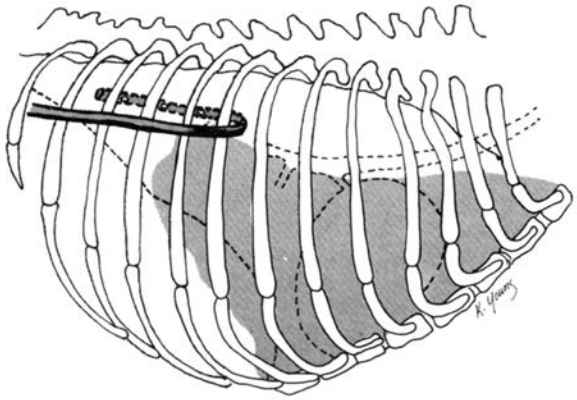


Figure 27-25. Line drawing of a lateral radiograph demonstrates improper placement and kinking of the chest drain. (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

Chest Tube Placement with the Chest Closed

A "closed" tube thoracostomy is performed outside the operating room with the patient in a sitting or standing position or whichever position causes the least distress to the animal. This factor is particularly important in patients showing any signs of respiratory distress. Anxiety and struggling may be dangerous to the animal with compromised ventilation, and restraint should be kept to a minimum, especially in cats. A small amount of a sedation can be given intravenously to effect (e.g., butorphanol [Torbugesic], 0.1 to 0.4 mg/kg, and diazepam [Valium], 0.05 to 0.2 mg/kg or acepromazine, .02 to .05 mg/kg). If the patient continues to struggle despite the sedation, the chest tube should be placed while the patient is under general anesthesia. Rapid induction is essential to gain rapid control of the airway. A cuffed endotracheal tube is placed, and positive-pressure ventilation is instituted. Ventilation is closely monitored because peak airway pressures greater than 30 cm H_2O can cause significant decreases in cardiac output. Because of the underlying disorder, delivery of normal tidal volumes may not be possible. In these patients, smaller tidal volumes with a more rapid ventilatory rate should be used.

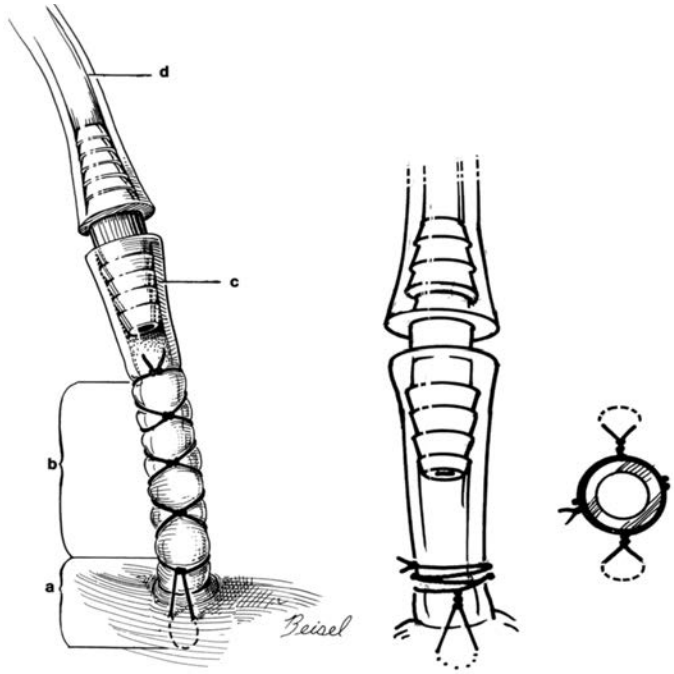


Figure 27-26. Securing the drain tube using a Chinese finger trap friction suture. First, the suture is tied without tension to prevent irritation of the skin *(a);* then, in a criss-cross fashion, multiple surgeon's knots are tied around the tube *(b),* chest catheter *(c),* and gum-rubber tubing *(d).* Although the drawing depicts a finger trap, all that is really required are several "friction knots" tied in criss-cross fashion and wrapped around the tube *(inset).* (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

The skin is clipped over the entire lateral chest wall and cranial flank region and is aseptically prepared for surgery. Local anesthetic is infiltrated into the proposed site of tube insertion at the seventh intercostal space as previously described. This should include the nearby pleura and intercostal nerve. The skin over the lateral chest wall is pulled cranially by an assistant such that the skin over the ninth or tenth intercostal space overlies the seventh or eighth intercostal space. The skin should be pulled at least the same distance as two rib spaces (Figure 27-27A).

Using aseptic technique, a small skin incision is made in the middle of the seventh intercostal space (Figure 27-27B). Curved

Kelly forceps are then used to separate the intercostal muscles in a controlled fashion (Figure 27-27C). The tips of the forceps are inserted into the incision, and mild pressure is exerted in a medial direction; the tips are then opened to spread the tissues, and then the forceps are removed (Figure 27-27D). This dissecting action is used to create a small defect in the pleural space (Figure 27-27E). A small amount of air is intentionally allowed to move into the pleural space, to cause the lung to retract away from the parietal pleura as the tips of the forceps penetrate the pleural space. This maneuver permits the chest tube to be inserted without injuring the lung. The hemostat is left in place to allow continued identification of the thoracotomy site. A stylet is used in the tube to help guide it into the appropriate position. The tip of the stylet should not protrude beyond the end of the tube. The tube tip is then passed into the chest cavity through intercostal musculature previously separated by the tip of the hemostat and is gently guided (without undue force) into the cranioventral thorax (Figure 27-27F). The stylet is removed, and the tube is rotated to ensure that it is not kinked. The assistant releases the skin so the skin returns to its original position, thus creating a subcutaneous tunnel for the tube (Figure 27-28). The tube is then anchored as described previously. If an assistant is not available, the skin incision should be made over the tenth or eleventh intercostal space, and a curved hemostat should be used bluntly to create a tunnel cranial to the seventh or eighth intercostal space. The catheter tip is then grasped in the jaws of stout hemostatic clamps, is passed down the subcutaneous tunnel, and is forced into the chest cavity through intercostal musculature previously separated by the tip of the hemostat. This maneuver is difficult and must be closely controlled to prevent overpenetration. Practice with a cadaver is recommended. Placing a tube using local anesthetic alone can be more easily accomplished using the former technique.

Placement of a thoracostomy tube can also be accomplished using a commercially available tube and trocar stylet unit, which is pushed through the chest wall. This procedure is strongly discouraged because of the high likelihood of iatrogenic injury to intrathoracic structures and the high degree of tolerance of the first procedure described earlier. The skin over the tenth to eleventh intercostal space is pulled cranially by an assistant to overlie the eighth to ninth intercostal space. The trocar-pointed stylet is then forced through the intercostal space with a controlled thrust. As soon as the tip of the tube enters the chest, the metal stylet is retracted to just inside the cannula. The rigidity of the stylet aids in manipulating the tube into the correct cranioventral position. The assistant then allows the patient's skin to retract caudally to its normal position. Once released, the skin and subcutaneous tissue form a seal over the hole.

Bandaging the Chest Tube

An occlusive dressing is placed using sterile antibiotic ointment or petrolatum over the ostomy site. The exiting catheter and torso are then wrapped gently but securely with gauze and tape for further protection. A stockinette can also be used to cover the entire area. The end of the catheter should be exposed near the dorsum of the animal's back, and the rest of the catheter should be covered to prevent its being damaged or dislodged.

Methods of Pleural Space Evacuation

The open end of the tube must be attached to one of the following: 1) a Heimlich valve (Bard-Parker, Rutherford, NJ) or another one-way egress valve; 2) a three-way stopcock; 3) an underwater seal; 4) an underwater seal with controlled continuous, low-vacuum suction drainage (high-volume or low-volume types depend on the rate of air or fluid-blood accumulation); 5) an underwater seal with controlled, intermittent low-vacuum suction drainage; or 6) under emergency conditions, a regular suction unit with a side hole cut into the connective tubing to control the suction pressure. The choice of device depends on the size of the patient, the size of the air leak, the nature of the pleural fluid, and the patient's tractability. All attachments to the chest tube should be secured with tape placed in a criss-cross fashion. This allows the inside of the tubing or attachment to be visualized. If the attachment is inadvertently pulled, the tape will tighten and prevent loosening or detachment.

Heimlich Valve

The Heimlich valve consists of a rubber one-way flutter valve that is enclosed in a clear plastic tube open at each end (Figure 27-29). The end of the chest tube is attached to the wide end of the flutter valve and is an excellent device for evacuating air. It is a good temporary device for evacuating blood and other fluids; however, the valve should be replaced frequently during drainage of blood or other tenacious fluids because the rubber valve becomes sticky and does not open freely. The end of a Heimlich valve has a fitting that accommodates a syringe in case manual suction is required. Although the valve has been used with success in animals weighing less than 15 kg, some smaller patients may not be able to generate sufficient increases in intrapleural pressure during expiration to open the valve and to allow evacuation. One-way valves are especially useful in the initial management of tension pneumothorax in patients weighing more than 15 kg if an underwater seal and suction system is not immediately available.

Stopcock

A stopcock attached to the end of a catheter prevents air or fluid from moving either in or out without manual operation. Its use is recommended in animals weighing less than 15 kg and in animals that are not accumulating air or fluid rapidly in their pleural cavity. The rate of fluid or air evacuation is determined by the size of the stopcock because the stopcock is of a smaller diameter than the chest tube. A large syringe is used for periodic aspiration by opening and closing the valve as needed to accomplish thoracentesis. The syringe plunger should be pulled back gently with only sufficient pressure applied to evacuate the fluid. Excessive pressure (greater than 30 cm H_2O) can lead to lung injury or ineffective evacuation caused by the aspiration of mediastinal tissue.

Temporary Emergency Underwater Seal and Suction System

A disposable plastic intravenous administration set can be used to facilitate emergency drainage of large quantities of pleural

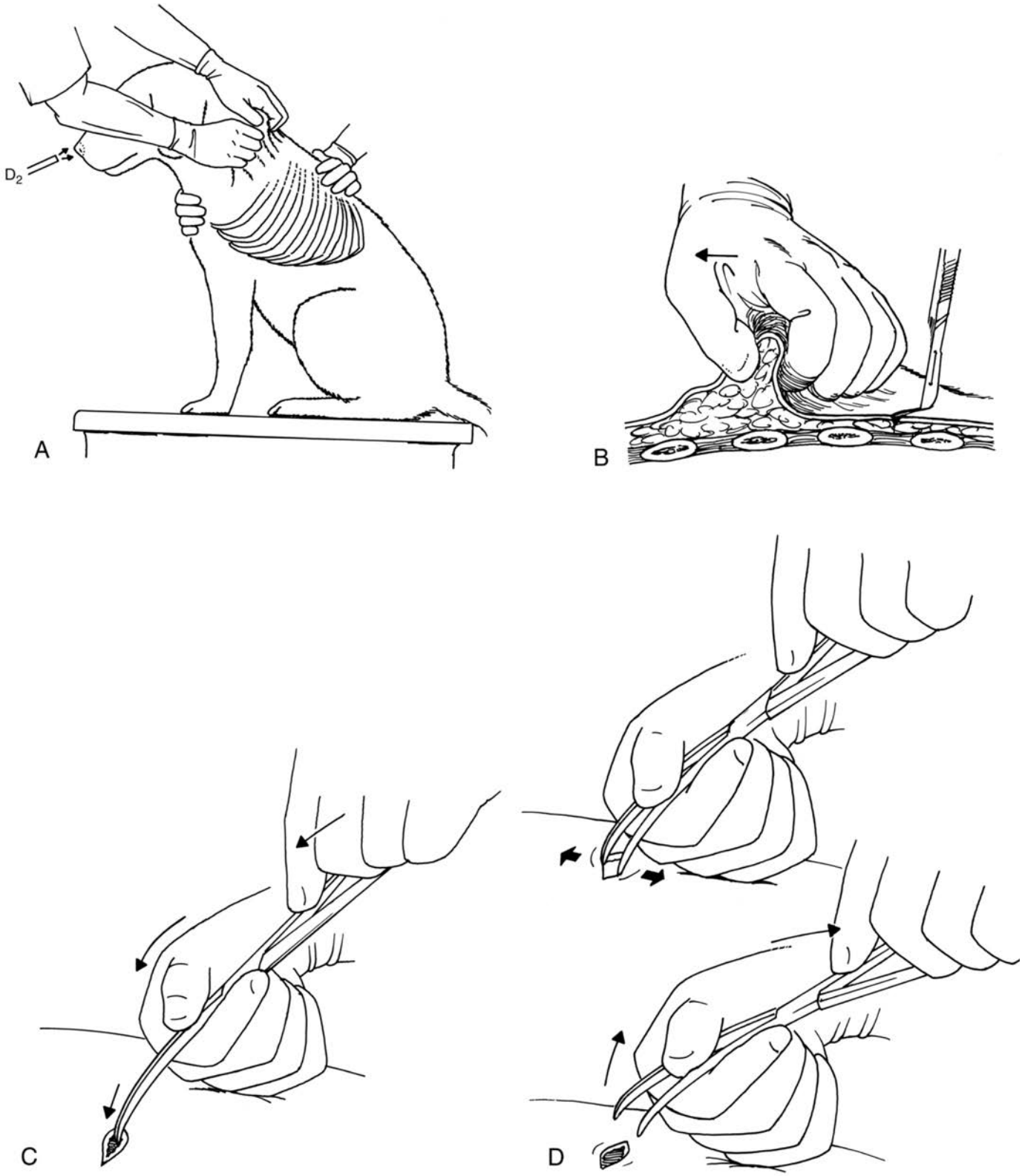


Figure 27-27. A-F. Placement of a chest tube with the skin pulled as far forward as possible that creates a flap when the tube is inserted and the skin is released.

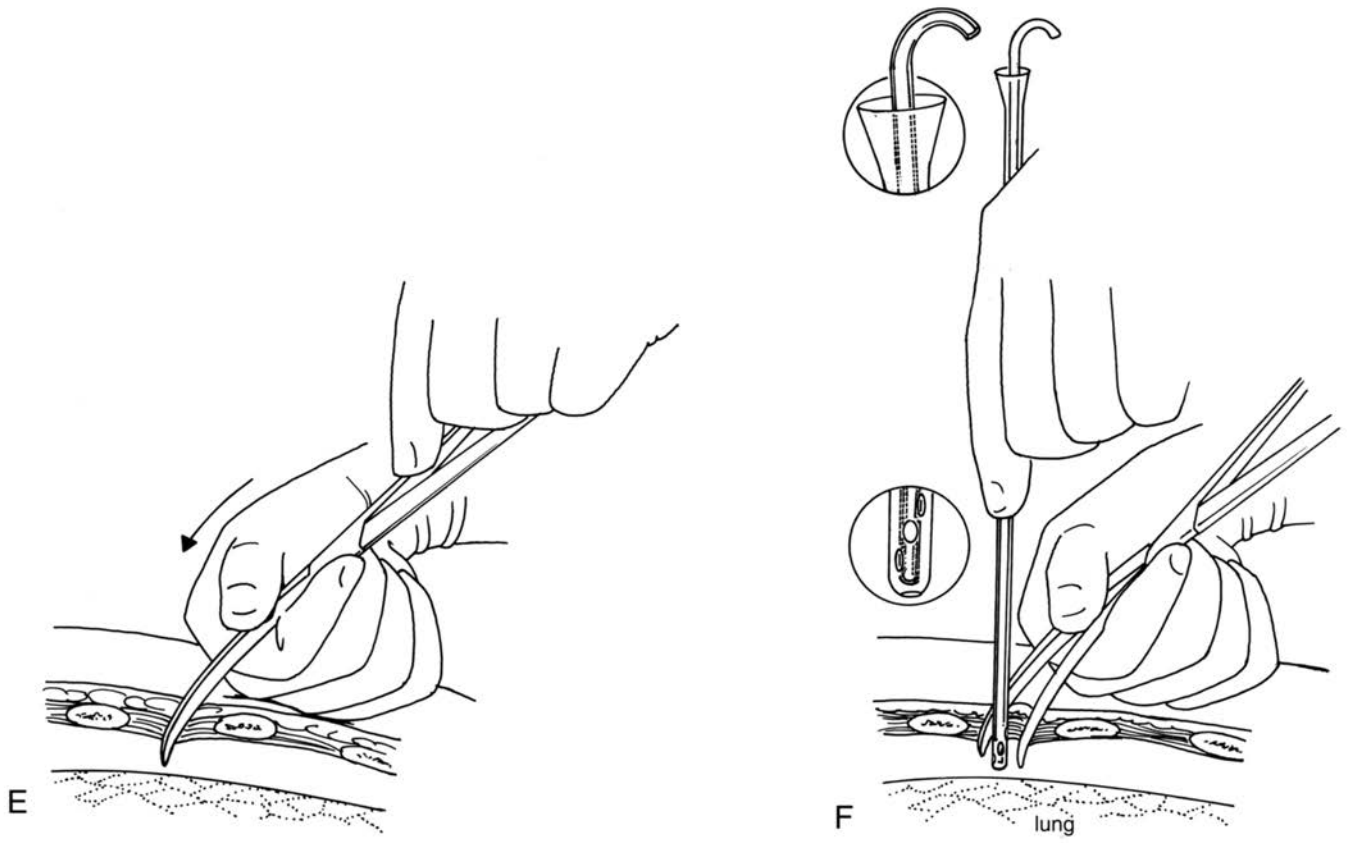


Figure 27-27. A-F. *(continued)*

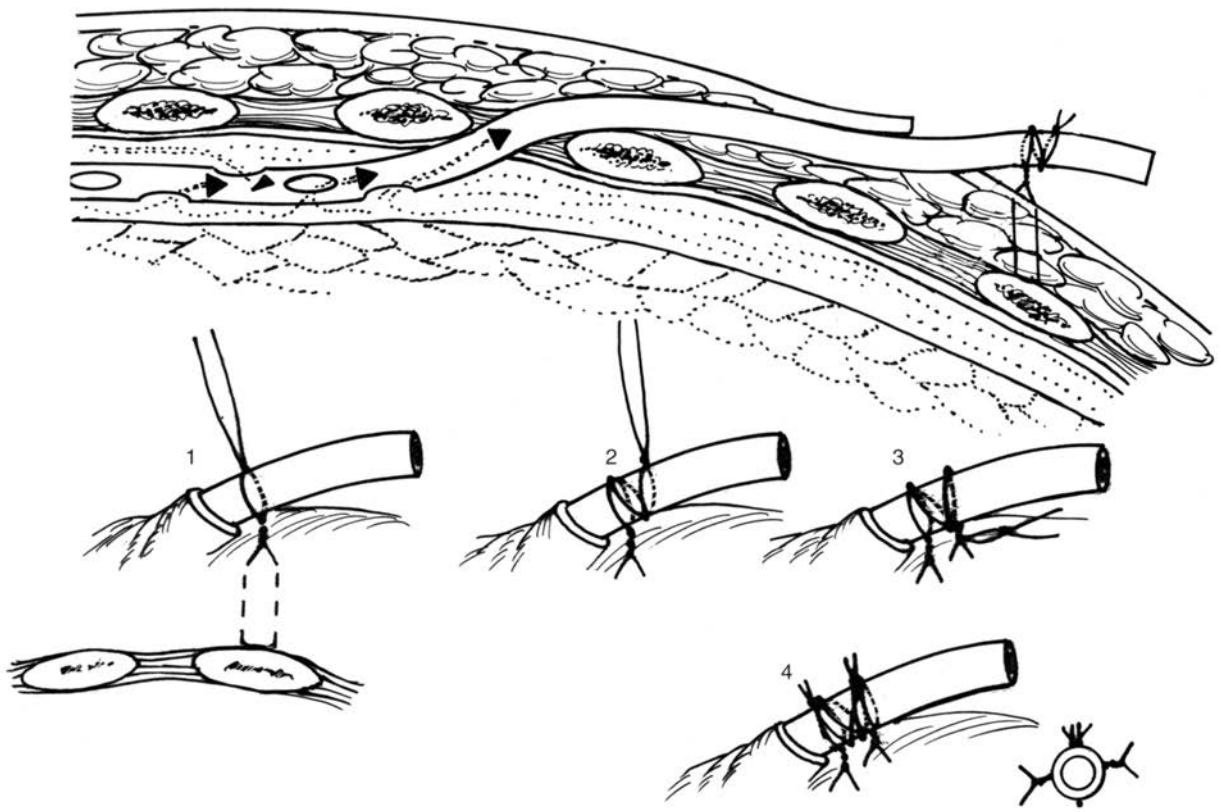


Figure 27-28. When the skin is allowed to return to normal position, a tunnel is created that helps to prevent air from migrating into the pleural space. Note the position of some of the side holes in the tube that allow air and fluid to drain from the pleural space as the lung reexpands *(1 to 4)*.

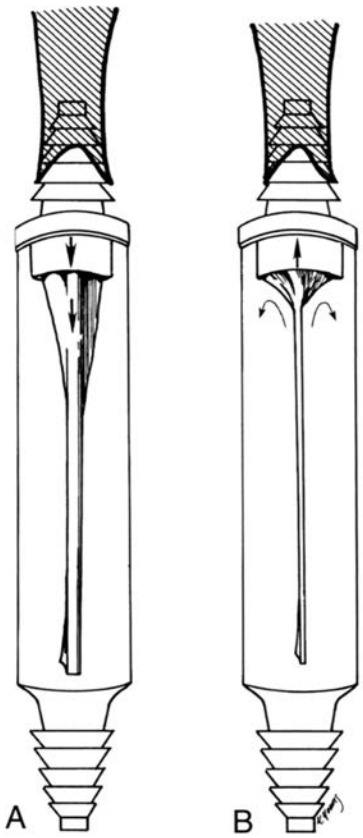


Figure 27-29. These diagrams demonstrate the function of the Heimlich flutter valves. **A.** During inspiration, the valve stays closed, and no air can enter the thoracic cavity. **B.** During expiration, as intrapleural pressure increases, the air or fluid is forced out of the pleural space through the chest tube and one-way valve. (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

effusion. The male end of the plastic tubing is fitted to the side arm of the stopcock, and the drip chamber is cut from the other end and is placed underwater. When the side arm tubing is filled and the stopcock is opened, drainage of the pleural space to a collecting vessel is possible by siphon action. To make and use an underwater seal, a length of tubing connected to the chest catheter is placed 1 to 2 cm below the fluid's surface in a bowl or bottle containing 2 to 3 cm of sterile saline solution. This useful, quickly made underwater seal and one-way valve are recommended as a temporary measure when no other instruments or one-way valves are available and when time does not permit delayed action. The device can also be used for patients that need a vent if pleural fluid or air accumulates. When using this technique, care is taken to make sure that the tube stays submerged because, if the seal is broken, pneumothorax rapidly develops. Constant observation of this temporary device is mandatory.

Underwater Seal and Suction Drainage

Underwater seal and suction drainage of the pleura can be easily accomplished using several systems. Both two-bottle (Figure 27-30) and three-bottle (Figure 27-31) systems are adaptable to veterinary practice, and the equipment is unsophisticated and reusable. With a two-bottle suction drainage system, the chest

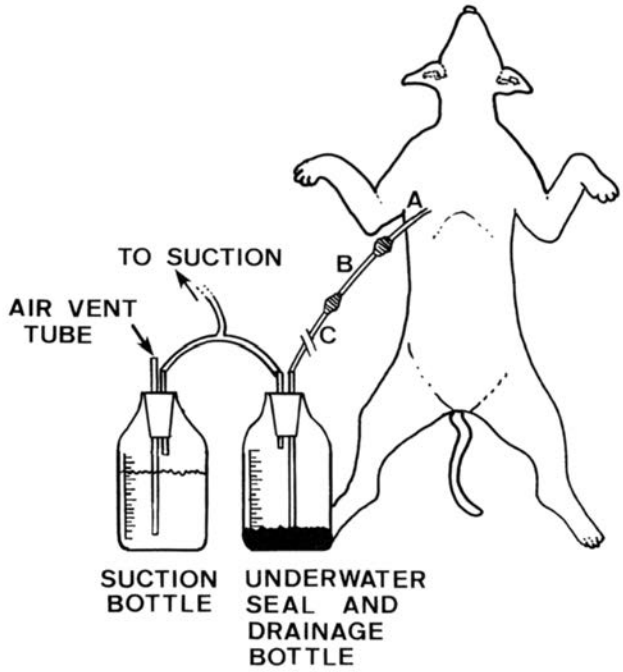


Figure 27-30. Two-bottle suction drainage: *A,* Distal end of the chest tube exiting from the bandaged thorax: *B,* gum-rubber tubing (approximately half an inch in diameter) to allow "stripping" of the chest tube, about 3 feet long (see text): *C,* polyvinyl chloride "bubble" tubing. (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.)

catheter is connected to a 500- to 2000-mL sterile glass bottle containing enough sterile saline solution to fill it to a level of 2 to 3 cm from the bottom. The tube within the bottle is placed 1 to 2 cm below the surface of the saline solution. The bottle acts as both a collection reservoir and an underwater seal system to prevent air from being aspirated into the pleural space. A second bottle is partially filled with sterile saline solution and is connected to the first. A rigid plastic vent tube is open to room air, so it permits air to be aspirated into the bottle as vacuum is applied. Thus, by raising or lowering the tube in the second bottle, the amount of vacuum applied to the catheter extending into the patient's chest can be controlled. If the vacuum regulation tube is submerged to 10 cm, the patient will not experience more than 20 cm water transpleural suction pressure.

Experimental and clinical studies have shown that a continuous 15 to 20 cm negative pressure effectively aspirates tension pneumothorax and allows pulmonary visceral and parietal pleural surfaces to be approximated and to remain approximated. This pressure has proved to be key to the successful, spontaneous sealing of large defects in the lungs of human and animal patients. With the use of suction drainage, many pneumothoraces close, and the need for thoracotomy is thus obviated. This finding is in contrast to drainage without suction, experimental and clinical studies of which have shown that large leaks either do not seal or seal slowly.

With a three-bottle suction drainage system, the first bottle is connected to the chest catheter and acts as a fluid trap. Such a system is particularly useful if hemorrhage or hydrothorax is voluminous. If traumatic hemorrhage is severe, autotransfusion

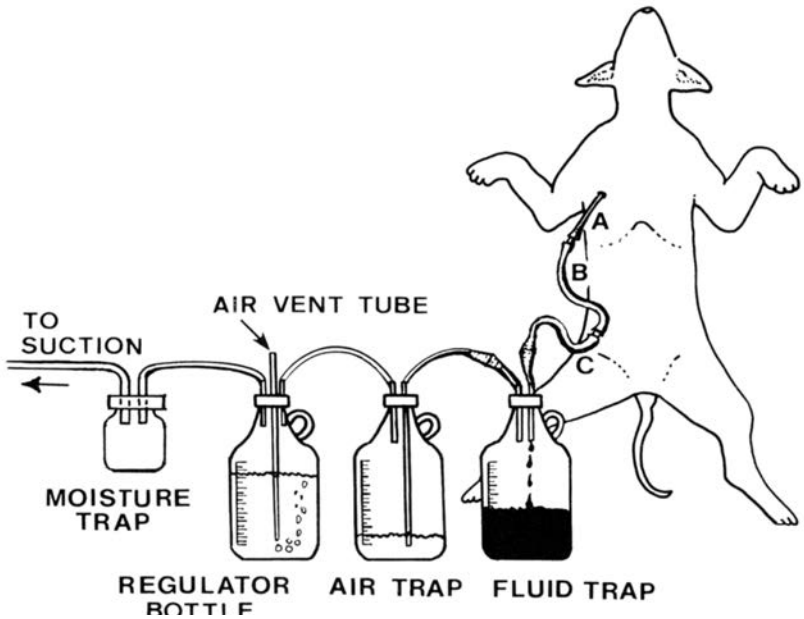


Figure 27-31. Three-bottle suction drainage: *A,* Distal end of the chest tube exiting from the bandaged thorax; *B,* gum-rubber tubing (approximately half an inch in diameter) to allow "stripping" of the tube, about 3 feet in length (see text); *C,* polyvinyl chloride "bubble" tubing. (From Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea& Febiger, 1983.)

may be considered from this vessel. In this case, approximately 50 to 75 mL anticoagulant solution is initially added to the bottle. When 500 to 1000 mL blood has been aspirated, a second fluid-trap bottle containing anticoagulant is substituted for the first bottle, and autotransfusion is begun. The second bottle of the three-bottle system is connected to the first bottle and acts as the underwater seal. Its function and filling are similar to those of the first bottle of a two-bottle system. The third bottle is connected to the second and again acts as suction regulator.

For the underwater seal and suction drainage system, at least the first 3 feet of the tubing leading from the chest catheter to the underwater seal should be made of gum rubber (Tomac amber latex intravenous tubing, American Hospital Supply Corp., McGaw Park, IL). Any animal whose chest catheter is connected to an underwater seal device by a tube must be watched carefully because knocking over of the bottles and detachment or chewing of the tubing can lead to massive pneumothorax. This possibility is the major drawback of the use of bottle suction systems in many small animal practices in which staff coverage is not available on a 24-hour basis. If an intensive care unit, hospital with 24-hour staff coverage, or emergency practice is available, however, continuous suction and drainage may be accomplished and continued for as long as necessary.

With several alternatives available, selection of a drainage system depends on the following criteria: 1) the patient's size; 2) the type of material drained and its rate of accumulation within the pleural space; 3) the facilities and staff available for monitoring; and 4) economic considerations. Without question, the underwater seal and suction drainage system is the most effective. A three-bottle system is no longer available, but one may buy a two-bottle and a one-bottle system and combine them (American Hospital Supply Corp.). The Pleur-evac chest drainage unit (Deknatel, Inc., Fall River, MA) is a commercially available underwater seal system that is in essence a three-bottle system. This also has an autotransfusion system that can be attached for collecting blood for autotransfusion. The Pleur-evac does require the use of a suction unit to generate the vacuum powering the system. The AN50 Thorovac (H. W. Andersen Products, Inc., Haw River, NC) is a commercial example of a two-bottle system. This is an electrically driven underwater seal suction system. Up to 20 cm of water pressure can be generated; however, in patients with large leaks, the unit may not be able to evacuate rapidly enough. It is generally useful if the air leak from a pneumothorax is less than 500 mL per hour.

Troubleshooting and Tube Stripping

When using any form of continuous underwater suction system, the chest tube should be intermittently stripped and, in some cases, hand suctioned using a stopcock and syringe to ensure that the system is working adequately. The best way to hand suction using a stopcock is to attach a "Y" connector (Abbott Laboratories, Chicago) to the chest tube. A red rubber tube (Sovereign, Sherwood Medical Products) is used to connect the stopcock to the Y connector. The other end of the Y connector is attached to the suction tubing (Figure 27-32). A clamp is placed across the section of tubing not being used. This method allows either continuous suctioning or syringe aspiration without disruption of the connections.

With continuous-suction systems, leaks and generation of inadequate suction pressure are the two most common complications. Leaks can occur anywhere along the system from the ostomy site to the suction unit. If the tube was not tunneled at least two spaces, the tube may start to leak at the ostomy site. This is more likely to occur the longer the tube is in place because the skin edges retract around the ostomy site, thereby creating a larger hole. If the tube backs out of the chest, holes in the tube may communicate with the environment.

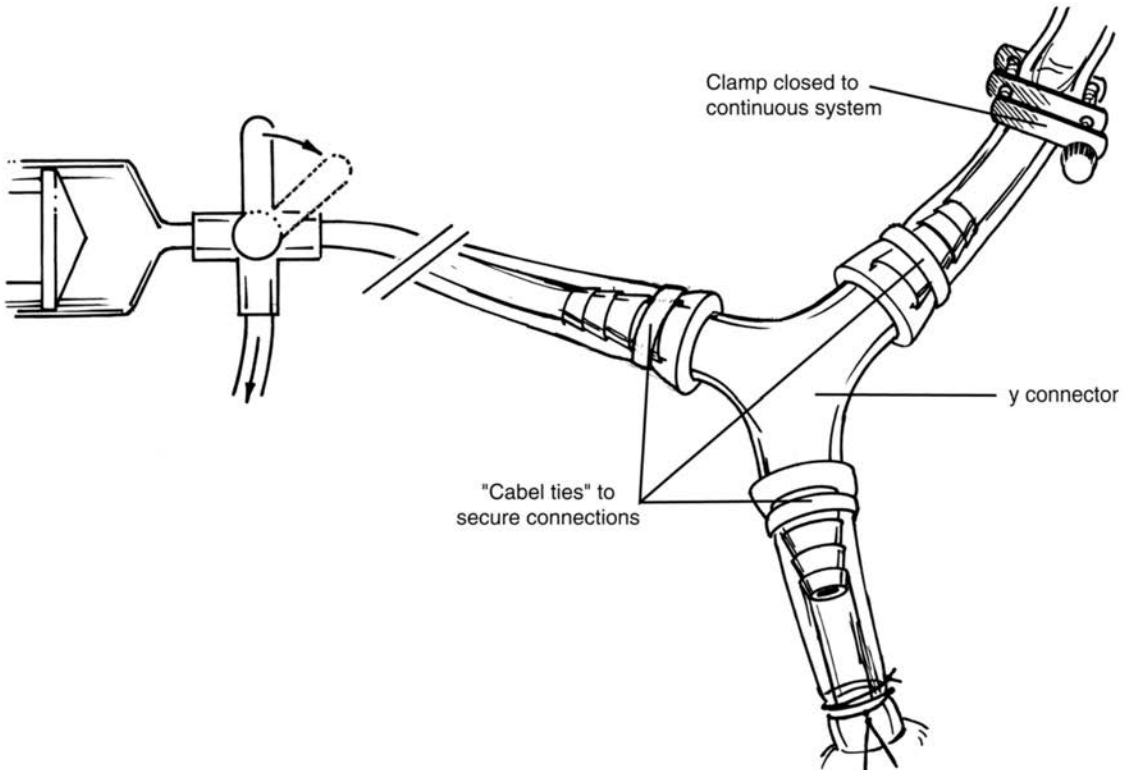


Figure 27-32. Y connecter attached to a chest tube to allow a continuous-suction system to be connected as well as a stopcock to aspirate intermittently, to ensure function of the continuous system and to act as a "fail safe" for evacuation of the pleural space if the system stops working properly.

The pressure generated at the chest tube should be checked periodically. This can be done by placing a manometer near the chest tube and monitoring the pressure as the suction is applied. A commercial manometer (Vital Signs Inc., Totawa, NJ) can be used for this purpose, or tubing can be placed in a bottle of sterile saline. A column of saline pulled upward into the tubing should be between 15 and 20 cm above the surface of the saline. The pressure indicated at the suction unit itself is always less than the pressure generated at the chest tube because of resistance within the tubing. This problem worsens in proportion to the length and collapsibility of the tubing.

Fluid accumulations within the suction tubing also interfere with operation of the system. Stripping is required to keep the fluid from accumulating. By grasping the tubing as near to the patient as possible and by pinching it closed, a stripping motion (a sliding motion, with the tube pinched off) is applied along the length of the tube for 20 to 40 cm (Figure 27-33). The stripping action creates a sudden, high negative pressure inside the tube past the area where the tube has been pinched closed. At the end of each stripping action, the pinch is released, and a surge of negative pressure is transferred to the thoracic catheter. The high negative pressure generated also loosens and evacuates fibrin clots and debris inside the catheter. This stripping should be done every hour when a significant amount of blood or other viscous or sticky fluid is encountered. The frequency of stripping may be decreased as the amount of fluid removed decreases. Generally, by the second day, stripping is only necessary every 4 to 8 hours.

Special Considerations for the Rapid Accumulation of Fluid or Air

Currently, an underwater seal and suction drainage system attached to the chest tube is the recommended method of treatment for trauma or disease conditions involving the continuous or rapid accumulation of air or fluid in the pleural space. In these situations, a Heimlich valve should only be used as a temporary means of evacuating the chest if the patient's weight exceeds 15 kg, such as when transporting the patient from the emergency treatment area to the intensive care unit. For patients under 15 kg, use of a three-way stopcock and syringe is the only method recommended for the drainage of rapid accumulation of air or fluid other than underwater seal and suction systems.

Under emergency conditions, if an underwater seal and suction system is not immediately available, a regular suction unit can be used. The vacuum is reduced to 20 to 30 cm H_2O by one of three methods: 1) cutting a small hole in the side of the tubing; 2) partially clamping the tubing; and, 3) opening the "escape" valve or using the control valve on the suction unit.

Analgesia

The presence of chest tubes can be painful for the patient, and analgesia should be administered on a regular basis as required. Intercostal nerve blocks can be provided with 0.25 to 1.0 mL of 0.25% bupivacaine through intermittent injections or with the use of an indwelling catheter. Intrapleural analgesia is best provided with 0.25 to 0.5% bupivacaine (up to 2 mg/kg) administered into

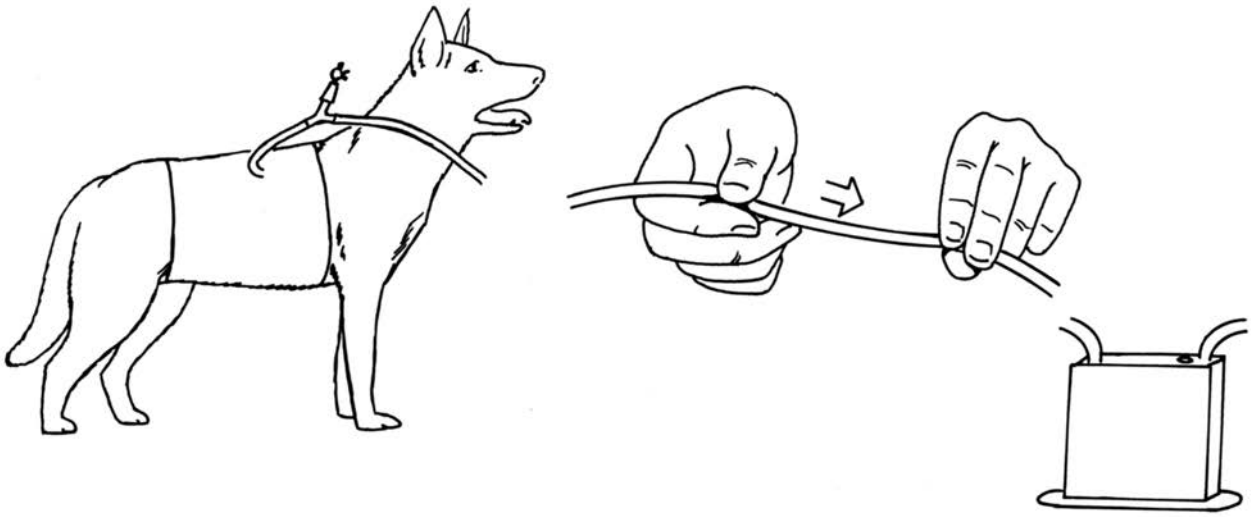


Figure 27-33. Chest tube stripping done by a nurse every 6 to 8 hours to keep the tubing and the tube patent. The left hand pinches the tubing (made of gum rubber) shut, and the right hand is used to strip the tube, by pinching and then sliding using the thumb and index finger, which are lubricated with water or petroleum jelly. When the right hand meets the left, the tube in the left hand is allowed to snap open, creating a sudden popping of air.

the chest tube. The addition of sodium bicarbonate (one-third sodium bicarbonate to two-thirds bupivacaine) to the local anesthetic helps to decrease the irritation from the acidity of the drug. Warming the medication to body temperature and administering the drugs slowly also provide less discomfort. Systemic administration of a neuroleptanalgesic is also recommended in combination with local analgesia.

Tube Removal

The chest drain should be removed whenever it is no longer needed. This time may range from the immediate postoperative period to more than a week. Suction should be continued until no air has been removed for 12 to 24 hours or until fluid accumulations are less than 1 to 2 mL/kg per day. If any question exists concerning the safe removal of the chest tube, it should be clamped for 24 hours. The patient should be closely monitored during this time, and the tube should be suctioned if the patient has any evidence of respiratory compromise. The tube is aspirated after the 24-hour period, and radiographs are then taken to determine whether any intrapleural accumulation of air or fluid is present. If no accumulation is present, the tube may be safely removed.

When the surgeon determines that the tube is no longer needed, the bandage and sutures are removed, and the tube is quickly removed using traction. The hole is covered with a gauze dressing impregnated with an antibiotic ointment. The gauze is held in place with a torso bandage. Complete sealing of the wound generally occurs in 2 or 3 days. Until then, the dressing is changed as required to maintain a clean, dry, and occlusive (with ointment) environment.

Complications

As previously mentioned, whenever the patient must be left unattended, the entire chest catheter and attached apparatus must be covered completely under a well-secured dressing to prevent disturbance or dis-lodgment. If disconnection occurs in the patient with a large-bore chest tube, death can occur within 5 to 10 minutes because of the effects of a progressive pneumothorax.

An occasional problem is the accumulation of fibrin clots, especially when a small-lumen-diameter catheter (smaller than 20 French) is used or when a large amount of fibrin, blood, or other proteinaceous material is drained. Blockage is prevented by frequent stripping of the tubing. When using a three-way stopcock on the end of the chest catheter, a small amount of sterile heparinized saline solution can be infused every few hours; when using the Heimlich valve or other one-way rubber valve, it may be necessary to change the valve frequently.

Reexpansion pulmonary edema has been occasionally reported in patients with chronic cases of atelectasis when the lung is reinflated rapidly after rapid removal of pleural fluid or air. In general, this complication is not seen until the lungs have been atelectatic for longer than 3 days.

Another reported complication is subcutaneous emphysema as the result of a large hole in the chest wall that is not completely occluded by the presence of the drainage tube. An occlusive dressing applied around the exit site helps to minimize this problem. Lung tissue entrapment and subsequent infarction by vigorous chest suction have been reported. This complication may be considered whenever a radiographic pulmonary infiltrate appears near a side or end hole of the chest tube. Unregulated, high vacuum levels, as in operating room or portable suction units (80 to 120 mm Hg), should not be used. All active suction must be regulated by a two- or three-bottle system, the emergency system mentioned earlier, or, if one is aspirating with a syringe, it should be done gently.

Although infection can occur whenever any indwelling catheter is used, this problem is minimized by careful tube placement and care. In a randomized study of 120 human patients with indwelling chest drains, half were treated with prophylactic antibiotics,

and the other half were given a placebo. Those patients given antibiotics had the higher infection rate. Our clinical results with the use of chest drains in dogs and cats also seem to indicate similar conclusions. Proper wound care at the site where the drainage catheter enters the chest and strict attention to aseptic technique and suction drainage remain the most important factors in preventing serious infection of the pleural cavity and subcutaneous tissue. If any concerns exists, the evacuated fluid should undergo periodic cytologic assessment, and Gram staining and culture should be performed as indicated. Culture of tips of the tubes on removal should be considered in any tubes that have been in place for an extended period.

A rare complication of chest tubes is phrenic nerve irritation and palsy. This problem may be severe enough to cause diaphragmatic paresis. If the tube rubs the pericardium or the heart after pericardi-ectomy, arrhythmias may occur. These are generally self-limiting.

If the tube has been in place for several days, adhesions may have formed, and mild intrathoracic bleeding may occur when the tube is removed. Rarely, bleeding may persist to the point that surgical exploration and vessel ligation are required.

Comments

Often, animals suffering from multiple injuries, including fractures, have a pneumothorax. Mild pneumothoraces do not cause respiratory distress, but they are readily diagnosed by chest radiographs. If anesthesia is necessary for fracture repair, a chest tube should be inserted to aid resolution of the pneumothorax, to help in lung healing, and to allow earlier and safer use of anesthesia. Positive-pressure ventilation during anesthesia may predispose the healing lung or bronchus to rupture. Without a chest tube in place, a tension pneumothorax can rapidly develop and can prove fatal. The placement of prophylactic chest tubes is also indicated in patients with lung injury that require positive-pressure ventilation.

Bilateral chest tubes may be required to permit adequate evacuation of the pleural space. In many trauma patients, the mediastinum ruptures, thus allowing both sides of the thorax to be evacuated with a unilateral tube. However, the mediastinum may seal, and a second tube may be required. In many patients with bilateral fluid accumulations, chest tubes may be required on both sides of the thorax to provide effective drainage because the mediastinum is intact and is often thicker than normal.

Chest tubes can be used as a method of core re-warming of the severely hypothermic patient. In such cases, through-and-through lavage is done with warm sterile saline. Instillation of sterile saline or lactated Ringer's solution into the pleural cavity using chest tubes can also be used for the treatment of uremia, similar to peritoneal dialysis.

Suggested Readings

Brandstetter RD, Cohen RP. Hypoxemia after thoracentesis. JAMA 1979;242:1060.

Butler WB. Use of a flutter valve in treatment of pneumothorax dogs and cats. J Am Vet Med Assoc 1969;155:1997.

Crowe DT. Help for the patient with thoracic hemorrhage. Vet Med 1988:83:578-588.

Graham JM, Mattox KL, Beall AC. Penetrating trauma of the lung. J. Trauma 1979; 19:665.

Griffith GL, et al. Acute traumatic hemothorax. Ann Thorac Surg 1978:26:204.

Harrah JD, Wangensteen SL. A simple emergency closed thoracostomy set. Surgery 1970:68:583.

Holtsinger RH, Beale BS, Bellah JR. et al. Spontaneous pneumothorax in the dog: a retrospective analysis of 21 cases 1993; 29:195-210.

Richards W. Tube thoracostomy. J Fam Pract 1978;6:629.

Sauer BW. Valve drainage of the pleural cavity of the dog. J Am Vet Med Assoc 1969;155:1977.

Turner WD, Breznock EM. Continuous suction drainage for management of canine pyothorax: a retrospective study. J Am Anim Hosp Assoc 1988;24:485-494.

Withrow SJ, Fenner WR, Wilkins RJ. Closed chest drainage and lavage for treatment of pyothorax in the cat. J Am Anim Hosp Assoc 1975:11:90.

Zimmerman JE, Dunbar BS, Klingenmaier CH. Management of subcutaneous emphysema, pneumomediastinum, and pneumothorax during respirator therapy. Crit Care Med 1975:3:69.

Chapter 28

Thoracic Wall

Thoracic Wall Neoplasia

Dennis Olsen

Biology of Thoracic Wall Neoplasia

Tumors of the thoracic wall are considered uncommon and can originate from skeletal or soft tissues structures. The tissue of origin and tumor type determine biologic behavior and behavior dictates the degree of surgical intervention. Benign soft tissue tumors (e.g. lipoma) can often be removed without wide margins or aggressive excision. However, malignant tumors, regardless of tissue of origin, should be removed with a variable margin of normal tissue dictated by the type of tumor. Those tumors that have a high probability of recurrence should have large borders of normal tissue removed three dimensionally around the tumor.[1] This degree of surgical excision often comprises the full thickness of the thoracic wall which, may affect function as well as dictate the type of closure or reconstruction required to restore integrity of the thoracic wall. Variations in surgical therapy recommendations emphasize the need for accurate differentiation between benign and malignant tumors before appropriate therapy can be planned and initiated.

Primary tumors affecting the skeletal structures of the thoracic wall are malignant more often than they are benign.[2-7] Most authors report that osteosarcoma is the most common type of malignant rib tumor followed by chondrosarcoma[1,3-7] however, at least one report has this order reversed.[7] Skeletal tumors often occur at the costochondral junction of the ribs and more rarely the sternum.[2,3,5,7] These tumors are often firmly attached to soft tissues of the thorax making them relatively immobile. This characteristic may be an indication of malignancy.[6] Young to middle aged dogs are most commonly diagnosed with these tumors.[2,5,7,8] The occurrence of skeletal tumors in this location in the cat is very rare.[7]

Clinically, dogs with osteosarcoma of the thorax are presented with a palpable mass of the ribs or sternum that may be painful,[9,10] although some authors describe them as nonpainful.[5,7] Dyspnea due to pulmonary impingment from intrathoracic extension of the tumor, pleural effusion, and pulmonary metastasis has been reported[2,5,7,9] but another source states that respiratory signs due to these conditions are not commonly seen.[10] One characteristic that is generally agreed upon is that the biologic behavior of osteosarcoma in the rib is similar to other locations. Locally, osteosarcoma is aggressive with lysis and production of bone and replacement with neoplastic tissue.[10] Early metastasis is a trait of osteosarcoma with the lungs as the primary location for tumor spread and this characteristic is responsible for the poor prognosis for animals with osteosarcoma.[4,7,10] *En bloc* resection of the tumor including wide margins of normal tissue with adjunctive radiation and or chemotherapy are recommended. The median survival times for cases treated by *en bloc* excision and excision plus adjunctive chemotherapy are three and eight months respectively.[9,11,12] The poor prognosis emphasizes the need for accurate diagnosis particularly when compared to chondrosarcoma.

Chondrosarcoma has a predilection for flat bones where it occurs 61% of the time.[10] In the canine, occurrence of chondrosarcoma on the ribs ranges from 6% to as high as 33%.[7] In cats common locations near the thorax are the scapula and vertebrae and rarely the ribs or sternum.[7] Biologically, chondrosarcomas are less malignant than osteosarcoma, however this tumor may attain large dimensions prior to diagnosis. It invades local tissues, the pleural space, and may cause pleural effusion.[7] Metastasis is reported to be slower than with osteosarcoma and the prognosis is somewhat better if early diagnosis and aggressive surgical resection is performed.[7,9] The reported median survival times for dogs with chondrosarcoma of the ribs are quite variable but are considerably longer than osteosarcoma with some authors reporting up to1080 days.[9,12] Therapy for chondrosarcoma is also *en bloc* resection of the tumor with reconstruction of the thoracic wall if needed.

Metastatic neoplasms of the thoracic wall have been described and the ribs are considered a common site while the sternum is rarely affected.[2,9] When metastasis to the ribs occurs, the diaphyseal area near the nutrient foramen is the common location.[7,9] The incidence of metastasis of appendicular osteosarcoma to other bones such as the ribs may be increased following chemotherapy regimens.[10]

Primary tumors of thoracic soft tissues include various sarcomas (e.g. fibrosarcoma, hemangiosarcoma, hemangiopericytoma, and malignant fibrous histiocytoma) and occasional discrete cell tumors (i.e. mast cell tumor).[3,6,12,15] Wide three dimensional surgical excision is recommended for these tumors. If removal requires *en bloc* excision of the thoracic wall, reconstruction may be required.

En Bloc Resection Technique

Prior to considering *en bloc* excision, the patient should be evaluated for the presence of distant metastasis. If regional lymph nodes are accessible, palpation followed by fine needle aspiration of the nodes should be performed. Three-view radiographs of the thorax should be obtained to evaluate for the presence of pulmonary metastasis.[10] Right and left laterally recumbent and either a dorsoventral or ventrodorsal views should be obtained. Ultrasound examination of the abdomen can be performed to check for metastasis or other concurrent disease that may be important prognostically. The presence of distant metastasis should be carefully considered prior to surgical therapy.

A plan for surgical treatment of thoracic tumors is developed by recognizing the extent of the neoplasm. While the external extent may be apparent, the internal extent may be more difficult to define. Diagnostic imaging studies that may include radiography, ultrasonography, computed tomography, and/or magnetic resonance imaging, should be performed to further define the extent of the disease. Once the extent of disease is determined, the excisional boundaries can be planned. It is generally accepted that wide excision is the method of choice for thoracic wall malignancies. Wide excision is defined as removing normal tissue

margins in excess of one centimeter. Two to three centimeters are regarded as standard margins in a wide excision.[1] When *en bloc* excision of thoracic wall malignancies is performed, one extra rib on each side of the mass is often taken in an attempt to obtain adequate margins.[4] Using this as a guideline along with knowledge of tumor extent allows estimation of surgical boundaries. This will allow the surgeon to determine the potential closure or reconstructive techniques that may be necessary after thoracic wall excision. When the excisional area involves only one rib and the surrounding tissues, standard soft tissue closure techniques can be utilized. When two or more ribs are excised with surrounding tissues, thoracic wall reconstruction techniques are required. Boundaries involving six ribs is considered the upper limit of surgical excision.[4-6] Reconstruction is also indicated when a part of or the entire sternum is removed.[5,6] It should be noted that altering the planned surgical boundaries in an effort to simplify closure of the thoracic defect may increase the potential for incomplete removal of the tumor. The planned closure of the defect should not influence the surgical excision plan. Rather, the excision should dictate the closure technique.

A centimeter ruler can be used to measure an appropriate distance around the periphery of the tumor. After this boundary is determined, it can be converted to an elliptical or fusiform shape to simplify cutaneous closure but the wide borders around the mass are maintained. If a previous biopsy has been performed, it is important to include the entire biopsy site within the surgical excision. The skin and subcutaneous tissues are incised along the planned boundary. As the dissection progresses, there is a tendency to get closer to the mass compromising margins and this should be avoided. The thoracic musculature is also incised widely around the mass (Figure 28-1). Hemostasis is best achieved through judicious use of electrocautery and ligation of larger vessels. Positive pressure ventilation should be initiated prior to the thoracic cavity being entered. As the external intercostal muscles and ribs are encountered, the ribs are cut dorsal and ventral to the mass. Circumcostal sutures that incorporate the intercostal vasculature caudal to each rib can be preplaced around each rib involved in the resection to decrease hemorrhage. Sutures should be placed dorsal and ventral to planned transection sites. The intercostal musculature is incised at the same level and the mass and surrounding tissues are removed (Figure 28-2). Following mass removal, surrounding soft tissues are evaluated for hemorrhage and the adjacent pleural cavity and pulmonary surfaces are inspected for evidence of damage or neoplastic invasion and these are treated as needed. A thoracostomy tube should now be placed under direct visualization to provide optimal positioning for restoration of negative pressure within the pleural space.

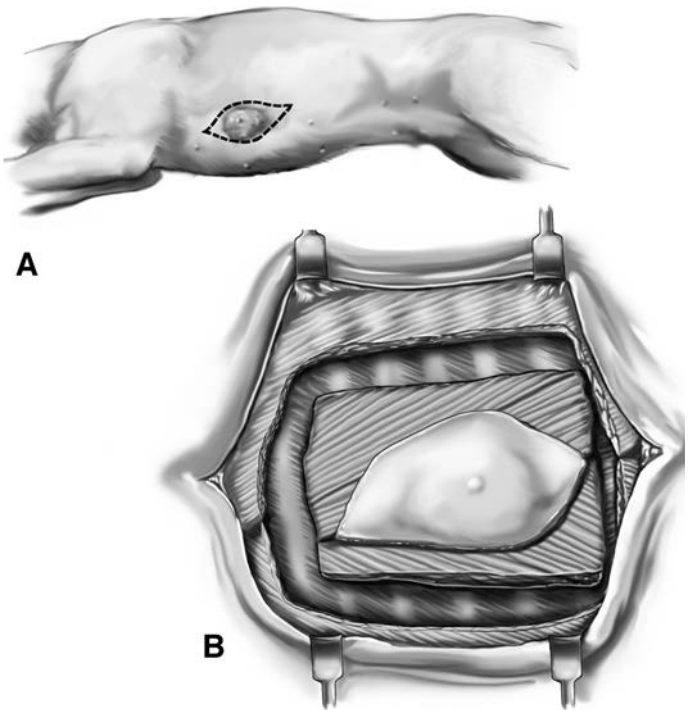


Figure 28-1. *En bloc* resection of thoracic wall tumor. **A.** Fusiform excisional boundary of a thoracic wall tumor. **B.** Wide excisional boundaries of thoracic musculature.

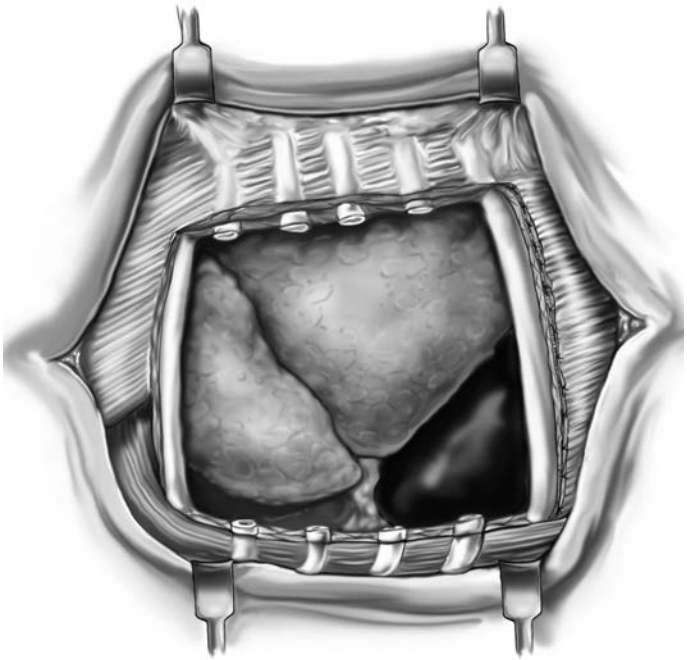


Figure 28-2. *En bloc* resection of thoracic wall tumor. All ribs involved with the tumor and one rib cranial and caudal are cut dorsally and ventrally. The intercostal musculature has been cut at the same level and the section of thoracic wall has been removed.

Thoracic Wall Reconstruction

Regardless of the technique used to close the thoracic wall, there are two general requirements that must be fulfilled during the repair. First, the repair must be relatively air tight so that negative pleural space pressure can be restored. Second, the repair should be sufficiently rigid so as to prevent excess paradoxic motion and protect thoracic organs.[5,6] Paradoxic motion involving a small section of the thoracic wall is considered a cosmetic defect and will have little effect on ventilation.

Use of autologous tissues to reconstruct thoracic wall defects is generally reserved for smaller defects. Standard soft tissue closure can be used with defects that only involve one rib and the surrounding muscles. Reconstructive muscular flaps using the latissimus dorsi and rectus abdominus muscles have been reported.[5,6] The origin of the muscles can be elevated and rotated

to cover the defect and this is followed by closure of the subcutaneous tissues and skin. When the defect is considered too large for simple closure or muscle flaps, the greater omentum can be isolated and utilized to augment wound coverage.[5,6] The greater omentum can be retrieved through a paracostal or transdiaphragmatic approach to the abdominal cavity. If the omentum can be exteriorized through the paracostal incision and manipulated through a subcutaneous tunnel to reach the defect, it is sutured over the defect and the remaining tissues are closed. When the defect cannot be reached, an omental pedicle extension flap can be prepared by previously described techniques.[13,14] The omental flap is then passed through the paracostal incision and a subcutaneous tunnel and sutured to the thoracic defect.

Larger thoracic defects may require the use of synthetic materials. Various materials are available for reconstruction such as polypropylene mesh, polymer composite struts, and combinations of synthetic materials.[4,6,10,11,16-22] When the defect is four ribs or fewer, mesh may be all that is required to cover the defect and available soft tissues are then used to cover the mesh. After the mass is excised and a thoracostomy tube is placed, a piece of mesh is cut such that it is approximately one centimeter larger than the thoracic wall defect on all sides. The edges of the mesh are folded away from the pulmonary surface and placed within the pleural cavity. This provides a double mesh layer for suturing. Along either the cranial or caudal border of the defect, non-absorbable monofilament sutures are placed around a rib and through the folded edge of the mesh implant. After the entire edge is secured, the dorsal and ventral borders are alternately sutured from the secured towards the unsecured side, engaging soft tissues and encircling the ribs or being passed through predrilled holes through the cut ends of ribs (Figure 28-3). It is important to stretch the mesh tightly and maintain even tension as the dorsal and ventral sutures are placed. The final border is now sutured in a similar manner as the initial border again stretching and maintaining tension on the mesh. At this point the superficial thoracic muscles are sutured using a four corner simple interrupted pattern to decrease the size of the defect.[4] (Figure 28-4) If the defect cannot be entirely closed using this technique the latissimus dorsi muscle can be undermined and sutured over the remaining area. If simple undermining and suturing is not sufficient then the origin of the muscle can be incised and then rotated into the defect for coverage. (Figure 28-5) Direct cutaneous vessels that perforate the caudal aspect of the muscle should be ligated and transected prior to rotation of the muscle.[4] Alternatively, other muscle flaps such as the rectus abdominus muscle can be used. The greater omentum can also be used as previously described to cover the mesh prior to muscular and/or subcutaneous and cutaneous closure.[4,13,14]

If more than four ribs have been excised, closure with mesh may not provide a stable repair and paradoxic thoracic motion may be seen. In order to prevent abnormal motion and provide protection, various devices such as synthetic, metal, or bioabsorbable plates or rib allografts have been attached to the osteotomized rib ends across the defect, over the mesh and secured with interrupted wire sutures[4,6,10,18,19] (Figure 28-6).

Bioprosthetic materials such as small intestinal submucosa may be considered for use in thoracic wall reconstruction as an adjunct to or an alternative to synthetic mesh materials. These have been used successfully in humans to reconstruct *en bloc* resections of the thoracic wall.[23,24] Reports of its use in veterinary surgery for thoracic wall reconstruction are lacking. The physiologic properties of these bioprosthetic materials have been shown to be acceptable for soft tissue augmentation and it is reasonable that this would be true for animals as well.[25]

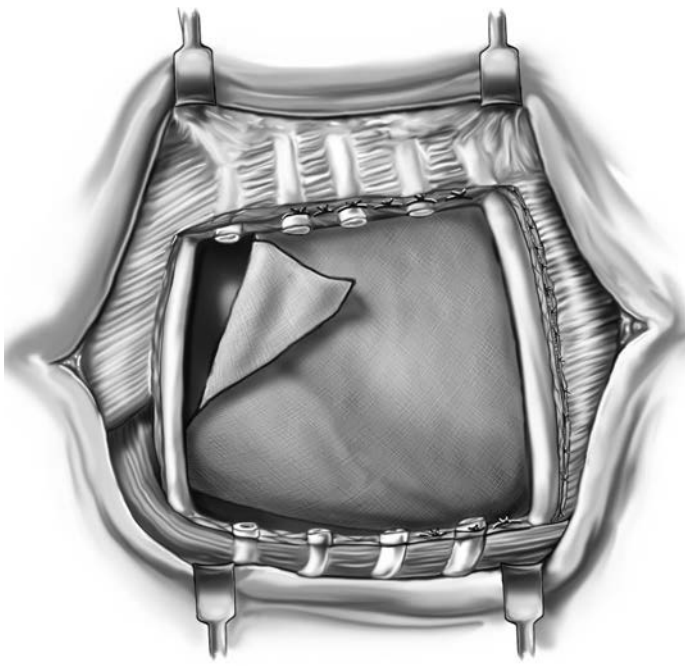


Figure 28-3. Synthetic mesh placement for thoracic wall reconstruction. The caudal edge of the mesh has been folded and sutured in place. The dorsal and ventral edges are likewise folded away from the lung and alternately sutured towards the unsecured edge.

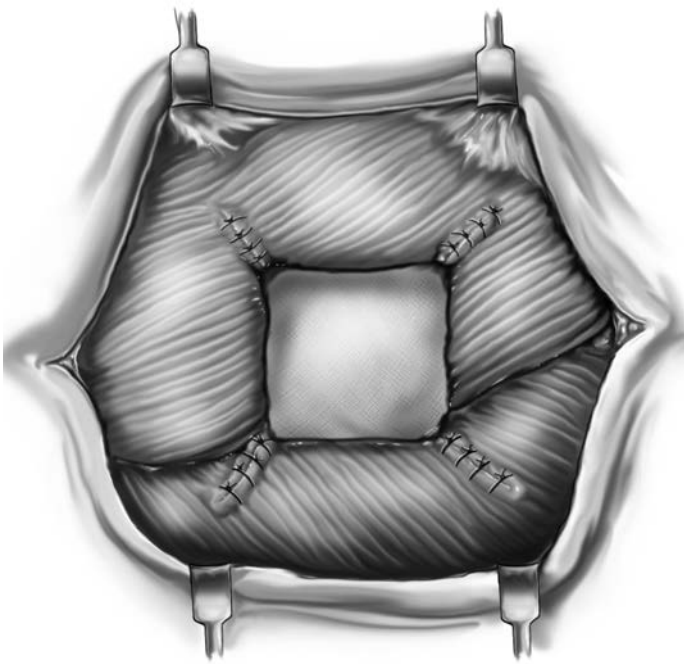


Figure 28-4. Synthetic mesh placement for thoracic wall reconstruction. Thoracic musculature is sutured in a four corner simple interrupted pattern to decrease the size of the thoracic wall defect.

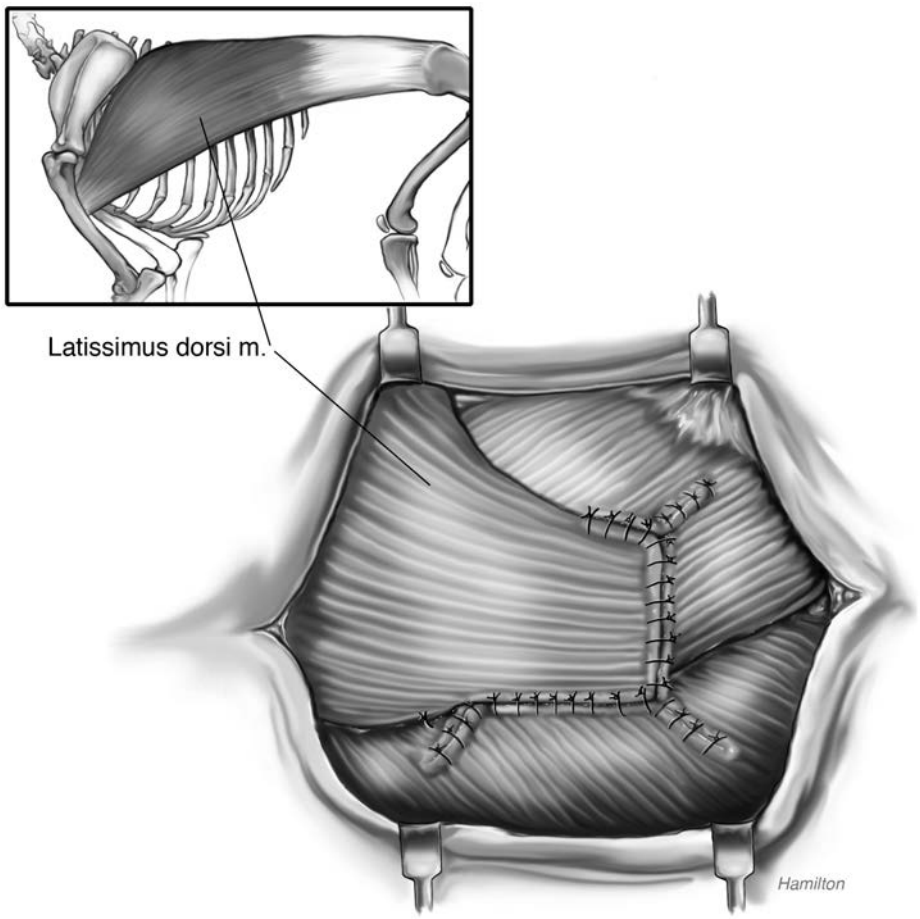


Figure 28-5. Coverage of a thoracic wall defect with a latissimus dorsi flap. The origin of the latissimus dorsi is identified and elevated and rotated to cover the thoracic wall defect and secured.

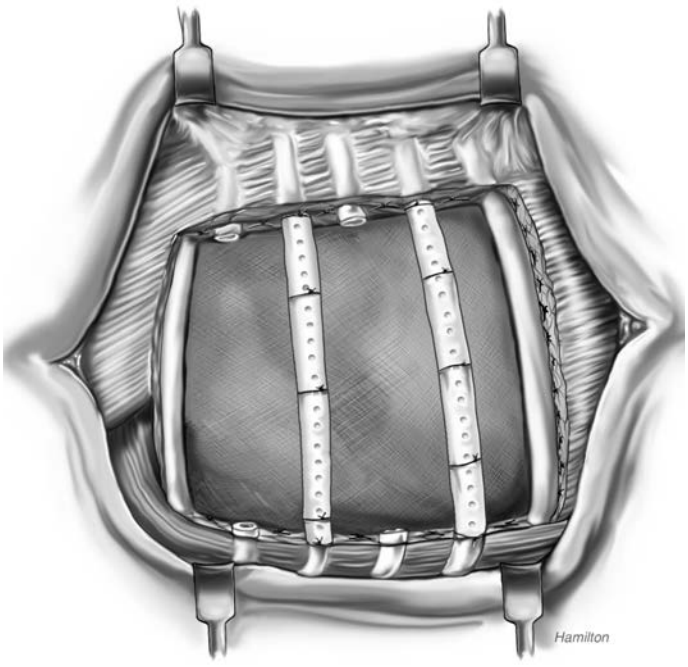


Figure 28-6. Placement of plate struts to stabilize large thoracic wall defects of 4 or more ribs. Plates have been attached to transected rib ends and secured to the underlying mesh.

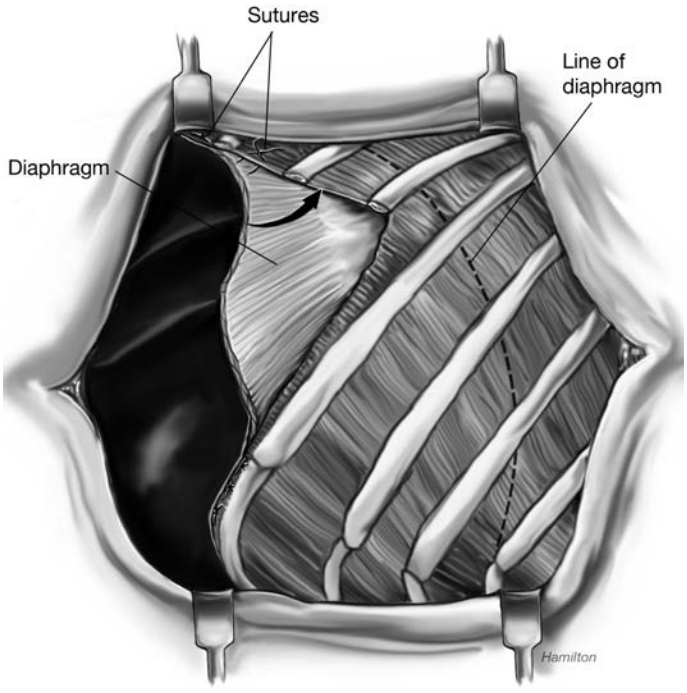


Figure 28-7. Diaphragmatic advancement for caudal thoracic wall reconstruction. The caudal diaphragm attachment is transposed cranially and sutured to the intercostal musculature, osteotomized ribs, and around the remaining caudal rib if necessary.

Diaphragmatic Advancement

If thoracic wall neoplasia involves the caudal ribs, *en bloc* excision is performed as described, however closure of the pleural space can be accomplished by diaphragmatic advancement.[4,5,6,10,26] This technique can be used when reconstruction from the eighth to the thirteenth rib is required.[26] The eighth rib articulates with the sternum and maintains thoracic stability and protection of the thoracic organs. Therefore the diaphragm can be advanced and attached to this rib. Following transection of caudal ribs and costal cartilages the line of diaphragmatic attachment will be exposed. The diaphragm is sutured to the cut edge of the thoracic wall and osteotomized ribs. (Figure 28-7) Cranial transposition of the diaphragm decreases the size of the thoracic cavity and if larger caudal thoracic resections are required for tumor resection, it may be necessary to perform a caudal lung lobectomy.[6]

References

1. Withrow SJ: Surgical Oncology *In* Withrow SJ, MacEwen EG, eds: Small Animal Clinical Oncology, 3rd ed. Philadelphia: WB Saunders, 2001, p 70.

2. Fossum TW: Thoracic Wall and Sternum: Diseases, Disruptions, and Deformities *In* Bojrab MJ, ed.: Disease Mechanisms in Small Animal Surgery, 2nd ed. Philadelphia: Lea & Febiger, 1993, p 411.

3. Sweet DC, Waters DJ: Role of surgery in the management of dogs with pathologic conditions of the thorax. Compend Contin Educ Pract Vet 13:1671, 1991.

4. Orton EC: Small Animal Thoracic Surgery. Philadelphia: Williams & Wilkins, 1995, p 73.

5. Fossum TW: Surgery of the lower respiratory system: lungs and thoracic wall *In* Fossum TW, ed.: Small Animal Surgery, 3rd ed. St. Louis: Mosby, Inc., 2007, p 867.

6. Orton EC: Thoracic wall *In* Slatter D, ed: Textbook of Small Animal Surgery, 3rd ed. Philadelphia: Elsevier Science, 2003, p 373.

7. Bell FW: Neoplastic diseases of the thorax. Vet Clin North Am Small Anim Pract 17:387, 1987.

8. Bauer T, Woodfield JA: Mediastinal, pleural and extrapleural diseases. In Ettinger SJ, Feldman EC, eds.: Textbook of Veterinary Internal Medicine, 4th ed. Philadelphia: WB Saunders, 1995, p 815.

9. Feeney DA, Johnston GR, Grindem, et al.: Malignant neoplasia of canine ribs: clinical, radiographic and pathologic findings. J Am Vet Med Assoc 180:927, 1982.

10. Dernell WS, Straw RC, Withrow SJ: Tumors of the skeletal system *In* Withrow SJ, MacEwen EG, eds: Small Animal Clinical Oncology, 3rd ed. Philadelphia: WB Saunders, 2001, p 378.

11. Matthiesen DT, Clark GN, Orsher RJ, et al.: En bloc resection of primary rib tumors in 40 dogs. Vet Surg 21:201, 1992.

12. Pirkey-Ehrhart N, Withrow SJ, Straw RC, et al.: Primary rib tumors in 54 dogs. J Am Anim Hosp Assoc 31:65, 1995.

13. Ross WE, Pardo AD: Evaluation of an omental pedicle extension technique in the dog. Vet Surg 22:37, 1993.

14. Hedlund CS: Surgery of the integumentary system *In* Fossum TW, ed.: Small Animal Surgery, 3rd ed. St. Louis: Mosby, Inc., 2007, p 222.

15. MacEwen EG, Powers BE, Macy D, et al.: Soft tissue sarcoma *In* Withrow SJ, MacEwen EG, eds: Small Animal Clinical Oncology, 3rd ed. Philadelphia: WB Saunders, 2001, p 283.

16. Lampl LH, Loeprecht H: Chest wall reconstruction: alloplastic replacement. Thorac Cardiovasc Surg 36:157, 1988.

17. Akiba T, Takagi M, Shioya H: Reconstruction of thoracic wall defects after tumor resection using polytetrafluoroethylene soft tissue (Gore-Tex) patch. Jpn J Thorac Cardiovasc Surg 46:526, 1998.

18. Johnson KA Goldsmid SE: Methylmethacrylate and polypropylene mesh reconstruction of ventral thoracic wall deficit following sternal liposarcoma resection. Vet Comp Orthop Traumatol 6:62, 1993.

19. Spackman CJA, Caywood DD: Management of Thoracic Trauma and chest wall reconstruction. Vet Clin North Am Small Anim Pract 17:431, 1987.

20. Ellison GW, Trotter GW, Lumb WV: Reconstructive thoracoplasty using spinal fixation plates and polypropylene mesh. J Am Anim Hosp Assoc 17:613, 1981.

21. Briccoli A, Manfrini M, Rocca M, et al.: Sternal reconstruction with synthetic mesh and metallic plates for high grade tumours of the chest wall. Eur J Surg 168:494, 2002.

22. Tuggle DW, Mantor PC, Foley DS, et al.: Using a bioabsorbable copolymer plate for chest wall reconstruction. J Pediatr Surg 39:626, 2004.

23. Cothren CC, Gallego K, Anderson ED, et al.: Chest wall reconstruction with acellular dermal matrix (Alloderm) and a latissimus dorsi flap. Plast Reconstr Surg 114:1015, 2004.

24. Berberoglu U, Alogol H: Reconstruction of a chest wall defect with dehydrated human dura mater graft. Thorac Cardiovasc Surg 41:133, 1993.

25. Spiegel JH, Egan TJ: Porcine intestine submucosa for soft tissue augmentation. Dermatol Surg 30:1486, 2004.

26. Aronsohn MG: Diaphragmatic advancement for reconstruction of the caudal thoracic wall. *In* Bojrab MJ, Ellison GW, Slocum B, eds. In Current Techniques in Small Animal Surgery, 4th ed. Baltimore: Williams & Wilkins, 1998, p 419.

Management of Flail Chest

Dennis Olsen

Pathophysiology

Flail chest exists when costal support of a section of the thoracic wall has been lost due to segmental (minimum of two) fractures, dorsal and ventral, of at least two adjacent ribs. It is also reported to occur in young animals with only dorsal fractures of adjacent ribs and pliable costal cartilages that cannot resist the interpleural pressure changes that accompany respiration.[1,2] The fractures create a section of thoracic wall that has lost not only structural but functional continuity with adjacent normal thoracic wall. The section "flails" asynchronously with normal motion of the thorax during respiration and is characterized by paradoxic inward displacement during inhalation and outward displacement during exhalation. For many years the clinical signs associated with flail chest were thought to be due, in large part, to the paradoxic movement of the flailing section.[2-8] It was thought that pendulous airflow which occurs between opposite lungs resulted from the loss of thoracic wall integrity (Pendelluft theory).[3,4,7,8] Simply stated, the air in the lung beneath the flail section would flow across to the lung in the opposite hemithorax upon inhalation and then back again during exhalation. This abnormal airflow would result in increased physiologic "dead space" and contribute to decreased vital and functional residual capacities, increased airway resistance, and hypoxemia. The end result was severe respiratory distress attributed to the erratic thoracic wall motion. Therapeutic efforts were primarily

directed at stabilizing the unstable section as soon as possible and this treatment is still recommended by some authors.[5,6,9,10] Consequently, there are many published techniques for thoracic wall stabilization, from procedures that place and maintain traction on ribs in the unstable section with braces or external fixation devices to internal fixation of the fractures in an effort to restore synchronous motion of the thoracic wall.[2,3,5,8-10]

Increased understanding of flail chest pathophysiology has revealed that paradoxic motion may produce a transient, minimum volume of pendulous airflow between lungs as well as mechanical disruption of normal thoracic movement but these problems alone seem to have little effect on ventilation.[2,11,12] These findings have redirected focus from the unstable flail section to underlying pulmonary damage, inflammatory mediators, and pain as the main contributors to respiratory dysfunction.[2-4,7,8,12-16] Pulmonary contusions are often seen in cases of thoracic trauma and are considered the most common accompanying lesion following traumatic incidents that lead to flail chest.[8,14,17-20] Pulmonary contusions are inevitable when trauma is sufficient to result in solitary rib fractures or create a flail chest.[2,3-5,7-10,12,13] The damage seen in the lungs includes rupture of alveoli, blood vessels and capillaries resulting in intraalveolar and interstitial hemorrhage. Pulmonary parenchyma is also damaged and plasma components begin leaking into the tissues and airways.[14] The alveolar damage and vascular leakage leads to obstruction of airways, decreased pulmonary compliance, and arteriovenous shunting, all of which contribute to hypoventilation and hypoxemia. In addition to structural damage, there is release of inflammatory mediators such as arachodonic acid and eicosanoids that adversely affect pulmonary function by acting as chemotactic factors for granulocytes which contribute to local tissue damage through the effects of oxygen radicals.[14,16] Although the role of pulmonary damage is more clearly understood, the dramatic appearance of a flailing chest wall in a dyspneic patient may lead to the less readily apparent pulmonary contusion being overlooked and misdirected therapy to the unstable thoracic wall.

In addition to contusions, the pulmonary parenchyma can be directly damaged by the ends of fractured ribs involved in the flail section.[2,22,23] Direct pulmonary damage can lead to leakage of air into the pleural space (pneumothorax) causing loss of negative pressure and resultant varying degrees of lung atelectasis. Leakage of air can be self-limiting as long as there is not continued pulmonary damage from fractured ribs and a fibrin seal forms over the traumatized parenchyma. Rupture of alveoli and small airways caused by the initial trauma can also lead to pneumothorax with the same negative effects on ventilation. The degree of respiratory insufficiency caused by contusions is compounded when a pneumothorax exists due to the inability of the lungs to expand. Alveolar and small airway rupture can also cause pneumomediastinum that can progress to subcutaneous emphysema as the air migrates through fascial planes at the thoracic inlet. Air can also reach the subcutaneous tissues if the pleura and intercostals muscles are disrupted. Generally, subcutaneous emphysema alone is not deleterious to the patient and therefore not of major concern.[23,24]

Pain is another recognized component in the pathophysiology of respiratory distress that accompanies flail chest.[2,3,7,9,25] Pain contributes to hypoventilation due to patient reluctance to fully expand the thoracic wall, which results in hypoxemia, pulmonary atelectasis, and also in a diminished cough reflex which leads to the accumulation of pulmonary secretions.[3,7,26,27]

Medical Treatment

The dramatic appearance of a flailing section of thoracic wall often motivates the clinician to focus therapeutic efforts on stopping the abnormal thoracic wall motion. However, it is critical to understand that trauma sufficient to cause flail chest has likely produced multisystemic problems, some of which may require more immediate therapy. Emergency triage is essential in order to identify critical abnormalities so primary therapy will focus on stabilization of the traumatized patient. Life threatening injuries are addressed as soon as they are recognized and the familiar "A, B, C" acronym provides a time proven guide for evaluation and treatment priority.

Following stabilization of conditions that are an immediate threat to life such as open pneumothorax with measures such as thoracostomy tube placement, specific therapy directed to the pathologic consequences of flail chest can be initiated. Placing the patient in lateral recumbency with the affected side down will minimize the paradoxic motion of the flail section, which will in turn decrease pain and potential further injury to the lung lobes. Severely effected animals may show hemoptysis or an accumulation of a foamy blood-tinged fluid in the airways, which can lead to airway obstruction. These cases will benefit from immediate endotracheal intubation and airway suction with a catheter placed through the tube into the mainstem bronchi and intermittent aspiration.

It should be assumed that animals with flail chest have pulmonary contusions.[28] Therapy for pulmonary contusions is considered supportive and the degree of therapy depends on the severity of the lesion.[14,28,29] Basic support begins with maintaining and/or improving oxygenation. Oxygen supplementation through an oxygen cage, hood, or nasal cannula can be used to maintain arterial oxygen saturation (SpO_2) above 92% and partial pressure of arterial oxygen (PaO_2) above 60 mm Hg.[14,28] Continued leaking of plasma components, interstitial fluid, and increasing edema can contribute to clinical deterioration and this must be closely monitored. If hypoxemia worsens as evidenced by a falling SpO_2 or a PaO_2 that is not responsive to O_2 supplementation then positive pressure ventilation may be necessary. Positive pressure ventilation provides oxygen and is effective in treating hypoxemia caused by atelectasis, pain, and blood within the airways. A progressive decrease in peak inspiratory pressure required for patient stabilization has been shown to be a sign of improving pulmonary function.[30] Positive pressure ventilation has several other advantages for the flail chest patient. It stops paradoxic motion of the flail section, decreases pain, and allows better apposition of the fractured ribs. Unfortunately, long term maintenance of a veterinary patient on positive pressure ventilation is difficult and not without complications.[14,31] Ventilatory support should also include frequent positional changes to

minimize lung lobe atelectasis. If the patient's condition permits then intermittent standing episodes or short walks can improve thoracic expansion.[14,28,31]

Pain management is an important aspect of medical therapy for flail chest. Pain contributes to reduced ventilatory efforts, which contributes to hypoxia and atelectasis. The cough response is also decreased due to pain and pulmonary secretions accumulate contributing to airway obstruction and potentially to bacterial infection. Proper pain management has become one of the major components of medical management and has been shown to improve ventilatory efforts, which decreases atelectasis, improves blood oxygen content, and enhances the ability to cough. The method of pain control selected is important and can effect patient ventilation. Some opioid analgesics are known to depress respiration and are potent antitussives. Because achieving a balance between these potentially harmful effects and effective pain control is difficult to achieve, alternative methods of pain control are available.[14] Intercostal nerve blocks using long acting local anesthetic agents such as bupivacaine hydrochloride (Marcaine, Abbott) have been shown to be effective in controlling pain and improving ventilation.[3,14,28,32] Nerve blocks are performed by injecting the local anesthetic caudal to all fractured ribs and one rib cranial and caudal to the flail section without entering the pleural space. Some authors advocate blocking the nerves dorsal to the fractures while others suggest both dorsal and ventral to the fractures[28,33] (Figure 28-8). A small gauge needle (25 to 27 g) is carefully "walked" off the caudal margin of the rib where 0.25 to 0.5 cc of the anesthetic is to be deposited (Figure 28-9). When bupivacaine hydrochloride is used the total dose should not exceed 1.5 mg/kg.[28] Gentle aspiration of the syringe will assure that injection will not be into an intercostal vessel. Since local anesthetics block motor nerves as well as sensory nerves it is important not to block excess intercostal nerves as ventilatory capability may be compromised.[28]

Another effective pain control is interpleural instillation of a local anesthetic agent. Research has shown that interpleural bupivacaine can be an effective analgesic in cases of human thoracic trauma as well as post thoracotomy in veterinary patients.[34-36]

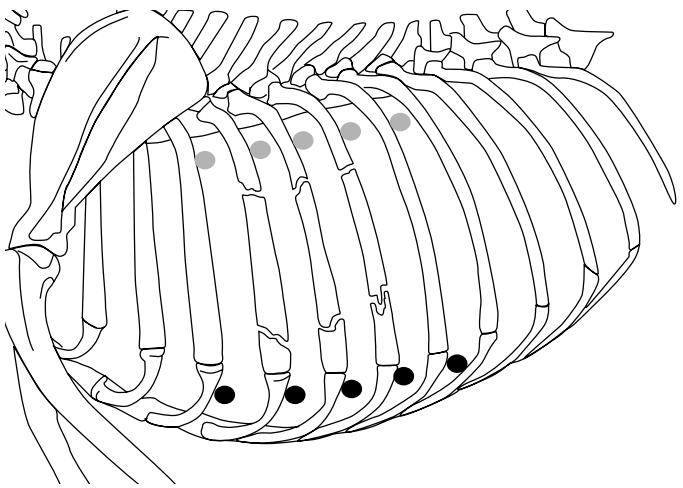


Figure 28-8. Schematic representation of the locations for placement of intercostal nerve blocks for a 3 rib flail section. Grey dots indicate dorsal location while the black dots indicate the optional ventral location.

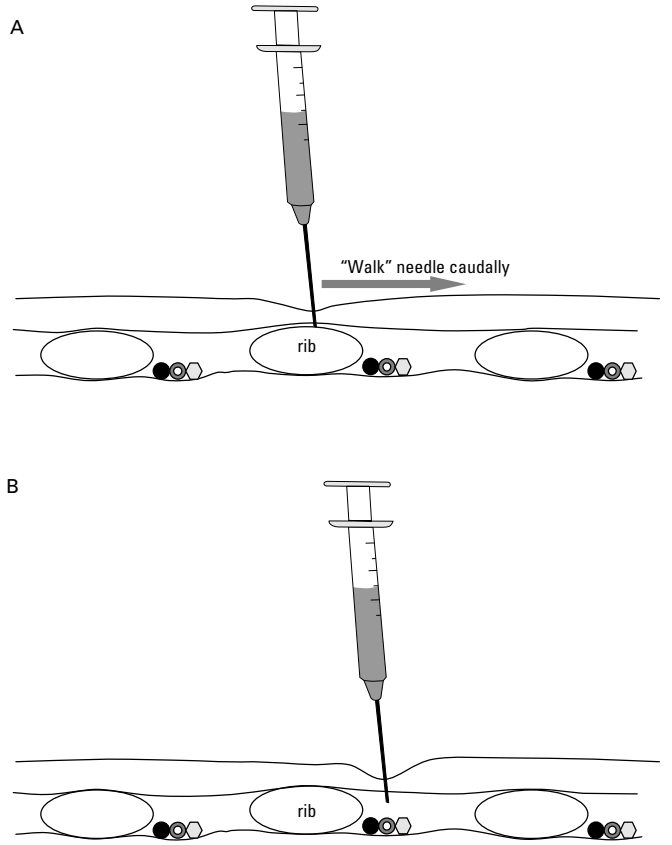


Figure 28-9. Schematic drawing of the technique for instillation of local anesthetic for intercostal nerve block. **A.** locating the rib with the hypodermic needle. **B.** Needle is "walked" off the rib in a caudal direction prior to instillation of the anesthetic.

In cases where a thoracostomy tube has been placed the drug can be instilled through the tube and the patient placed in lateral recumbency with the flail side down. This will allow the parietal pleural surface to be bathed with the local anesthetic. When a thoracostomy tube is not in place, an over the needle catheter can be introduced into the pleural space for drug instillation. Local anesthetics are mildly acidic and cause short term pain on injection. The addition of sodium bicarbonate to the local anesthetic drug increases the pH and decreases the pain on injection. In addition, it is theorized that more of the anesthetic agent molecules are converted to the nonionic form, which increases the rate of penetration and shortens the onset of anesthesia. Unfortunately, a slight increase in the pH of bupivacaine can lead to precipitation and inactivation.[37] To minimize the discomfort of interpleural instillation of bupivicaine, a preliminary dose of alkalinized lidocaine (1 cc 8.4% sodium bicarbonate in 10 cc 1% lidocaine) at 1.5 mg/kg can be instilled followed by the bupivacaine also at 1.5 mg/kg.

Epidural analgesia has also been shown to be an effective pain control method.[14,28,38] Drugs used in epidural analgesia include opioids, local anesthetics, alpha 2 agonists, and nonsteroidal anti-inflammatory drugs.[38,39] Combinations of drugs can be administered to achieve a synergistic action. As previously described, opioids can lead to respiratory depression and reduce the protective cough reflex. When opioids are administered epidurally these potentially detrimental side effects are diminished and if seen

the opioid can be easily reversed.[14] The site for epidural administration of analgesics is the lumbosacral space. The landmarks for locating the space are the ilial wings and the dorsal spinous process of L7. The site for injection is a depression on the dorsal midline caudal to the L7 dorsal spinous process on an imaginary line between the iliac crests. Once located, the area is clipped and prepared aseptically and an appropriate spinal needle is used to penetrate the skin, subcutaneous tissues, supraspinous and interspinous ligaments, and ligamentum flavum. Because the ligamentum flavum offers increased resistance to the passage of the needle a distinct "pop" may be felt indicating entry into the epidural space. Accurate placement can be verified by injecting a small amount of sterile saline or air in a separate syringe and encountering little to no resistance. When there is no resistance, the syringe containing the anesthetic agent is placed on the needle and the drug is injected. For appropriate drugs and doses to administer epidurally an appropriate anesthesia text or formulary should be consulted (See Chapter 9). Complications from epidurals are relatively uncommon and may be related to the drug and amount used.

Fluid therapy is often necessary in the initial management of flail chest cases because patients may be in shock. However, the presence of pulmonary contusions that accompany flail chest can complicate fluid therapy. It is important to maintain adequate tissue perfusion and hydration without contributing to fluid overload and pulmonary edema that could occur with high fluid rates that may be required in cases of shock.[14,22,31,40] The type of fluid, crystalloid (isotonic or hypertonic) or colloid, that should be used is a point of debate and controversy.[14,28,31] There is agreement, however, that regardless of the fluid type, the therapy should maintain cardiac performance and tissue perfusion. This can be accomplished with various fluid types but requires careful monitoring of physiologic parameters such as indicators of perfusion, arterial blood pressure, central venous pressure, urine output, and respiratory function. Therefore, whether delivering isotonic crystalloids for shock (90 ml/kg/hr in dogs, 45 to 50 ml/kg/hr in cats), hypertonic saline (4 to 5 ml/kg) followed by isotonic crystalloids, or hypertonic saline and colloid combinations, the primary aim is to maintain tissue perfusion.[14,41] The use of diuretics to decrease pulmonary edema should only be considered if generalized fluid overload occurs because the increased vascular permeability that often attends pulmonary contusions renders diuretics such as furosemide ineffective.[14,28]

Antibiotics should be administered when cases of flail chest have been caused by penetrating injury such as bite wounds. However, antibiotics are not indicated when pulmonary contusions are the primary concern because of the low incidence of bacterial pneumonia.[14,28,41] Inflammatory mediators released in trauma cases are known to exacerbate clinical signs that can accompany flail chest and one key to minimizing pulmonary injury may be to control the inflammatory cascade. The use of corticosteroids is controversial in that some studies have shown benefit while others suggest no effect or potential adverse consequences. A high dose of methylprednisolone (30 mg/kg) given within a short time of the trauma (~30 minutes) may have benefit but studies do not agree on this point.[3,14,28] Other approaches to mitigate the effects of anti-inflammatory mediators have shown promise in laboratory models and initial clinical trials but there are many that do not.[14,31,42,43] Further research is needed before general recommendations regarding anti-inflammatory therapy can be made.

Surgical Therapy

Therapeutic recommendations in veterinary medicine for many years have largely involved surgical stabilization of the flail segment but it is emphasized that surgery should only be performed when the patient has been clinically stabilized or if there is imminent risk of further trauma to thoracic organs due to motion of the flail section. Because of previous concerns relative to chest wall instability there are many methods described for stabilization.[2,3,5,6,8-10]

If flail chest has resulted in severe tissue disruption, open pneumothorax, or fracture fragments that have, or may lacerate thoracic organs, then open reduction of the fractured ribs and restoration of thoracic wall continuity is indicated as soon as the patient's condition permits. Repair of rib fractures, depending on the size of the patient, can be undertaken with appropriately sized orthopedic pins and wire or plates and screws. In addition to orthopedic repair, it is equally important to re-establish soft tissue integrity such that negative pleural space pressure can be restored. Repair of soft tissues when one intercostal space has been disrupted can be accomplished in a manner similar to closure of an intercostal thoracotomy following adequate debridement of devitalized tissues.[10] If the soft tissue integrity of multiple intercostal spaces has been disrupted it may be necessary to place a series of staggered overlapping circumcostal sutures incorporating all of the affected ribs and one rib cranial and caudal to the effected section. This creates a "basket weave" pattern and can act as a support for soft tissues mobilized to cover the defect such as the latissimus dorsi or external abdominal oblique muscles or a flap created from the greater omentum.[10] Placement of a thoracostomy tube will facilitate reestablishment of negative interpleural pressure and aid in postoperative management.

The more common methods of flail section stabilization involve the percutaneous placement of sutures that encircle the ribs of the flail section, applying traction with those sutures and attaching them to an external brace that uses the adjacent intact thoracic wall to provide counter traction for stabilization of the flail segment. Prior intercostal nerve blocks with long acting local anesthesia will facilitate placement of the external brace. One such method utilizes heat sensitive plastic or fiberglass casting material that has been molded to fit the thoracic wall over the area of the flail section. It is important that the prosthetic material extend beyond the borders of the flail section so that it rests across non-fractured ribs. Once molded and set, two holes are placed through the material in locations that will correspond to each fractured rib in the flail section. It is important to place holes sufficient for passage of two sutures per fractured rib, dorsally and ventrally positioned. This will prevent pivoting of the ribs that may occur with only one point of fixation.[3,33] The area for suture placement should be prepared aseptically and monofilament non-absorbable sutures should be passed around

each rib, dorsally and ventrally, so that the suture ends can be passed through the holes placed through the bracing material. In order to avoid interference of the brace with proper suture placement it is important to preplace all of the sutures prior to securing the brace. When passing the suture it is prudent that as the needle passes around the rib it remains immediately adjacent to the bone especially along the caudal and medial borders. This will minimize the potential of encircling the neurovascular bundle caudally and lacerating pulmonary parenchyma (Figure 28-10). It has been reported that placement of circumcostal sutures does not usually damage the underlying lung because the existing pneumothorax results in a gap between the visceral and parietal pleura, caution should none-the-less be exercised during placement.[2] After suture placement, light padding can be interposed between the thoracic wall and the bracing material. The suture ends are passed medial to lateral through the holes in the brace and secured (Figure 28-11). A light thoracic bandage can then be placed to help secure and protect the brace. The brace should be left in place for 3 to 4 weeks to allow for soft tissue healing and callus formation around the fractured ribs. The bandage should be checked on a periodic basis to assure proper position and evaluate the skin under the edges of the brace. If cutaneous lesions become evident, the padding may need to be increased around the edges of the brace.

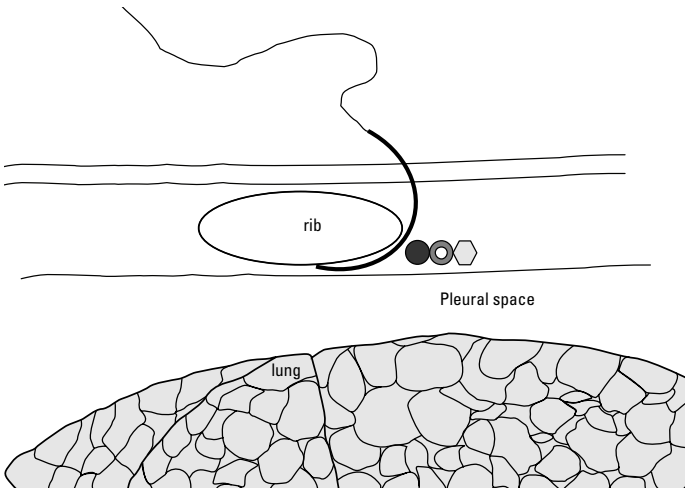


Figure 28-10. Schematic drawing of the technique for passing suture around the rib. The needle should stay adjacent to the bone to avoid the neurovascular bundle and underlying lung.

An alternative method of thoracic wall stabilization creates an external brace that is also effective at controlling abnormal motion. This method utilizes one suture passed around the midpoint of each rib in the flail section as previously described. The suture is then tied around a tongue depressor such that the long axis of the depressor lies vertically over the rib. At this point rigid counter braces, such as additional tongue depressors, are placed at the dorsal and ventral extents of the tongue depressors attached to each rib. The counter braces must rest across stable thoracic wall and are placed beneath and perpendicular (horizontally oriented) to the tongue depressors so that the flail section cannot be drawn inward. Cotton padding is placed between the tongue depressor ends and the counter braces to increase traction on the flail section for added stability. This simplified method of stabilization requires materials that are readily available and only requires the placement of one circumcostal suture[2,9] (Figure 28-12). The bracing should be protected from becoming entangled in bedding or being dislodged by covering it with a padded bandage. The brace is left in place for 3 to 4 weeks to allow osseous callus formation and soft tissue healing.

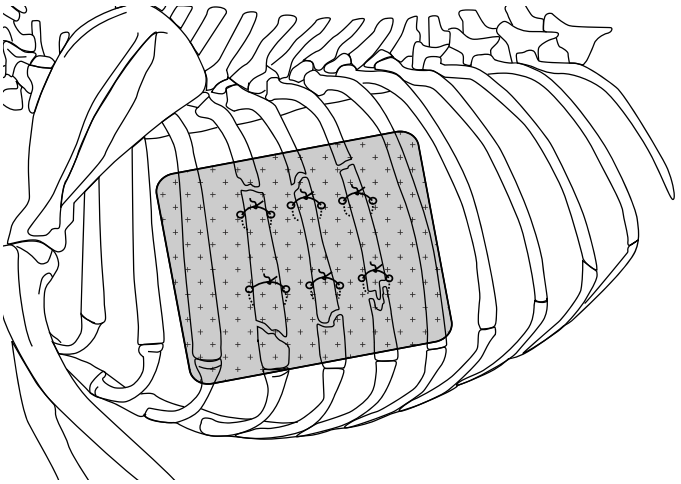


Figure 28-11. Schematic drawing of an external moldable splint for stabilization of a flail section. Two circumcostal sutures are pre-placed at the dorsal and ventral extents of each rib of the flail section and then secured to the moldable splint through appropriately placed perforations. The splint extends beyond the flail section to rest on stable thoracic wall.

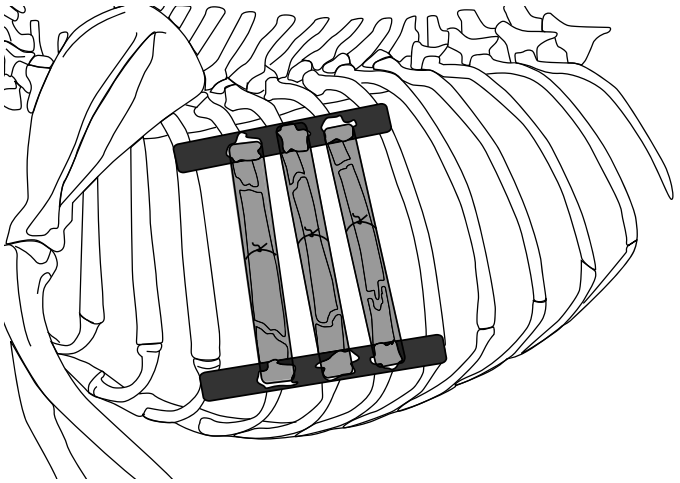


Figure 28-12. Schematic drawing of a simplified bracing of a flail section. One circumcostal suture is placed around the mid portion of each rib in the flail section and then tied around a tongue depressor. Horizontal counter braces are placed beneath the dorsal and ventral extents of the tongue depressors and cotton padding is placed between each depressor and counter brace contact point. Padding is sufficient to result in lateral traction on the flail section create stability.

References

1. Kolata RJ: Management of thoracic trauma. Vet Clin North Am Small Anim Pract 11:103, 1981.

2. Bjorling DE: Surgical management of flail chest. *In* Bojrab MJ, Ellison GW, Slocum B, eds.: Current Techniques in Small Animal Surgery. Baltimore: Williams and Wilkins, 1998, p 421.

3. Anderson M, Payne JT, Mann FA, *et al.*: Flail chest: Pathophysiology, treatment, and prognosis. Comp Cont Ed Pract Vet 15:65, 1993.

4. Trinkle JK, Richardson JD, Franz JL, *et al.*: Management of flail chest without mechanical ventilation. Ann Thor Surg 19:355, 1975.

5. Kagen KG: Thoracic Trauma. Vet Clin N Am Sm Anim Pract 10:641, 1980.

6. Dixon JS: Use of a slab traction splint to stabilize canine flail chest. Vet Med Sm Anim Clin 77:601, 1982.

7. Shackford SR, Smith DE, Zarins CK, *et al.*: The management of flail chest: A comparison of ventilatory and nonventilatory treatment. Am J Surg 132:759, 1976.

8. Bjorling DE, Kolata RJ, DeNovo RC: Flail chest: Review, clinical experience and new method of stabilization. J Am Anim Hosp Assoc 18:269, 1982.

9. McAnulty JF: A simplified method for stabilization of flail chest injuries in small animals. J Am Anim Hosp Assoc 31:137, 1995.

10. Orton EC: Thoracic wall. *In* Slatter D, ed.: Textbook of Small Animal Surgery (ed 3). Philadelphia: WB Saunders, 1993, p 373.

11. Harada K, Saoyama N, Izumi K, *et al.*: Experimental pendulum air in the flail chest. Jpn J Surg 13:219, 1983.

12. Craven KD, Oppenheimer L, Wood LDH: Effects of contusion and flail chest on pulmonary perfusion and oxygen exchange. J Appl Physiol 47:729, 1979.

13. Parham AM, Yarbrough DR, Redding JS: Flail chest syndrome and pulmonary contusion. Arch Surg 113:900, 1978.

14. Hackner SG: Emergency management of traumatic pulmonary contusions. Comp Cont Ed Pract Vet 17:677, 1995.

15. Cappello M, Yuehua C, DeTroyer A: Rib cage distortion in a canine model of flail chest. Am J Respir Crit Care Med 151:1481, 1995.

16. Melton SM, Davis KA, Moomey CB, *et al.*: Mediator-dependent secondary injury after unilateral blunt thoracic trauma. Shock 11:396, 1999.

17. Spackman CJA, Caywood DD, Feeney DA, *et al.*: Thoracic wall and pulmonary trauma in dogs sustaining fractures as a result of motor vehicle accidents. J Am Vet Med Assoc 185:975, 1984.

18. Crowe DT: Traumatic pulmonary contusions, hematomas, pseudocysts, and acute respiratory distress syndrome: An update-Part I. Comp Cont Ed Pract Vet 5:396, 1983.

19. Sweet DC, Waters DJ: Role of surgery in the management of dogs with pathologic conditions of the thorax-Part II. Comp Cont Ed Pract Vet 13:1671, 1991.

20. Tamas PM, Paddleford RR, Krahwinkel DJ: Thoracic trauma in dogs and cats presented for limb fractures. J Am Anim Hosp Assoc 21:161, 1985.

21. Griffon DJ, Walter PA, Wallace LJ: Thoracic injuries in cats with traumatic fractures. Vet Comp Orthop Traum 7:98, 1994.

22. Cockshutt JR: Management of fracture-associated thoracic trauma. Vet Clin N Anim Clin 25: 1031, 1995.

23. Fossum TW: Thoracic wall and sternum: Diseases, disruptions, and deformities *In* Bojrab MJ, ed.: Disease Mechanisms in Small Animal Surgery. Philadelphia: Lea & Febiger, 1993, p 411.

24. Fossum TW: Surgery of the lower respiratory system: Lungs and thoracic wall *in* Fossum TW, ed.: Small Animal Surgery. 3rd ed. St. Louis: Mosby, 2007, p 867.

25. Rich W, Reichenberger M: Managing flail chest. Nursing 11:26, 1981.

26. MacKersie RC, Shackford SR, Hoyt DB, *et al.*: Continuous epidural fentanyl analgesia: Ventilatory function improvement with routine use in treatment of blunt chest injury. J Trauma 27:1207, 1987.

27. Cullen P, Modell JH, Kirby RR, et al.: Treatment of Flail Chest: Use of intermittent mandatory ventilation and positive end expiratory pressure. Arch Surg 110:1099, 1975.

28. Beal MW: Thoracic trauma *In* Ettinger SJ, Feldman EC, eds.: Textbook of Veterinary Internal Medicine, 6th ed. St. Louis: Elsevier Inc., 2005, p 461.

29. Nelson OL, Sellon RK: Pulmonary parenchymal disease *In* Ettinger SJ, Feldman EC, eds.: Textbook of Veterinary Internal Medicine, 6th ed. St. Louis: Elsevier Inc., 2005, p1239.

30. Campbell VL, King LG: Pulmonary function, ventilator management , and outcome of dogs with thoracic trauma and pulmonary contusions: 10 cases (1994-1998). JAVMA 217:1505, 2000.

31. Bateman SW: Managing the acutely lung injured patient *In* Proceedings of the 11th Annual ACVS Symposium, Chicago, American College of Veterinary Surgeons, 2001, p 559.

32. McCool FD, Rochester DF: Lung and chest wall diseases. *In* Murray JF, Nadel JA, eds.: Textbook of Respiratory Medicine. Philadelphia: WB Saunders 1994, p 2524.

33. Spackman CJA, Caywood DD: Management of thoracic trauma and chest wall reconstruction. Vet Clin North Am Sm Anim Pract 17:431, 1987.

34. Knottenbelt JD, James MF, Bloomfield M: Intrapleural bupivacaine analgesia in chest trauma: a randomized double-blind controlled trial. Injury 22:114, 1991.

35. Thompson SE, Johnson JM: Analgesia in dogs after intercostals thoracotomy. A comparison of morphine, selective intercostals nerve block, and interpleural regional analgesia with bupivacaine. Vet Surg 20:73, 1991.

36. Conzemius MG Brockman DJ, King LG, *et al.*: Analgesia in dogs after intercostals thoracotomy: a clinical trial comparing intravenous buprenorphine and interpleural bupivacaine. Vet Surg 23:291, 1994.

37. Grabinsky A: Mechanisms of Neural Blockade. Pain Physician 8:411, 2005.

38. Wetmore LA, Glowaski MM: Epidural analgesia in veterinary critical care. Clin Tech Small Anim Pract 15:177, 2000.

39. Gallivan ST, Johnston SA, Broadstone RV, *et al.*: The clinical, cerebrospinal fluid, and histopathologic effects of epidural ketorolac in dogs. Vet Surg 29:436, 2000.

40. Van Pelt DR: Respiratory emergencies *In* Wingfield WE, ed.: Veterinary Emergency Medicine Secrets. Philadelphia, Hanley and Belfus 1997, p 50.

41. Mann FA: Pulmonary emergencies *In* Ettinger SJ, Feldman EC, eds.: Textbook of Veterinary Internal Medicine, 6th ed. St. Louis: Elsevier Inc., 2005, p 443.

42. Dahelm P, van Aalderen, de Neef M, *et al.*: Randomized controlled trial of aerosolized prostacyclin therapy in children with acute lung injury. Crit Care Med 32:1089, 2004.

43. Kelly ME, Miller PR, Greenhaw JJ, *et al.*: Novel resuscitation strategy for pulmonary contusion after severe chest trauma. J Trauma 55:94, 2003.

Section E

Urogenital System

Chapter 29

Kidney and Ureter

Nephrectomy

Eberhard Rosin

Nephrectomy may be indicated by the following unilateral conditions: 1) solitary renal cysts causing serious renal dysfunction; 2) hydronephrosis; 3) polycystic disease of the kidney complicated by pyelonephritis refractive to medical treatment; 4) infestation by *Dioctophyma renale* with severe degenerative changes; 5) neoplasms of the kidney if metastasis has not occurred; 6) traumatic destruction of most of the renal parenchyma; 7) avulsion of the renal pedicle or uncontrolled hemorrhage; and 8) abnormal kidney drained by an ectopic ureter. The diagnosis of these conditions and assessment of adequate function of the contralateral kidney are described elsewhere.[1]

Nephrectomy is seldom performed when the architecture and vascular supply of the kidney are normal. In certain chronic pathologic states, the kidney is frequently enlarged and is extensively supplied by neovascularization. The normal renal artery and vein can be present or nonexistent. Surgical technique for nephrectomy in such instances is improvised by the veterinary surgeon and may approximate the dissection required to remove any abdominal mass. The operative technique described in the following paragraphs is based on the removal of a kidney in which the gross anatomic structure is recognizable.

Surgical Technique

The patient is anesthetized and is placed in dorsal recumbency. The abdomen is prepared for an aseptic surgical procedure. A midline abdominal incision is made from the xiphoid process through the umbilicus. The edges of the incision are protected with moist laparotomy pack, and a Balfour retractor is inserted.

The right kidney is exposed by lifting the descending portion of the duodenum and by positioning the other loops of intestine to the left of the mesoduodenum. The left kidney is similarly exposed by using the mesentery of the descending colon as a retractor to displace bowel loops to the right (Figure 29-1). The viscera are covered with moist laparotomy packs.

To mobilize the kidney to be removed, first the peritoneum over the caudal pole of the kidney is grasped with tissue forceps and is incised with scissors. The surgeon inserts a finger into the opening and gently peels the peritoneum from the kidney. Occasionally, the peritoneum adheres firmly to the kidney surface at scattered points; these attachments are severed with scissors. Bleeding generated by this reflection of the peritoneum is controlled by electrocautery. Perirenal fat is reflected from the ventromedial surface of the renal hilus to expose the renal vein and ureter. The ureter is further mobilized by dissection through the retroperitoneum, to permit ligation as close to the urinary bladder as feasible. The ureter is divided between 2-0 absorbable ligatures (Figure 29-2).

The kidney is lifted from its bed and is retracted medially to expose the perirenal fat on the dorsolateral surface of the renal hilus (See Figure 29-2). Reflection of this fat exposes the renal artery. Care must be taken to avoid transection of one or more branches of the renal artery that may be present.

The exposed renal artery and vein are separated and are independently ligated with 3-0 suture material (Figure 29-3). The artery and vein are transected distal to each ligature, and the kidney is removed. A separate suture ligature of 4-0 suture material is passed through the lumen of the renal artery and vein, distal to the first ligature, to transfix the distal ligature and to prevent retraction of the vessel from the ligature (Figure 29-4).

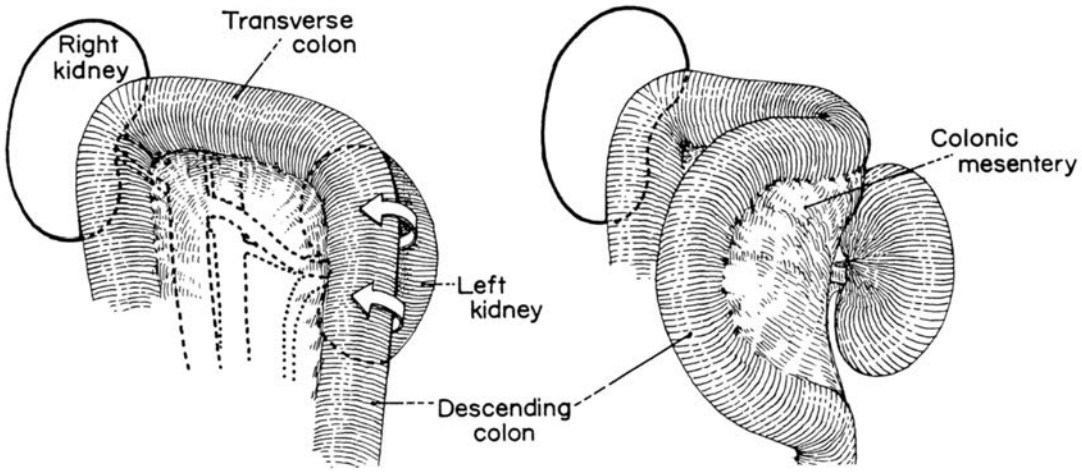


Figure 29-1. The left kidney is exposed by using the mesentery of the descending colon as a retractor for the small intestine.

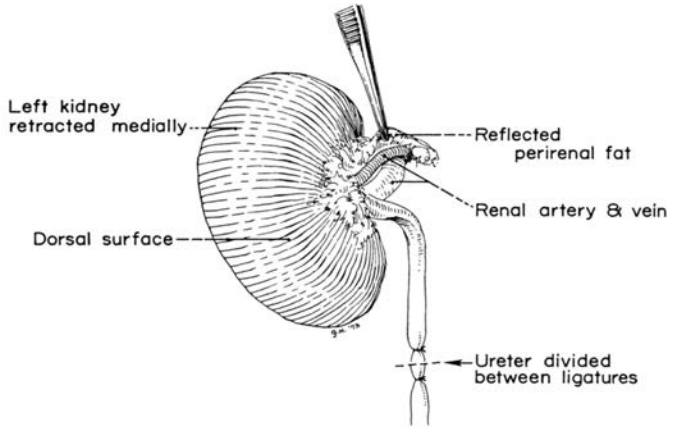


Figure 29-2. Reflection of the perirenal fat on the dorsal lateral surface of the renal hilus exposes the renal artery.

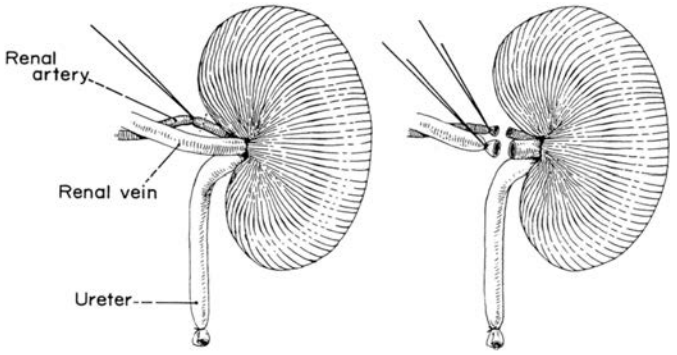


Figure 29-3. The renal artery and vein are separated, ligated individually, and transected.

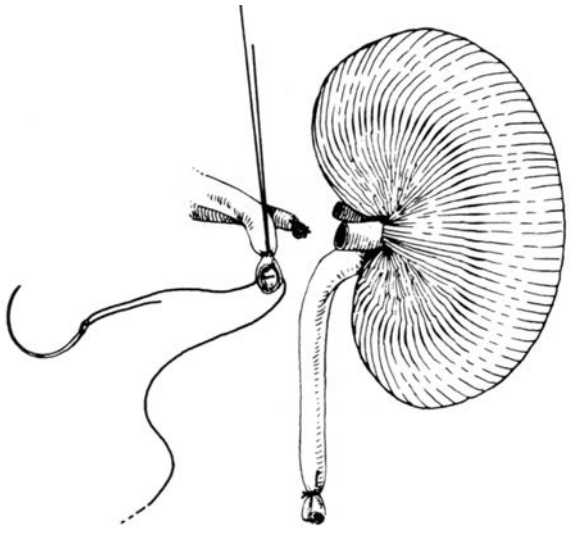


Figure 29-4. A second ligature is passed through the lumen of the renal artery and vein distal to the first ligature.

The intestines are returned to normal position, the greater omentum is repositioned over the small intestine, and the abdomen is closed in a standard manner.

Reference

1. Osborne CA, Finco DR, eds. Canine and feline nephrology and urology. Baltimore: Williams & Wilkins, 1995.

Nephrotomy

Nancy Zimmerman-Pope and Michael King

Surgical Anatomy

Kidneys and ureters lie against the sublumbar muscles of the dorsolateral abdomen within the retroperitoneal space. The cranial pole of the right kidney is nestled in the renal fossa of the caudate liver lobe at the approximate level of the 13th rib (slightly cranial to the left kidney). A thin fibrous capsule envelopes each kidney. Gross appearance of the feline kidney is distinctive due to a radial network of subcapsular veins that course over the surface of the kidney toward the hilus.

The renal artery, vein, and ureter enter the concave surface of the kidney at the hilus (Figure 29-5). The primary renal artery may arborize into several branches after leaving the aorta and before entering the hilus. Arterial branching is present in 5 to 10% of dogs and cats and is most common in the left kidney. Cats may also have multiple renal veins. The left testicular or ovarian vein drains into the left renal vein rather than the caudal vena cava. Care must be taken to preserve these vessels when performing renal surgery in an intact dog or cat. The ureter is a firm tubular structure that exits the caudodorsal surface of each kidney at the hilus and courses in a caudal direction in the retroperitoneal space. The left ureter courses lateral to the aorta, but the right may be dorsal or lateral to the vena cava. In male dogs and cats, the ureter crosses dorsal to the ductus deferens and in the female it courses in the dorsal aspect of the broad ligament.[17] Each ureter traverses the respective right or left lateral ligament

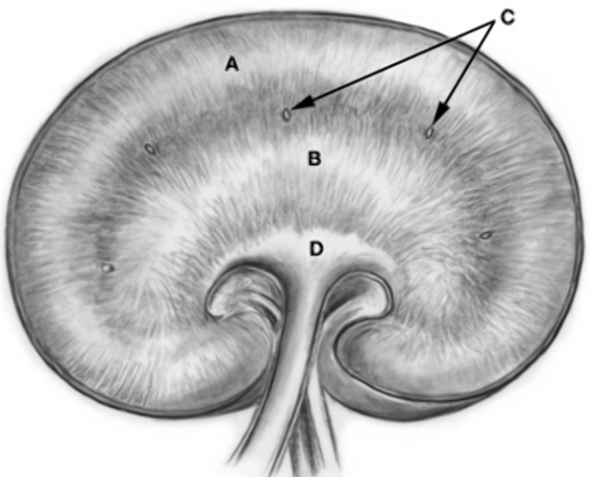


Figure 29-5. The renal cortex *A.* medulla *B.* arcuate vessels *C.* and renal pelvis *D.* are identified. The ureter originates in the renal pelvis. Calculi located in the renal pelvis may cause ureteral obstruction.

of the urinary bladder and enters the bladder on the dorsolateral mucosal surface at the trigone.

Traditional surgical approach to the kidneys and ureters is via a ventral midline celiotomy. The left kidney is exposed by grasping and retracting the colon and associated mesocolon across midline toward the right side (Figure 29-6). The right kidney is similarly exposed by grasping and retracting the duodenum and associated mesoduodenum toward the left side (Figure 29-7). Gentle retraction of the duodenum is recommended to minimize trauma to the pancreas.

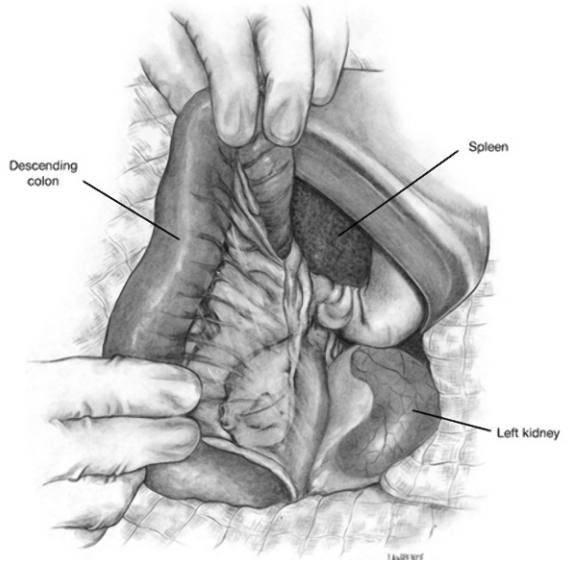


Figure 29-6. Exposure of the left canine kidney from a standard ventral midline approach.

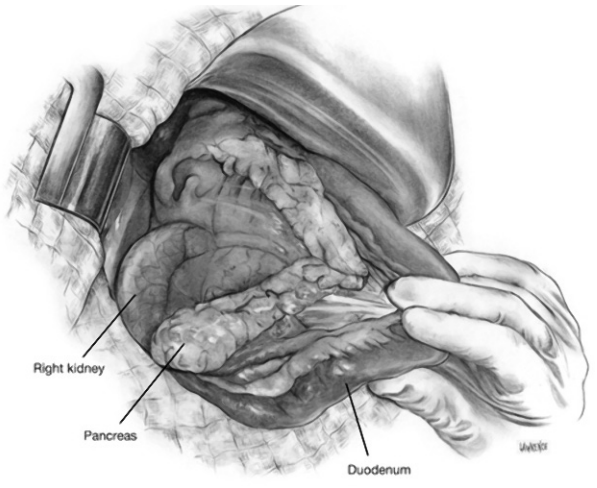


Figure 29-7. Exposure of the right canine kidney from a standard ventral midline approach.

Preoperative Assessment of Renal Function

Kidney function can be estimated from serum blood urea nitrogen (BUN) and creatinine (SCr) levels, but these biochemical markers are relatively insensitive. The BUN and SCr levels should be interpreted concurrently with a urinalysis and urine specific gravity. Urine specific gravity is most accurate when obtained prior to initiation of fluid therapy. Measurement of BUN and SCr levels are the simplest methods of evaluating renal function in the clinical patient however elevation of values beyond the normal range does not occur until severe kidney disease is present (less than 30% functional nephrons remaining). An additional limiting factor is that biochemical markers only provide information regarding total renal function and do not provide specific quantification of individual kidney function. Assessment of individual kidney function is important when trying to determine whether efforts to preserve a kidney via nephrotomy or pyelolithotomy should be considered or if nephrectomy is indicated. Determination of glomerular filtration rate (GFR) is essential in dogs and cats with underlying renal disease to guid specific treatment recommendations and provide prognostic information.

Scintigraphy is a reliable, non-invasive method of assessing total and individual kidney function in the dog and cat. Renal function is determined though measurement of GFR of labeled radioisotopes.[1] Normal total GFR in dogs is greater than 3 ml/min/kg; in cats, normal total GFR is greater than 2 ml/min/kg. Quantitative renal scintigraphy also measures individual kidney function and is sensitive enough to detect changes in function before BUN or SCr increase. Scintigraphic assessment of GFR using 99 m Technetium-diethylenetriaminepentaacetic acid (99 mTc-DTPA) correlates well with other methods of assessing renal function in the dog and cat.[2,3] The use of scintigraphy may be limited by availability and requires isolation of the patient while the radioactive material is cleared and reaches safe levels for human exposure.

Glomerular filtration rate can also be determined using contrast-enhanced computed tomography (CT). Collection of serial CT images of specific regions of interest for the kidneys and aorta permits construction of time attenuation curves that can be used to calculate GFR using graphical analysis. Tomography also provides morphologic information of the kidneys and ureters. CT use is limited by availability and the need for general anesthesia of the patient.[14-15]

Survey radiographs, excretory urography, and ultrasonography are valuable in evaluating renal and ureteral size and architecture. Location and number of urinary calculi may be determined through radiographs or ultrasound. Excretory urography can be used to evaluate the anatomy and patency of the urinary system but is not accurate in quantitative assessment of kidney function. Selection of diagnostics is based on the specific clinical problem and availability of imaging modalities.

Results of preoperative diagnostics may influence the anesthetic protocol, guide surgical planning, and aid in determining prognosis. Dogs and cats with normal renal function that receive appropriate perioperative intravenous fluids usually adjust to temporary changes in cardiovascular function and renal perfusion during anesthesia, however, patients with decreased renal function may not be able to adjust to these changes and could develop serious postoperative complications (i.e. acute renal failure). Fluid therapy should be carefully monitored, especially in cats, to avoid fluid overload. Preoperative assessment of renal function is important to reduce risk of postoperative complications and to provide the most accurate prognosis for expected outcome following surgery.

Other perioperative considerations include administration of fluids, diuretics, or vasopressors to support kidney function and maintain urine output. Intraoperative and postoperative urine output and central venous pressure monitoring should be considered especially in animals with preexisting renal disease. Electrolyte levels, body weight, and hydration status should be closely monitored.[15]

Surgical Technique

Indications for renal surgery include neoplasia, obstructive renal calculi, trauma, persistent renal hemorrhage, chronic inflammation or infection, severe hydronephrosis, renal cystic disease and in some cases, treatment of ectopic ureters.[4] Appropriate preoperative diagnostics and careful assessment of the patient will guide the clinician in formulating an overall treatment plan.

Nephrotomy

Nephrotomy is most commonly performed to remove obstructive or infected calculi but is also indicated to evaluate the renal pelvis for causes of hematuria or chronic infection, or to biopsy tumors. It is important to recognize that not all nephroliths require surgical removal. Nephrotomy or pyelolithotomy for urinary calculi is indicated when there is evidence of urinary obstruction or chronic infection. Historically, bisection nephrotomy was thought to decrease renal function by 20 to 50% in normal dogs however, more recent studies have reported that nephrotomy has no significant adverse effect on renal function in the normal dog or cat.[5-9] The effect of nephrotomy on renal function in patients with kidney disease has not been reported.

To perform nephrotomy, a ventral midline celiotomy is routinely used. A generous incision extending from the xiphoid to a few centimeters caudal to the umbilicus is recommended. Moistened laparotomy sponges are placed over the edges of the abdominal wall and self-retaining Balfour retractors are used to maintain abdominal exposure. The left or right kidney is exposed as previously described. Exposure of either kidney can be maintained or improved by use of laparotomy sponges and malleable retractors held in place by a sterile surgical assistant. Peritoneum overlying the kidney is incised and the kidney is bluntly dissected from peritoneal and fascial attachments. Perihilar fat is carefully dissected to expose the renal artery, vein, and ureter (Figure 29-8). The renal artery is often difficult to visualize since it lies craniodorsal and is intimately associated with the renal vein, however it is generally easily palpated. Careful dissection continues until the renal artery can be isolated. Once the artery is adequately exposed, it is temporarily occluded with either a Rumel tourniquet or a vascular clamp (i.e. Bulldog clamp) placed near the aorta. Successful renal arterial occlusion is confirmed by gross blanching of renal color and palpable softening of the parenchyma. The kidney is grasped gently to stabilize it as an incision is made with a scalpel blade along the convex surface (approximately one-half to two-thirds the length of the convex surface). Blunt and sharp dissection of the renal parenchyma is continued to the pelvis (Figure 29-9). Arcuate vessels located within the parenchyma can be ligated if necessary, but bleeding is usually minimal if all branches of the renal artery have been occluded. Once the renal pelvis is exposed, samples can be collected as indicated for histopathology, culture, and mineral analysis. A 3.5 or 5.0 Fr red rubber catheter can be passed normograde into the proximal ureter and gently flushed with warm sterile saline to confirm ureteral patency (Figure 29-10). Once all samples have been collected and/or calculi removed, the bisected renal parenchyma is held gently but firmly in apposition as the capsule is closed.

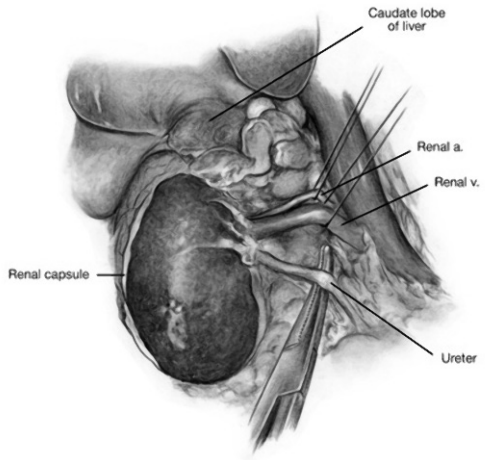


Figure 29-8. Appearance of the right canine kidney in situ, with renal vessels and ureter identified. The peritoneal attachments and renal capsule have been incised to aid in mobilization of the kidney. Isolation of the renal vessels is by blunt dissection.

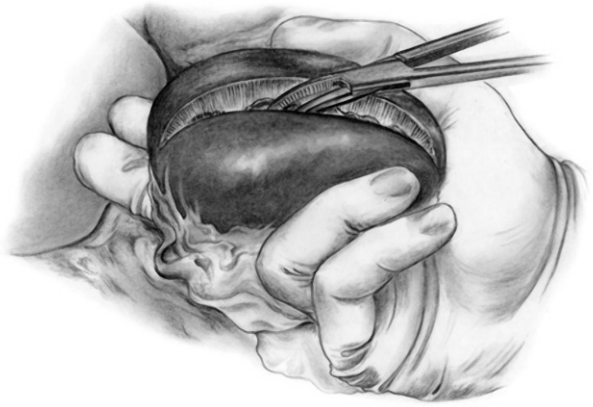


Figure 29-9. The kidney is held to expose the convex surface as an incision is made about 2/3 the length of the kidney. A blunt instrument (i.e. hemostat or scalpel handle) can be utilized to dissect to the level of the renal pelvis.

A simple continuous pattern using 4-0 or 5-0 monofilament absorbable suture on a taper needle is generally effective at providing satisfactory closure and hemostasis. Sutures bites are placed 2-3 mm apart in the fibrous capsule to minimize tension and tearing. Renal cortical tissue is occasionally included in suture placement if the capsule tears or does not hold suture adequately (Figure 29-11). Once the capsule is closed, the vascular occlusion device is removed and normal kidney color and parenchymal consistency promptly return. Total vascular occlusion of the kidney during nephrotomy should not exceed 15 to 20 minutes.[10] If hemorrhage occurs from the sutured incision it can be controlled with direct digital pressure

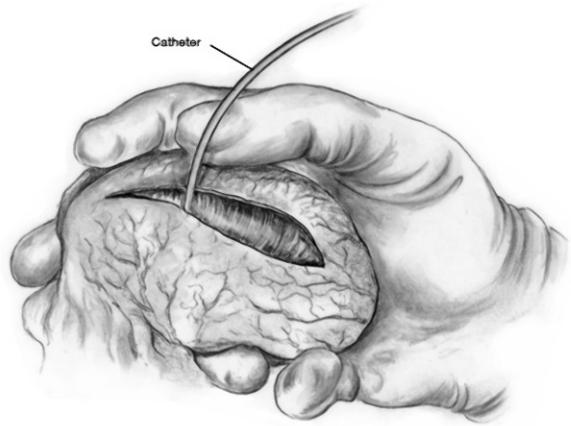


Figure 29-10. The renal pelvis and proximal ureter are catheterized and gently flushed to confirm patency and remove any remaining fragments.

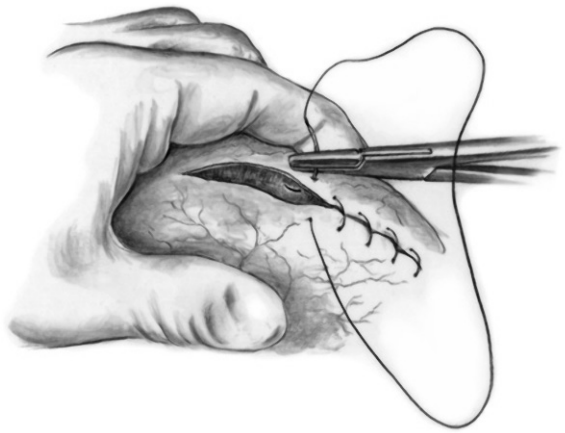


Figure 29-11. A simple continuous suture pattern is used to close the renal capsule incorporating a minimal portion of renal parenchyma if necessary.

or placement of a mattress suture(s) through cortical tissue at the level of hemorrhage. After hemostasis is obtained, the kidney is returned to its normal position and orientation within the abdomen; tacking sutures between each pole of the kidney and the sublumbar musculature may be necessary to prevent kidney rotation that could cause occlusion of the renal vasculature or ureter. Samples should be submitted for culture, histologic examination, and mineral analysis as indicated. The abdomen is lavaged with warm sterile saline and closure is routine. Sponge counts are recommended before abdominal closure to ensure nothing is inadvertently left in the abdomen. If bilateral nephrotomies are necessary, the procedures should be staged at 4 week intervals to lessen the risk of postoperative acute renal failure or decompensation.[12]

Pyelolithotomy

Pyelolithotomy is an alternative to nephrotomy and can be used to remove calculi from the renal pelvis if the proximal ureter is sufficiently dilated. Extracorporeal shock wave lithotripsy may also be considered to treat dogs with small nehroliths (< 1-2 cm).[16] Excretory urography, ultrasonography and scintigraphy can be used to confirm and estimate the severity of obstruction of the renal pelvis or ureter. In cases of ureteral obstruction, placement of a nephrostomy tube or ureteral stenting may be warranted prior to definitve treatment or as adjunctive treatment.[15]

The ureter exits the caudodorsal aspect of the renal hilus and may be obscured by overlying vessels and preihilar fat. Adequate exposure is generally obtained from the ventral surface of the hilus, but if necessary, the kidney can be elevated from the peritoneal attachments and rotated medially to expose the dorsal surface. Vascular occlusion of the kidney is not necessary during pyelolithotomy. The ureter is isolated by blunt dissection and a longitudinal incision is made over the renal pelvis extending along the proximal ureter. An 11-blade and iris scissors may facilitate pyelolithotomy; magnification is also extremely helpful, especially when operating cats or small dogs. The length of the ureteral incision should be adequate to allow the calculus to be gently removed without tearing tissues or fragmenting the calculus (Figure 29-12). After removing the calculus, a 3.5 Fr red rubber catheter should be passed proximally into the renal pelvis and distally into the ureter to gently flush any remaining calculi fragments (Figure 29-13). The catheter may be used to temporarily aid the surgeon to visualize ureteral tissue layers as the pyelolithotomy is closed. It is important to appose tissues accurately to avoid stricture or urine leakage at the surgical site. Absorbable monofilament 4-0 or 5-0 suture in a simple continuous pattern is recommended (Figure 29-14). If peritoneal attachments between the kidney and abdominal wall were disrupted during dissection, the kidney should be pexied to the abdominal wall as previously described. Samples should be submitted for histologic examination, calculus analysis, and culture as indicated. Closure of the abdomen is routine.

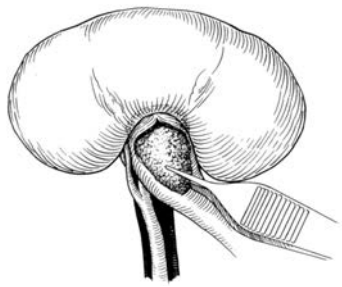


Figure 29-12. Incision in renal pelvis and ureter should be long enough to allow safe and gentle removal of calculi.

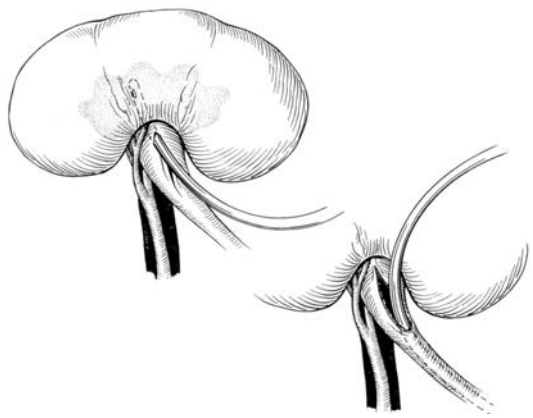


Figure 29-13. A catheter is placed to gently flush any remaining fragments from the renal pelvis and ureter.

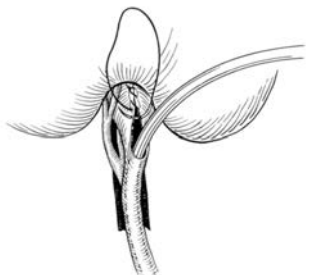


Figure 29-14. The catheter can be used to facilitate closure of the pyelolithotomy.

References

1. Daniel GB, Mitchell SK, Mawby D, *et al.*: Renal Nuclear Medicine: A Review. Vet Radiol Ultrasound 401: 572, 1999.

2. Uribe D, Krawiec D, Twardock A, *et al.*: Quantitative renal scintigraphic determination of the glomerular filtration rate in cats with normal and abnormal kidney function, using 99mTc-diethylenetriaminepentaacetic acid. *Am J Vet Res* 53: 1101, 1992.

3. Krawiec DR, Badertscher RR, Twardock AR, *et al.*: Evaluation of 99mTc-diethylenetriaminepentaacetic acid nuclear imaging for quantitative determinationof the glomerular filtration rate of dogs. *Am J Vet Res* 47: 2175, 1986.

4. Rosin, E: Kidney – Nephrectomy *In* Bojrab MJ, 4th ed: Current Techniques in Small Animal Surgery. Maryland: Williams and Wilkins, 1998, p 429.

5. Gahring DR, Crowe DT, Powers TE, *et al.*: Comparative renal function studies of nephrotomy closure with and without sutures in dogs. *JAVMA* 171: 537, 1977.

6. Fitzpatrick JM, Sleight MW, Braack A, *et al.*: Intrarenal access; Effects on renal function and morphology. *British J of Urology* 52: 409, 1980.

7. Stone EA, Robertson JL, and Metcalf MR: The effect of nephrotomy on renal function and morphology in dogs. *Vet Surgery* 31: 391, 2002.

8. Zimmerman-Pope N, Waldron DR, Barber DL, et al: Effect of fenoldopam on renal function after nephrotomy in normal dogs. *Vet Sug* 36: 566, 2003.

9. King M, Waldron DR, Barber DL, *et al.*: The effect of nephrotomy on renal function and morphology in normal cats. *Ver Surg* 35: 749-758, 2006.

10. Selkurt EE: The changes in renal clearance following complete ischemia of the kidney. *AM J Physiol* 144: 395-403, 1945.

11. Maddern JP: Surgery of the Staghorn Calculus. *Brit J Urol* 39: 237, 1967.

12. Rawlings CA, Bjorling DE, Christie BA: Kidneys *In* Slatter D, 3rd ed.: Textbook of Small Animal Surgery, Philadelphia, 2002, p 1606.

13. Alexander K, Dunn, M, Carmel EN, et al: Clinical application of Patlak Ploty CT-GFR in animals with upper urinary tract disease. Ver Radiol Ultrasound 47 (2), 127-135,2006.

14. Anderson KJ,Twardock R, Grimm JB, et al: Determination of glomrular filtration rate in dogs using contrast-enhanced computed tomgraphy. Vet Radiol Ultrasound 47 (2), 86-103,2011.

15. Berent AB: Ureteral obstructions in dogs and cats: a review of traditional and new interventional diagnostic and therapeuitc options. J Vet Emerg Crit Care 21 (2), 86-103,2011.

16. Lane IF: Lithotripsy: an update on urologic applications in small animals. Vet Clin NA Small Animal Pract 34 (4): 1011-1025,2004.

Nephroliths and Ureteroliths in Cats

S. Kathleen Salisbury

Introduction

The location and composition of uroliths in cats has changed dramatically over the past three decades. Between 1981 and 1999 there was a dramatic increase in the number of upper tract uroliths submitted to the Minnesota Urolith Center.[1] Approximately 75% of upper tract uroliths are composed of calcium oxalate.[1] During this 20-year period there was a 10-fold increase in the frequency of upper tract uroliths in cats at nine veterinary teaching hospitals.[1] A more recent case series of cats treated for ureterolithiasis found that approximately 98% of ureteroliths contain calcium oxalate.[2] Veterinary surgeons are increasingly faced with the challenge of surgical management of upper tract uroliths in cats.

Clinical Signs

Clinical signs of cats with ureteroliths or nephroliths tend to be nonspecific and include anorexia, vomiting, lethargy, and weight loss.[2] Polydipsia and polyuria, stranguria or pollakiuria, hematuria, and inappropriate urination may be seen. Pain may be evident if the ureter becomes acutely obstructed, however, pain appears to be much less common than in humans with ureteroliths. Affected cats may be asymptomatic and the calculi are detected during a work-up for other problems. Many cats with ureteroliths and nephroliths also have chronic kidney disease, therefore, unilateral ureteral obstruction may result in signs of renal failure. Physical examination findings are usually non-specific, but some cats will have small, irregularly shaped kidneys. Acute ureteral obstruction may result in the affected kidney being enlarged, firm, and painful.

Diagnosis and Preoperative Evaluation

Nephroliths and ureteroliths should be suspected in cats with chronic kidney disease, renomegaly, abdominal or lumbar pain, vomiting, or recurrent urinary tract infection. Cats that are presented with vague signs of illness or signs of renal disease should be evaluated for the presence of uroliths by survey abdominal radiographs and abdominal ultrasonography. Most uroliths of the upper urinary tract in cats are radiodense and can be seen on survey radiographs. However, calculi can be quite small and may be obscured by fecal material or other structures. It is common to find that one kidney is small and irregular in contour while the other kidney may be of normal size or enlarged. Ultrasonography is very helpful in confirming the presence of calculi and in assessing the degree of dilation of the renal pelvis and ureter. However, ultrasonography failed to identify ureteroliths in 23% of cats in one report.[2] The combination of abdominal radiographs and ultrasonography is reported to have a sensitivity of 90% for detection of ureteroliths in cats.[2] Excretory urography can be helpful in identifying ureteral obstruction, assessing the degree of dilation of the renal pelvis and ureter, and determining the tortuosity of the ureters

in preparation for surgery. However, many cats with ureteral obstruction do not concentrate the intravenously administered contrast medium adequately to delineate the ureters. In these cats, a percutaneous antegrade pyelogram can be performed. Contrast medium is injected directly into the renal pelvis using ultrasound guidance and radiographs are made of its passage down the ureter.[3,4] The technique also allows a urine sample to be obtained directly from the renal pelvis for bacterial culture.

A complete blood count (CBC), serum chemistry profile, and urinalysis should be performed to evaluate renal function and the cat's general health. A CBC may show a nonregenerative anemia if the cat has chronic renal failure; a leukocytosis and left shift may be present in cats with pyelonephritis. A serum chemistry profile may be normal or may show azotemia, hyperphosphatemia, and hyperkalemia. An idiopathic hypercalcemia is reported to occur in approximately 35% of cats with calcium oxalate uroliths.[5] A urinalysis and urine culture should be performed to determine if there is a urinary tract infection. If surgery is planned, a cross-match or blood typing should be performed in case administration of blood is needed during or after surgery. Compatible whole blood or packed red cells should be available.

Indications for Surgery

Indications for surgical removal of nephroliths and ureteroliths in cats are controversial. In general, nephroliths that are not associated with a urinary tract infection and that are not causing ureteral obstruction do not require surgical removal. However, if a cat with nephroliths has a urinary tract infection that cannot be cleared with appropriate antimicrobial therapy, then surgical removal of the nephroliths is recommended to allow clearance of the bacteria. If a nephrolith is causing complete or partial obstruction of urine flow, removal is indicated. Nephroliths that appear quiescent are generally not removed because the consequences of surgical removal are renal scarring and possible reduced renal function. In addition, it can be quite difficult to locate small nephroliths by nephrotomy or pyelolithotomy. If bilateral nephrotomies are required, the procedures should be staged with the nephrotomies separated by approximately 4 weeks. In general, the kidney that appears to have the most functional capacity should be operated first. Pyelolithotomies can be performed bilaterally at the same surgery.

There are no clear recommendations regarding surgical removal of ureteroliths in cats. Most ureteroliths cause some degree of obstruction of the ureter. Prolonged ureteral obstruction can lead to renal damage and loss of function. If a cat with a ureterolith is treated conservatively to allow the calculus to pass spontaneously, there is a chance of further loss of renal function during the weeks or months that it may take for passage, if passage of the calculus ever occurs. One study showed that resolution of ureteral obstruction occurred in very few cats treated with medical therapy alone.[10] It has not been determined if there is a "safe" waiting time for conservative management of ureteroliths in cats. The overall status of the cat's renal function should be considered in determining whether conservative or surgical therapy will be pursued. Many cats with nephroliths and/or ureteroliths are azotemic and have chronic kidney disease. Assessment of individual kidney function by nuclear scintigraphy is useful in cats with upper urinary calculi however this diagnostic aid is not widely available. If a cat has a ureterolith in one ureter and the other kidney has end-stage renal disease, surgical removal of the ureterolith is recommended to preserve the function of the obstructed kidney. If the cat is very ill due to ureteral obstruction by a ureterolith, it may not be appropriate to wait for the ureterolith to pass. As I have gained experience with ureteral surgery in cats, I have become more aggressive in pursuing surgery sooner rather than later. This is consistent with another report.[10] Aggressive fluid therapy is administered to stabilize the cat while monitoring the cat carefully for fluid overload. If the ureteral obstruction persists, surgical intervention is usually performed in 2-4 days. If bilateral ureterotomies are necessary, they can be performed in the same surgery.

Many cats with ureteroliths have concurrent nephroliths. Following ureterotomy, these cats are at risk for recurrent ureteral obstruction by nephroliths that may pass into the ureter. Because of this, ureterotomy is now generally reserved for cats with a single ureterolith and no nephroliths. Cats with multiple ureteroliths and nephroliths are generally being treated with ureteral stenting or subcutaneous ureteral bypass (SUB) placement.[6] Ureteral stenting results in dilation of the ureter so that urine can pass around and through the stent thus relieving the obstruction and preserving renal function. SUB placement allows urine to be diverted from the renal pelvis to the urinary bladder through a combination of a locking-loop nephrostomy catheter and a locking-loop cystostomy catheter.[6]

Surgical Treatment

Nephroliths

Nephroliths can be removed by either nephrotomy or pyelolithotomy. With either technique, however, it is not always possible to retrieve all the calculi. Nephrotomy should be avoided when possible because it can cause renal scarring and loss of function. Many cats with nephroliths already have reduced renal function and further loss of function should be avoided. Pyelolithotomy is the preferred technique for surgical removal of nephroliths because it does not require interruption of renal blood flow or incision into the renal parenchyma and the resulting loss of function. However, pyelolithotomy cannot be performed unless the renal pelvis is dilated beyond the renal parenchyma. If a kidney is severely hydronephrotic and non-functional, nephrectomy and ureterectomy are indicated.

All retrieved nephroliths and ureteroliths should be submitted for quantitative analysis so that appropriate preventative strategies can be implemented. Bacterial culture should also be performed on any calculi that are available.

Nephrotomy

After performing a complete abdominal exploratory, the kidney is packed off from the rest of the abdomen. The peritoneum is incised along the greater curvature of the kidney and the kidney is reflected medially. The renal artery is located on the dorsal

aspect of the renal hilus, the renal vein is ventral and the ureter is caudal. The renal artery is isolated by careful dissection and a bulldog vascular clamp is applied. It is not necessary to occlude the renal vein. The kidney should become soft and dark-colored if the entire arterial supply has been occluded. If the kidney does not become soft, the clamp should be removed and further dissection performed to identify additional branches of the renal artery. After occluding the renal arterial supply, a longitudinal incision is made through the renal capsule along the greater curvature for approximately two-thirds the length of the kidney. The renal parenchyma is separated by pushing the blunt handle of a scalpel through the tissue toward the renal pelvis. Once the renal pelvis is reached, the parenchyma is spread so that calculi in the pelvis can be visualized. Calculi are removed, the diverticula are explored for additional calculi, and the renal pelvis is flushed with saline. The ureter is catheterized and flushed to the bladder if possible to confirm its patency. The edges of the kidney are pressed together and the renal capsule is carefully closed with a simple continuous suture of 4-0 polydioxanone. The vascular clamp is removed from the renal artery and direct pressure is applied to the suture line to control hemorrhage as necessary. The warm ischemia time of the kidney should not exceed 20 minutes.[6] The kidney is tacked in place with a few capsular sutures to the surrounding psoas musculature to prevent the kidney from twisting on its blood supply and causing renal ischemia.

Pyelolithotomy

Magnification is helpful for performing pyelolithotomy in cats. I prefer to use an operating microscope unless the renal pelvis and proximal ureter are extremely dilated. The kidney is reflected medially and the dilated renal pelvis and proximal ureter are exposed by dissecting the perirenal fat away from the ureter at the caudal aspect of the renal hilus. A stay suture of 5-0 to 7-0 suture is placed in the dilated pelvis and a #11 blade is used to make a stab incision into the exposed pelvis. The incision is extended longitudinally with iris scissors. Calculi are retrieved from the renal pelvis and proximal ureter and the renal pelvis is flushed by passing a catheter through the ureteral/pelvic incision and up into the renal pelvis. If possible, the ureter should be flushed distally to the bladder to assure patency, however, this is not always possible due to the small diameter of the normal feline ureter. The pyelolithotomy is closed with full-thickness simple interrupted sutures of 5-0 to 7-0 polyglactin 910 or polydioxanone. The kidney is tacked in place to surrounding psoas musculature with a few capsular sutures.

Ureteroliths

Ureteral calculi can be removed by ureterotomy or partial ureterectomy and ureteroneocystostomy. Both procedures are technically demanding because of the small size of the feline ureter and should be performed using an operating microscope. Surgeons should have experience with microsurgical techniques and microsurgical instrumentation should be used to avoid unnecessary trauma to the ureter. Because of the difficulties associated with ureteral surgery in cats, some surgeons recommend that ureteroliths located in the middle or distal thirds of the ureter be treated by resection of the portion of the ureter from the calculus to the bladder to remove the calculus and reimplantation of the proximal ureter into the urinary bladder. I prefer to perform ureterotomies for all ureteroliths regardless of location. I reserve partial ureterectomy and ureteroneocystostomy for treatment of complications that could occur secondary to ureterotomy, such as ureteral stricture. Abdominal radiographs should be made immediately before surgery to confirm the current location of the calculi.

Ureterotomy

The ureter is examined visually using the preoperative radiographs to help locate the ureterolith. In many cases the calculus can be seen through the wall of the ureter. The ureter can be palpated gently to identify the ureterolith. If the calculus is located in the proximal ureter, care should be taken not to push the calculus back into the renal pelvis. To prevent the calculus from moving retrograde into the renal pelvis, a loop of moistened umbilical tape or a vascular tie can be placed around the most proximal aspect of the ureter immediately distal to the renal pelvis and the ureter can be gently occluded by applying pressure to the vascular tie. After the ureterolith is identified, the peritoneum is incised over the affected area of the ureter and the periureteral fat is dissected to expose the ventral aspect of the ureteral wall. The operating microscope is positioned over the ureter and a stay suture of 8-0 suture material is placed in the ureter at one end of the planned ureterotomy. A #11 blade is used to make a longitudinal incision into the ureter directly over the calculus and the incision is extended with microsurgical dissecting scissors. The calculus is removed and the ureter is flushed proximally and distally (if possible). If the ureter is very dilated, it can be flushed proximally with a 3.5 French tom cat catheter. If the ureter is not very dilated, a 27-gauge intravenous catheter can be used for flushing. It is often difficult to flush the distal segment of the ureter due to its small diameter. Some surgeons confirm patency of the ureter by passing a piece of suture material (size 2 polybutester[7]) down the ureter. I usually try to flush the distal ureter gently and palpate it carefully to be sure there is not another calculus more distally, but I do not usually pass anything down the ureter to avoid further trauma. A swab is taken from the ureter and/or calculus for aerobic bacterial culture and susceptibility testing. The ureterotomy is closed with full-thickness simple interrupted sutures of 8-0 polyglactin 910 with a BV130-4 taper needle (8-0 Coated VICRYL, Ethicon Inc, Somerville, NJ). In some cases the ureter is very thickened and fibrotic and it is difficult to pass the needle of the 8-0 polyglactin 910 through the wall. In those cases, 7-0 polydioxanone on a BV1 taper needle (PDS II, Ethicon Inc, Somerville, NJ) can be used. It is helpful to preplace the last two or three sutures to ensure proper suture placement. The final sutures are then tied. The suture line should be examined carefully under the operating microscope for urine leakage between sutures or through the needle holes. If urine leakage occurs between sutures, additional sutures should be placed. If urine leakage occurs through the needle holes, a small piece of absorbable gelatin sponge (Gelfoam®, Pharmacia and Upjohn Company, Kalamazoo, MI) soaked with the patient's blood can be placed over the suture line. After the ureterotomy is closed, the peritoneum can be closed over the site. However, if closure of the peritoneum compresses the distal ureter so that it causes a partial obstruction, the peritoneum can be left open. If calculi are present in more than one location in the ureter,

multiple ureterotomies can be performed at the same surgery. It is not usually possible to flush or milk calculi to a ureterotomy site that is more than a couple millimeters from the calculus unless the ureter is very dilated.

Partial Ureterectomy and Ureteroneocystostomy

Ureteroliths in the distal two-thirds of the ureter may be managed by resecting the ureter from the site of the calculus to the urinary bladder and then reimplanting the ureter into the bladder.[7] The ureter is ligated and transected proximal to the obstructing ureterolith and at its entry into the urinary bladder and the excised portion is removed with the calculus. The proximal portion of the ureter is implanted into the urinary bladder. Multiple techniques have been attempted for ureteroneocystostomy in cats but the best results occur with an extravesicular mucosal apposition technique (modified Lich Gregoir technique) using simple interrupted sutures.[8] This technique is performed by making a partial thickness incision through the serosa, muscularis, and submucosa of the ventral aspect of the apex of the urinary bladder to expose the mucosa. The distal end of the ureter is spatulated. An incision equal in length to the spatulated ureteral incision is made through the bladder mucosa at the caudal end of the muscularis incision. One suture is placed between the cranial end of the spatulation and the cranial end of the bladder mucosal incision. A second suture is placed between the distal end of the ureter and the caudal end of the mucosal incision. These sutures are placed full-thickness through the ureter and the bladder mucosa and tied. Then a stent of 4-0 polypropylene is placed in the ureteral lumen to aid in the placement of additional sutures. Two simple interrupted sutures are preplaced between the ureter and the bladder mucosa on one side of the stoma and then two similar sutures are preplaced on the other side of the stoma. If the ureter is very dilated, additional sutures may be needed on each side of the stoma. The sutures on one side of the stoma are tied and the polypropylene stent is removed. Then the remaining sutures are tied. The standard description of this technique recommends the use of 8-0 nylon swaged on a BV 130-5 taper needle (Ethicon Inc, Somerville, NJ) for the mucosal sutures. I prefer to use 8-0 polyglactin 910 swaged on a BV 130-4 taper needle (Ethicon Inc, Somerville, NJ) so that nonabsorbable suture material does not remain in the lumen of the urinary tract. After the mucosal sutures are completed, the bladder serosa and muscularis are apposed using simple interrupted sutures of 4-0 polydioxanone or polyglactin 910 to create a water-tight seal. The bladder is checked for leaks by injecting sterile saline into its lumen.

If there is tension on the anastomosis site between the ureter and the bladder, the kidney can be moved caudally (renal descensus) and the urinary bladder can be advanced cranially (psoas cystopexy).[7,9] The kidney is freed from its peritoneal and fascial attachments and moved to a more caudal and medial location taking care not to kink the renal vasculature. The renal capsule and a small amount of parenchyma is sutured to the body wall with 3 or 4 simple interrupted sutures of 4-0 nylon or polypropylene. To perform the cystopexy, the bladder is stretched cranially and the seromuscular layer of the dorsolateral bladder wall is sutured to the iliopsoas muscle with two or three simple interrupted nonabsorbable sutures.

Nephrostomy Tube Placement

Nephrostomy tube placement is indicated as an emergency procedure in cats with acute ureteral obstruction that are severely hyperkalemic and are poor candidates for a long surgical procedure. After instituting intravenous fluid therapy and attempting to lower the serum potassium concentration, the cat is anesthetized for nephrostomy tube placement. Although nephrostomy tubes can be placed percutaneously, it is recommended in cats they be placed via an open approach because feline kidneys are so mobile. A ventral midline celiotomy is performed to allow the kidney to be sutured to the body wall. Four sutures of 4-0 polydioxanone are placed from the greater curvature of the kidney to the dorsolateral body wall. The sutures are placed through the renal capsule and a small amount of renal parenchyma and through the transversus abdominus muscle and tied so that the kidney is secured to the body wall. The four sutures are placed to form a square (sutures are placed cranially, caudally, dorsally, and ventrally) so that the nephrostomy tube can be placed in the center of the square. A 5 French locking-loop pigtail nephrostomy catheter is preferred because it is less likely to become dislodged than a straight catheter.[12] A stab incision is made through the skin over the nephropexy site. Using ultrasound guidance, a 22-gauge intravenous catheter is inserted through the skin incision, body wall and greater curvature of the kidney into the renal pelvis at the site of the nephropexy. When urine backflows through the catheter, the stylette is removed. A urine sample is obtained from the renal pelvis for bacterial culture. At this point a pyelogram can be performed if desired. An angle-tipped hydrophilic 0.018-inch guidewire (Weasel Wire, Infiniti Medical LLC, Malibu, CA) is passed through the catheter and coiled in the renal pelvis. The catheter is removed over the wire. The pigtail nephrostomy catheter (5F Dawson-Meuller locking-loop pigtail catheter, Cook Medical, Bloomington, IN) is passed over the wire through the body wall and renal parenchyma and into the renal pelvis with the hollow cannula inside the pigtail catheter remaining secure to keep the catheter rigid during renal penetration. Once the tip of the pigtail catheter is confirmed to be in the renal pelvis, the cannula is immobilized as the catheter is advanced over the guidewire to form its loop. Once the loop of the pigtail is completely within the renal pelvis, the loop is locked in place by pulling on the string at the hub of the catheter. The string is secured and the cannula is removed from the catheter. The catheter is sutured securely to the skin and body wall with at least two friction sutures of 3-0 nylon. Each suture is tied tightly around the nephrostomy catheter being careful not to occlude the catheter lumen. The suture is then passed through the skin and body wall adjacent to the catheter. It is essential that the friction sutures are secured to the body wall and not just the skin because the mobility of the skin can cause dislodgment of the catheter. Alternatively, a Chinese finger trap suture may be used to secure the nephrostomy catheter. The nephrostomy catheter is attached to a sterile closed urine collection system. Following closure of the abdomen, a body bandage is applied to protect the nephrostomy tube.

If a locking-loop pigtail nephrostomy catheter is not available, a 16-gauge, 8-inch central venous catheter (Arrow International, Inc., Reading, PA) may be used for the nephrostomy tube. Additional side holes can be made near the tip of the catheter

before catheter placement. A nephropexy is performed as previously described.

A small stab incision is made with a #11 blade through the skin at the site of the nephropexy. The intravenous catheter is passed through the stab incision and body wall and then through the greater curvature of the kidney and into the renal pelvis. When urine backflows through the catheter, the catheter is advanced off the stylette into the renal pelvis and the stylette is withdrawn. A guide wire is threaded through the catheter into the renal pelvis and the catheter is withdrawn over the wire. A dilator is passed over the wire and into the renal pelvis. The dilator is withdrawn and the single lumen catheter is threaded onto the guide wire. The catheter is advanced up the guide wire until the distal two centimeters of the catheter (including any side holes) are in the renal pelvis. The guidewire is withdrawn while holding the catheter in place. The catheter is secured in place as previously described.

Once the cat is stable medically, the nephrostomy tube can be used to perform antegrade pyelography to document persistence of the ureteral obstruction. If the ureter remains obstructed, definitive ureteral surgery can be performed. One disadvantage of performing a ureterotomy after a nephrostomy tube has been placed is that the decompressed ureter is less dilated so performing the ureterotomy is more challenging than it would have been during the acute obstruction.

Nephrostomy tubes can be useful in some cats following ureterotomy when there is concern that the ureterotomy site may leak or develop an obstruction due to severe postoperative inflammation. Antegrade pyelography is performed four to six days postoperatively to evaluate the patency and integrity of the ureter. If the ureter is patent and there is no evidence of leakage at the ureterotomy site, the nephrostomy tube is removed. Nephrostomy tubes have also been used to treat ureteral urine leakage that may occur as a complication in the postoperative period. Nephrostomy tubes can become dislodged or obstructed. In addition, they can allow urine leakage from the kidney into the peritoneal cavity or the subcutaneous tissues.[10,12] Nephrostomy tubes that are maintained for several days or weeks can be associated with chronic, antibiotic-resistant urinary tract infections. Because of their potential complications and the increased nursing care required, I prefer not to place nephrostomy tubes unless there is a high likelihood of urine leakage or urethral obstruction postoperatively.

Postoperative Care

Many cats with ureteroliths and nephroliths are anorectic, so a gastrostomy or esophagostomy tube is usually placed at the time of surgery for postoperative nutritional support. Intravenous fluids are administered for three to five days after surgery to promote diuresis. Many affected cats are anemic at the time of surgery and the anemia may worsen postoperatively. If the anemia is moderate to severe, whole blood or packed red cells should be administered. Serum creatinine concentration is measured daily for the first few days after ureterotomy. Although the serum creatinine in some cats decreases immediately after surgery, it is common for it to remain high or even increase during the first couple of days after surgery. This is most likely due to partial ureteral obstruction from swelling at the ureterotomy site. Intravenous fluid therapy is continued and after three to four days the creatinine usually begins to decrease. Fluid therapy is discontinued when the creatinine is within the reference range or has remained stable for several days. Postoperative antibiotic therapy is indicated only if a urinary tract infection is present.

Outcomes and Postoperative Complications

Prevention

Dietary therapy should be based upon quantitative analysis of the calculus. Most nephroliths and ureteroliths in cats are composed of calcium oxalate. There are commercially available diets for prevention of calcium oxalate uroliths. Ideally, a canned diet should be fed so that the cat consumes more water. The urine pH can be monitored. If it remains acidic in spite of the use of a non-acidifying diet, potassium citrate can be administered to alkalinize the urine. The cat should be monitored every three to six months for recurrence of calculi by abdominal radiographs, ultrasonography, urinalysis and urine culture. If the cat has chronic kidney disease, a CBC and serum biochemistries should also be evaluated.

Complications

Postoperative complications are common following surgical removal of ureteral calculi in cats. In a series of 88 cats that survived surgical removal of ureteroliths, 31% developed major postoperative complications and 18% of these cats died.[10] Another report of 47 cats that underwent ureterotomy for urolith removal had a mortality rate of 21%.[13] The most common complications following removal of ureteral calculi are urine leakage and persistent ureteral obstruction. Urine leakage is usually apparent within two to four days. The blood urea nitrogen and serum creatinine concentrations will increase and the cat may show abdominal pain. If uroabdomen does not resolve spontaneously and requires a second surgical procedure, the prognosis is guarded. In the previously cited case series, the mortality rate of cats that underwent a second surgical procedure because of uroabdomen was 27% (3/11).[10] Three cats that developed uroabdomen were euthanized without additional surgery.[10] Partial or complete obstruction of the ureter following ureterotomy may be transient due to swelling at the surgery site. If the cat is becoming progressively more azotemic two to four days following surgery, an excretory urogram or percutaneous antegrade pyelography should be performed to determine if there is urine leakage or ureteral obstruction. Stricture at the ureterotomy site could occur as a long-term complication but this is not detected often.[14] Ureteral stricture can also be present at the time of initial surgery due to chronic ureterolithiasis and ureteral fibrosis. Approximately half of cats that recover from surgical removal of ureteroliths can be expected to have chronic kidney disease and maintain serum creatinine concentrations above the reference range.[10] Recurrence of ureterolithiasis has been reported in 40% of cats in which serial abdominal imaging was performed after medical or surgical management.[10] The second episode of ureterolithiasis occurred a median of 12.5 months (range 2 to 88 months) after the initial diagnosis.[10]

Editors Note: Minimally invasive therapy by interventional radiology has advantages when considering therapy for ureteral obstruction. Consultation with a specialist is recommended.

References

1. Lekcharoensuk C, Osborne CA, Lulich JP, et al: Trends in the frequency of calcium oxalate uroliths in the upper urinary tract of cats. J Am Anim Hosp Assoc 41:39, 2005.

2. Kyles AE, Hardie EM, Wooden BG, et al: Clinical, clinicopathologic, radiographic, and ultrasonographic abnormalities in cats with ureteral calculi: 163 cases (1984-2002). J Am Vet Med.Assoc 226:932, 2005.

3. Rivers BJ, Walter PA, Polzin DJ: Ultrasonographic-guided, percutaneous antegrade pyelography: technique and clinical application in the dog and cat. J Am Anim Hosp Assoc 33:61, 1997.

4. Adin CA, Herrgesell EJ, Nyland TG, et al: Antegrade pyelography for suspected ureteral obstruction in cats: 11 cases (1995-2001). J Am Vet Med Assoc 222:1576, 2003.

5. McClain HM, Barsanti JA, Bartges JW: Hypercalcemia and calcium oxalate urolithiasis in cats: a report of five cases. J Am Anim Hosp Assoc 35:297, 1999.

6. Berent AC: Ureteral obstructions in dogs and cats: a review of traditional and new interventional diagnostic and therapeutic options. J Vet Emerg Crit Care 21:86, 2011.

7. Kyles AE, Stone EA: Removal of nephroliths. In Bojrab MJ, Ellison GW, Slocum B, eds: Current Techniques in Small Animal Surgery, fourth ed. Baltimore: Williams & Wilkins, 1998, p 431.

8. Kyles AE, Stone EA, Gookin J, et al: Diagnosis and surgical management of obstructive ureteral calculi in cats: 11 cases (1993-1996). J Am Vet Med Assoc 213:1150, 1998.

9. Mehl ML, Kyles AE, Pollard R, et al: Comparison of 3 techniques for ureteroneocystostomy in cats. Vet Surg 34:114, 2005.

10. Stone EA: Surgical management of urinary tract disease: ureteral calculi in cats and urinary bladder neoplasia in dogs. Compendium on Continuing Education for the Practicing Veterinarian 19:62, 1997.

11. Kyles AE, Hardie EM, Wooden BG, et al: Management and outcome of cats with ureteral calculi: 153 cases (1984-2002). J Am Vet Med Assoc 226:937, 2005.

12. Berent AC, Weisse CW, Todd KL, Bagley DH: Use of locking-loop pigtail nephrostomy catheters in dogs and cats: 20 cases (2004-2009). J Am Vet Med Assoc 241:348, 2012.

13. Roberts SF, Aronson LR, Brown DC: Postoperative mortality in cats after ureterolithotomy. Vet Surg 40:438, 2011.

14. Zaid MS, Berent AC, Weisse C, Caceres A: Feline ureteral strictures: 10 cases (2007-2009). J Vet Intern Med 25:222, 2011.

Extracorporeal Shock-Wave Lithotripsy

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Introduction

Extracorporeal shock-wave lithotripsy (ESWL), in which high amplitude sound waves are generated outside the body and focused on a hard surface to create fissure and fragmentation, has been applied primarily to nephroliths and ureteroliths in dogs and people. In human medicine, adaptation of shock-wave treatment revolutionized the treatment of urolithiasis in the 1980s,[1] and since that time, the addition of endosurgical and percutaneous techniques to ESWL have made open surgery of the urinary tract uncommon. As shock wave lithotripsy and laser lithotripsy have become more available in human medicine, a similar transformation is occurring in veterinary medicine; however, limited availability and cost of these procedures limits the number of patients who can be treated in this fashion. Additionally, variability in lithotriptors makes treatment protocols and responses difficult to compare; effectiveness will vary with machine type as well. Currently, the most common applications of ESWL include the treatment of nephroliths and ureteroliths in dogs, and treatment of ureteroliths in cats. In specific cases, ESWL can be applied to fragment urocystoliths as well.

Methods and Equipment Required

Application of shock-wave lithotripsy requires a source to generate shock waves, a method for focusing the shock waves (SW) to a solitary point, and a method for transmitting (or "coupling") the SW to the patient. Shock waves are generated by electrohydraulic, electromagnetic, or piezoelectrical energy sources. With extracorporeal methods, the shock waves are generated outside the body, then reflected to converge on a target (the urolith) in the patient (Figure 29-15A,B). Like ultrasound waves, shock waves readily travel through fluid or soft tissue until they reach the "hard" acoustic surface of the urolith. Energy reflection, creation of tensile stresses along the surface of the stone, generation of cavitation bubbles, and dynamic fatigue lead to fragmentation with repeated shock waves.[2,3] Early lithotripsy treatments using the Dornier HM3 (Dornier, Marietta,

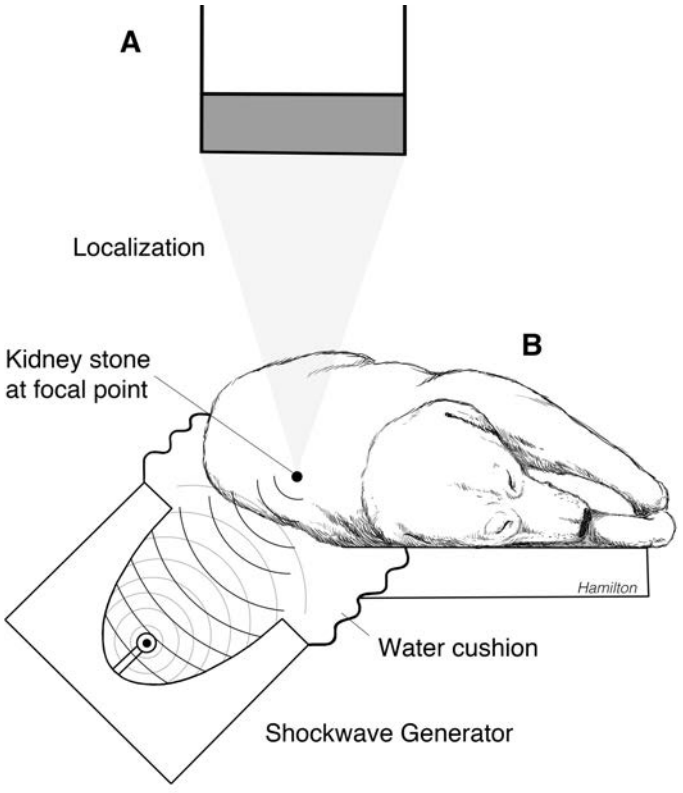


Figure 29-15. A. and **B.** Schematic depicting the extracorporeal shock-wave method. Shockwaves are generated outside the body, then reflected to converge on a target (urolith) in the patient.

GA), relied upon pulsatile sparks created by an electrohydraulic electrode and transmitted through a water bath medium ("wet" lithotripsy).[1,4,5] Newer lithotripters utilize other SW generators and "dry" methods, in which SW are coupled to the patient through a fluid filled cushion.[3,6-9] While these lithotriptors are easier to use and maintain, the efficacy of dry lithotriptors is lower than the "gold standard" water bath model, because of a smaller focal zone and in some cases, lower peak pressure. An advantage of this narrow focal zone is less damage to surrounding tissues; however, re-treatments are more common. The most recently produced lithotriptors are designed to increase portability and flexibility for various urologic procedures, as well as reduce cost of the equipment. Machines with mobile, handheld SW application sources may be useful for reaching uroliths in difficult locations and may allow for non-urologic applications (e.g. orthopedic) to be delivered by the same unit. However, these lithotriptors usually sacrifice efficiency and depth of penetration, which limits their effectiveness for nephroliths in larger human patients. While this would seem inconsequential in small animals, initial experience with the handheld units in dogs and cats suggests that efficiency is indeed sacrificed; a higher number of repetitive shocks and a higher retreatment rate are likely.[10] The cost of equipment varies widely; reconditioned dry ESWL lithotripters require at least a several-hundred-thousand dollar investment.

In general, ESWL treatment includes general anesthesia of the animal, localization of the urolith in the lithotriptor's focal zone, and application of sets of shock waves until sufficient fragmentation is observed on subsequent imaging. Shock-wave dose (power and number of shocks) and frequency varies depending on the patient and the machine settings. Usually, 1400-1500 SW are administered per kidney per treatment. Shock-waves are usually initiated at low power settings, then the power may be increased slowly to the effective level (usually 13 to 18 kV). Although this protocol was primarily created to improve patient comfort and procedure tolerance, it also affects urolith fragmentation by slowly creating small dust-like particles. Fluoroscopic or sonographic imaging is available for monitoring stone fragmentation. In-line sonographic visualization, such as that available with the Storz Modulith SL20 (Figure 29-16), can be very difficult in small animals and has not proven useful in our practice. Radiographic contrast media can be injected intravenously during treatment to enhance visualization of a ureterolith or radiolucent nephrolith; contrast nephropathy is possible, but rare.[11] Regardless of imaging capability, the degree of urolith fragmentation can be difficult to assess during treatment, since fragments may overly each other until they begin to move into the ureter.



Figure 29-16. The Storz Modulith SL 20 Lithotriptor.

Following lithotripsy treatment, a 2 to 4 day period of diuresis is continued to promote passage of stone fragments. Follow up radiographs and ultrasound are generally performed one or two days following treatment and every 3 to 4 weeks thereafter. Urolith passage may be rapid in some animals, or may take several months to completely clear from the urinary tract. Fragmentation has been considered complete in human beings when only clinically insignificant (< 2 mm) fragments remain visible.[13] Based on veterinary experience, even smaller fragments are desired in small animal patients in order to facilitate passage of all debris along the ureter. Small residual fragments also can serve as a nidus for urolith recurrence in stone-forming individuals.[12,13]

ESWL is contraindicated in animals with uncontrolled coagulopathy, hypertension, or other intra-abdominal disease such as chronic pancreatic or hepatic disease. Concurrent pyelonephritis or renal failure, while considered an indication for pursuing treatment of nephroliths, may increase the risk of SW induced renal injury in dogs and cats. I generally perform a more conservative lithotripsy regimen using less energy if measured glomerular filtration is subnormal, even if the animal is nonazotemic. Urinary tract infection should be managed and sterile urine obtained before performing ESWL. While small body size is not a contraindication, a greater percentage of the kidney is exposed to SW injury in patients or species with small kidneys.[14,15] The risk of damage to surrounding tissues, including lungs and bone, is also greater in very small animals.

Lithotripsy for Canine Nephroliths

If removal of nephroliths is indicated (progression in nephrolith growth, persistent urinary tract infection, presence of symptomatic or obstructive disease), lithotripsy is an option for treatment of the most common types of nephroliths in dogs (Table 29-1). Fragmentation of calcium oxalate nephroliths is reasonably effective in this species (Figure 29-17). In several reports, Adams has reported overall success in approximately 85% of dogs treated with the HM-3 lithotriptor.[4,11] We reported a similar overall response after our early experience with a Storz Modulith 20 dry lithotriptor,[16] and have since found fragmentation of canine nephroliths highly variable. Treatment of nephroliths up to 2 or 3 cm in their largest dimension can be treated using this technology; however, smaller nephroliths (< 1.5 cm) are generally more amenable to treatment in our experience.

Struvite nephroliths also can be fragmented by ESWL permitting more rapid elimination or to hasten medical dissolution; we have treated one dog in which all radiographic evidence of a large nephrolith was gone in less than one month. However, medical dissolution of struvite nephroliths is preferred when feasible, particularly for very large stones. Urate, xanthine and cystine

Table 29-1. Referral Considerations regarding ESWL for Canine Uroliths

- Do the uroliths require direct treatment or can they be monitored for progression or movement?
- Are uroliths clearly identifiable on survey radiographs so that they can be located readily during ESWL?
- Are nephroliths less than 1.5-2 cm in their largest diameter?
- Is the overall urolith burden reasonable for ESWL treatment?
- Does the risk posed by the urolith outweigh the risk of potential damage created by ESWL?
- Can the dog tolerate general anesthesia and fluid diuresis?
- Are concurrent problems such as chronic renal failure, hyperadrenocorticim, urinary tract infection and hypertension well controlled?
- Are the clients prepared for the costs and requirements for post-treatment monitoring?
- Is surgical intervention or repeat ESWL treatment readily available for an obstructive fragment?
- Is there a significant advantage of ESWL over surgical or laser lithotripy methods (urocystoliths)?

stones are more resistant to fragmentation. In 5 dogs with urate or xanthine stones, lithotripsy was effective in only 2.[11] For large or refractory uroliths, multiple treatments (separated by at least 4 weeks) may be considered. Ideally a ureteral stent is placed concurrently to facilitate fragment passage and prevent obstruction of the ureter. Transurethral, endoscopic ureteral stent placement may be feasible in some dogs using fluoroscopic guidance.[17] The reported re-treatment rate for nephroliths varies with machines, ranging from 30%[11] to 50%.[16]

Bilateral nephroliths may be treated at the same time or staged, depending on the size of the nephrolith and renal function. Bilateral uroliths can be treated during the same anesthetic episode unless concern about individual renal function dictates staged treatments. Treatment of large stones may also be staged, due to high shock wave dose and anesthetic time needed to create fragmentation. Additionally, large fragments may be expected, leading to the increased likelihood or ureteral obstruction by stone fragmentation post-ESWL.[11]

Potential Complications

Extracorporeal shock-wave lithotripsy, while considered safer than surgical approaches, is not without risk. Potential complications of lithotripsy for nephroliths include pain, the creation of obstructive ureteral fragments, damage to the kidney (parenchymal hemorrhage or subcapsular hematoma), or damage to other organs secondary to shock wave application. Adams (2013) estimates that 10% of ESWL treated dogs have transient ureteral obstruction. Stent placement or additional lithotripsy are indicated to alleviate persistent obstruction.[17a] Transient hematuria, transient or progressive decrease in renal function, retroperitoneal fluid accumulation, ureterectasia, pain, diarrhea and ureteral obstruction by urolith fragments have been observed in dogs.[7,18] I routinely treat with analgesics for 24 hours post treatment, and extend the treatment if fragments are actively moving along the ureter, or if clinical signs of pain are observed. Acute pancreatitis has been described as a consequence of right kidney ESWL treatment in two small (< 5 kg) dogs, with fatal complications in one dog.[19] Pancreatic injury may affect many ESWL treated dogs but clinical pancreatitis is seen in less than 2%.[17a] Fatal arrhythmia, possibly secondary to shock waves, was recently described in one dog treated with the HM-3.[11] We have observed a transient ventricular arrhythmia in one cat during ESWL application. Residual fragments are common, and may provide a nidus for harboring infection or for formation of recurrent uroliths. Complications can be minimized by ensuring the health and suitability of the patient for anesthesia and shock wave treatment, ensuring appropriate shock wave dosage and application, shielding other organs from shock waves during treatment, ensuring adequate diuresis and monitoring post treatment, and providing prompt treatment of obstructive fragments.

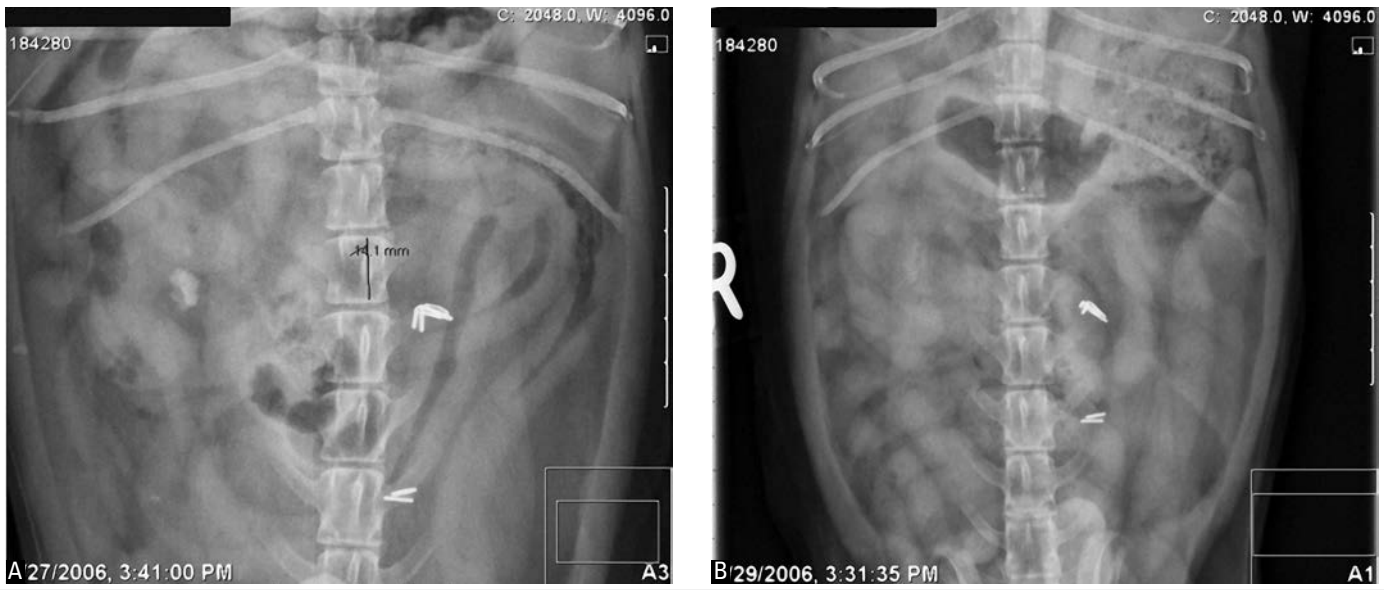


Figure 29-17. A. and **B.** Fragmentation of Calcium Oxalate Nephroliths in a canine patient using lithotripsy.

Lithotripsy (ESWL) for Canine Ureteroliths

Ureteroliths can also be fragmented using ESWL. The method is similar to that for nephroliths, although their treatment can be more difficult for several reasons. Ureteroliths are more difficult to image and focus, are not in contact with as much fluid as stones in the renal pelvis, have less room for fragments to fall away, and may be imbedded in the ureteral wall.[3] A higher shock wave dose may be required to sufficiently fragment ureteroliths. Using an aggressive treatment approach (mean 2600 SW at 14-19 kV) and a lithotripter with a small, high pressure focal zone, we have had very good success (> 90%) in fragmenting ureteroliths in dogs.[6,7] So far, only one ureterolith, lodged in the mid-ureter in a small dog (body weight < 3 kg), was insufficiently fragmented to pass after initial treatment. By comparison, retreatment rates for ureteroliths are approximately 50% using the HM3 lithotriptor.[11] Factors limiting successful fragmentation in human patients, that have led to an increase in ureteroscopic techniques, have included larger stone size (> 10 to 12 mm), distal (pelvic) location,[20,21] degree of obstruction and patient obesity.[20]

The primary complication of ureterolith fragmentation is further ureteral obstruction. Fragmentation or movement of a ureterolith can create a more lodged stone, even if the ureterolith was nonobstructive initially. In our experience, ESWL treatment of ureteroliths can be more painful postoperatively than treatment of nephroliths. Dogs appear to tolerate passage of ureteral fragments well, presumably due to the size and distensibility of the canine ureter. Breakthrough pain is an uncommon finding in ESWL treated dogs, whereas pain can be excruciating during stone passage in people.

Limitations of ESWL for Feline Uroliths

ESWL treatment of uroliths in cats has been limited by disappointing early results. Adams observed significant renal trauma (renal hemorrhage and functional impairment) in a small number of healthy cat kidneys treated with the HM-3, as well as insufficient fragmentation of upper tract uroliths in 5 clinically affected cats.[4] Using the HM-3 lithotriptor, Adams found that ureteroliths could be fragmented successfully in only 1 of 5 cats, and that fragmentation of nephroliths was incomplete. In addition, transient or permanent worsening of renal function occurred in several cats. Based on this experience, cat kidneys have been considered more sensitive to damage from ESWL.

Although promising results were obtained in a small group of healthy cats treated with a dry lithotriptor (no change in sonographic renal structure or function as assessed by renal scintigraphy)[22] fragmentation of nephroliths or ureteroliths to the size needed to pass through the extremely small ureteral lumen still poses a considerable challenge.[10,11] Feline uroliths also are more difficult to fragment *in vitro*,[23] a finding that correlates with clinical experience. Using a research electrohydraulic lithotriptor that simulates the function of the Dornier HM-3, breakage of intact calcium oxalate uroliths retrieved from dogs and cats was evaluated using digital image size.[23] In this study from the Minnesota Urolith Center, significantly less breakage was observed in feline stones than in canine uroliths following the same SW dosage (100 SW at 20 kV).[23] Increased shock-wave dosage (especially shock-wave number, while still limiting power and frequency) may help minimize the size of fragments, but can only be effectively applied to one or two small stones during a treatment session. The number and size of nephroliths (or the finding of multiple, concurrent nephroliths, ureteroliths and cystoliths) makes lithotripsy impractical for stone removal in many cats. Renoprotective agents may help minimize renal injury during aggressive shock wave treatment. Logical protective measures also might include pre-treatment with mannitol or calcium channel blockers.

Lithotripsy for Feline Ureteroliths

Lithotripsy of ureteroliths in cats poses similar, but magnified, challenges when compared to those encountered in dogs. Imaging of very small ureteroliths in cats can be extremely difficult using the available fluoroscopic monitors (Figure 29-18A-C). Distal ureteroliths, in particular, can be obscured by pelvic structures, whereas other small ureteroliths can be difficult to place precisely in the focal zone. Movement of the ureterolith during ESWL appears much more common in cats as well, either with respiration or due to mobility of the ureter or urolith. Frequent repositioning and coordination with ventilation is imperative for effective fragmentation. We have reported progressively improving results in several feline ureteroliths treated with ESWL[6] and have experienced an approximately 50% success rate (complete fragmentation and passage) after one or two treatments. Short term interim complications (retreatment, slow passage of fragments or debris) pose challenges; however most cats have had a favorable long term outcome. Unfortunately, further urinary tract compromise may occur in between treatments if the ureterolith remains obstructive. Surgical intervention is likely to alleviate obstruction more rapidly than lithotripsy in some cats, but is associated with significant morbidity.

Despite good fragmentation of a nephrolith, residual fragments still must be small enough to traverse the feline ureter (internal diameter < 0.4mm). Fluid and diuretic treatment to promote ureteral urine flow, or treatment with agents that may relax ureteral smooth muscle, are strategies that may improve the success of lithotripsy in cats. Based on experience with human beings, alpha antagonist and anti-inflammatory treatment may be the most promising adjunct treatments.[24] Amitriptyline also may relax urinary smooth muscle in cats.[25] Treated cats must be able to tolerate fluid diuresis, and should be screened for occult cardiac disease prior to treatment.

Although the primary risks of ESWL in cats have been viewed as damage to the kidney or worsening obstruction, other complications of ureteral treatments are possible. Ureteral rupture has been observed in one cat in our hospital. Pancreatic or bowel damage is also possible, given the size of the patient. Long-term effects on ureteral function or structure in small animals are currently unknown, but do not appear to be a major concern of ESWL in human patients.

Current Recommendations for Cats

At the current time, ESWL is most suited for treatment of a single (unilateral) obstructive ureterolith separated by some distance

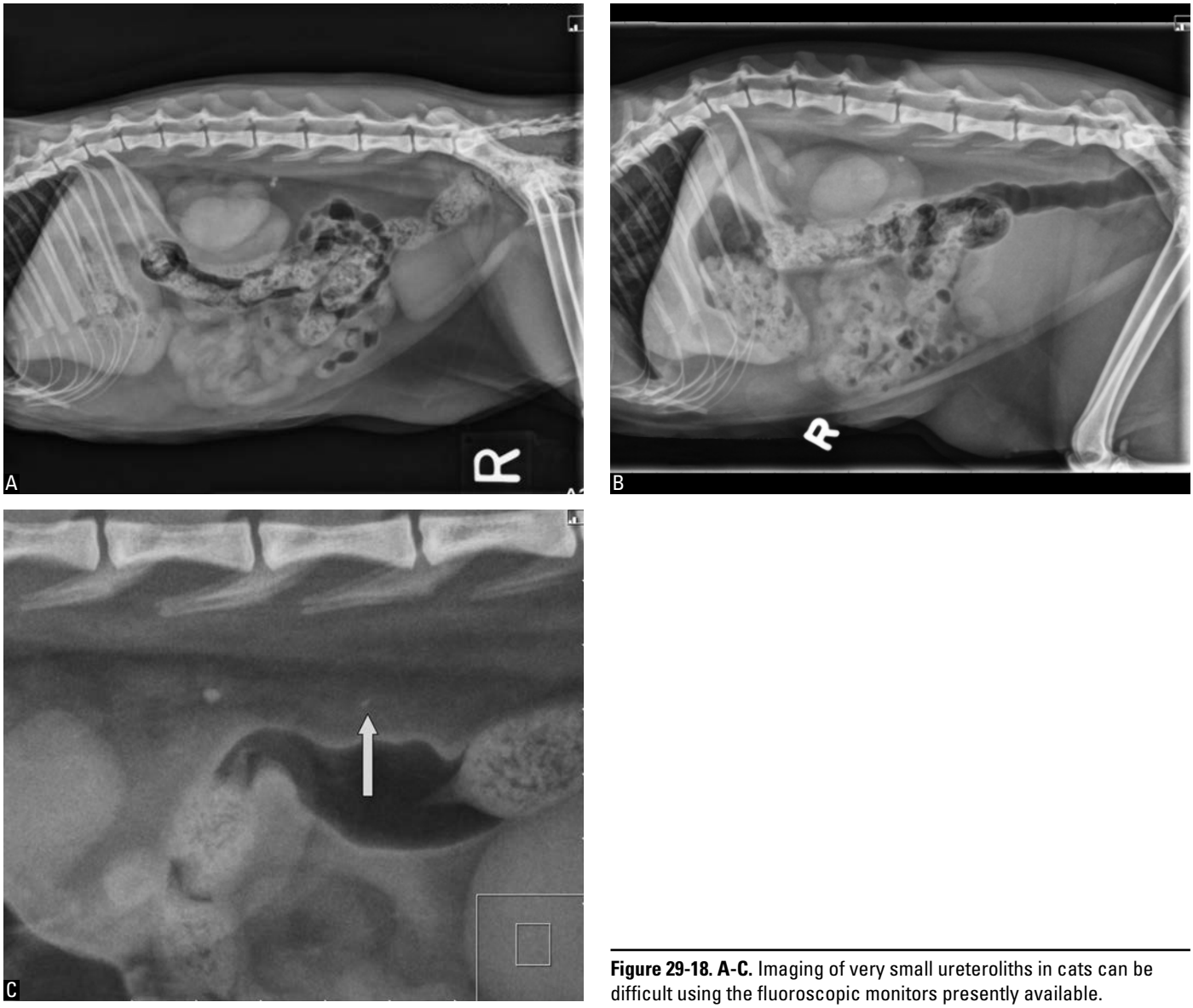


Figure 29-18. A-C. Imaging of very small ureteroliths in cats can be difficult using the fluoroscopic monitors presently available.

from the kidney. At this time, approximately one-half of cats with a single stone will have successful fragmentation of the stone (such that all fragments pass into the lower urinary tract) with one or two lithotripsy treatments. Obstructive nephroliths of small size (< 1 cm) also may be good candidates for ESWL, although the risk of renal injury increases with treatment of nephroliths. Owners of cats referred for lithotripsy should be prepared for multiple treatments, possible worsening of renal function, or progressive ureteral obstruction after ESWL (Table 29-2).[10] Surgical intervention or dialysis support may be necessary if these complications are severe. For these reasons, surgery or ureteral stenting[26] may be a preferred option for metabolically unstable, patients with completely obstructive ureteroliths, where the immediate relief of obstruction is of primary concern. Potential modifications of lithotripsy protocols, including slow rate of energy delivery, lower power regiments, newer lithotriptors, and use of ureteral stents may minimize renal damage in cats.

Lithotripsy for Urocystoliths in Dogs or Cats

Extracorporeal shock wave lithotripsy has not been widely recommended for treatment of bladder stones. Free movement of uroliths within the bladder limits the effect of the carefully targeted, repetitive shock waves, and may result in failure of fragmentation, or larger fragments than desired. In some cases, however, urocystoliths can be fragmented fairly easily. Most commonly, urocystoliths are treated concurrently when nephroliths are treated.[4] Extracorporeal lithotripsy can also be used to reduce the size of cystoliths for medical dissolution, removal by hydropropulsion, or prior to laser lithotripsy.[11] I have been pleased with the ability of the dry lithotriptor to fragment bladder stones for sufficient passage in several female dogs and one cat, but have avoided this treatment in male dogs due to the increased risk of urethral obstruction by small uroliths and stone fragments. Other clinicians have successfully applied the technique to small male dogs and removed the fragments by voiding urohydropropulsion.[11] A higher shock-wave dose may be required to create sufficiently small fragments; at this time it appears that urinary bladder tissue can tolerate this modification. For female dogs and cats, and male dogs large enough to undergo transurethral procedures, intracorporeal laser lithotripsy is preferred for optimal fragmentation of cystoliths.

Table 29-2. Referral Considerations Regarding ESWL for Feline Ureteroliths

- Do the uroliths require direct treatment or can they be monitored for progression or movement?
- Are ureteroliths clearly identifiable on survey radiographs so that they can be located readily during ESWL?
- Can a single stone be identified as the primary obstructive urolith?
- Is the obstructive ureterolith separated from the renal pelvis by 1 or more centimeters?
- Will an immediate benefit result from urolith removal in the patient (i.e., relief of obstruction, removal of infectious nidus, relief of pain)?
- Will a long-term benefit (e.g., protection of renal parenchyma, renal function, ureter) result from urolith removal?
- Does the risk posed by the urolith outweigh the risk of potential damage created by ESWL?
- Can the cat tolerate general anesthesia and fluid diuresis post treatment?
- Is the cat's metabolic condition stable enough to undergo lithotripsy and assess reponse to treatment over days to weeks?
- Are concurrent problems such as chronic renal failure and hypertension well controlled?
- Is surgical intervention or repeat ESWL treatment readily available for an obstructive fragment?

Referral Considerations

The many new options for nonsurgical management of uroliths provide exciting opportunities for case management. Appropriate case selection, however, is critical to the success of the procedure and to client satisfaction. In addition to reviewing guidelines and information available regarding lithotripsy, clinicians should review the many summaries now available in textbooks and journals regarding general management of nephroliths and ureteroliths. Most referral centers providing lithotripsy treatment have prepared handouts or websites summarizing the indications, protocols and costs of therapy. Both referring clinicians and clients should be aware that access to a lithotriptor and availability of trained personnel may limit appointments and create delays in treatment. Facilities with in-house equipment are more likely to be able to accommodate emergency case referrals (ESWL for obstructive ureteroliths, laser lithotripsy for urethroliths). Clients should be prepared for 4 to 7 days of hospitalization for their animal and the possibility of multiple procedures and follow-up examinations over several months. Adequate local follow-up examinations, including high quality sonographic evaluation of the urinary tract, must be available. Repeat treatments, when indicated, are usually performed at 4 to 8 week intervals. Due to the intensity of pre-treatment and post-treatment patient handling, ESWL is not well suited for aggressive animals.

Appendix

Centers Providing Extracorporeal Shock Wave Lithotripsy

The Animal Medical Center
510 East 62nd Street
New York, NY 10065
Interventional Radiology and Endoscopy
Contact: Phone: 212-838-8100 or info@amcny.org

Purdue University School of Veterinary Medicine
Lynn Hall
625 Harrison Street
West Lafayette, IN 47906
Contact: Phone 765-494-1107 or PUSAH@purdue.edu
ESWL, Laser

Tufts University Cummings School of Veterinary Medicine
Foster Small Animal Hospital
200 Westboro Road
North Grafton, MA 01536
Contact: Phone: 508-839-5302
ESWL, Laser

References

1. Chaussy C, W B, E S: Extracorporeally induced destruction of kidney stones by shock waves. Lancet 2:1265, 1980.

2. Preminger G: Shock wave physics. American Journal of Kidney Disease 17:431-435, 1991.

3. Lingeman J, DA L, AP E: Surgical management of urinary lithithiasis, in Walsh P (ed): Campbell's Urology, 8th edition. Philadelphia, WB Saunders, 2002, pp 3361-3452.

4. Adams LG, DF S: Electrohydraulic and extracorporeal shock-wave lithotripsy. Vet Clin North Am; Small Anim Pract 29:293-302, 1999.

5. Block G, Adams L: The use of extracorporeal shock-wave lithotripsy for treatment of spontaneous nephrolithiasis and ureterolithiasis in dogs. J Am Vet Med Assoc 208:531-536, 1996.

6. Lane I: Extracorporeal shock-wave lithotripsy for ureteroliths in dogs and cats, in 23rd American College of Veterinary Internal Medicine Forum, Baltimore, Md.

7. Lane I: Lithotripsy: an update on urologic applications in small animals. Vet Clin North Am; Small Anim Pract 34:1011-1025, 2004.

8. Bailey G, RL B: Dry extracorporeal shock wave lithotripsy for treatment of spontaneous nephrolithiasis and ureterolithiasis in dogs. J Am Vet Med Assoc 207:592-595, 1995.

9. Auge B, Preminger G: Update on shock wave lithotripsy technology. Current Opinion in Urology 12:287-290, 2002.

10. Lane I, Labato M, Adams LG: Lithotripsy, in JA A (ed): Consultations in Feline Internal Medicine, 5th ed. Philadelphia, Elsevier, 2006, pp 407-414.

11. Adams LG: Lithotripsy using shock waves and lasers, in 24th Annual ACVIM Forum, Louisville, KY, pp 439-441.

12. Tan Y, Wong M: How significant are clinically insignificant residual fragments following lithotripsy? Current Opinion in Urology 15:127-131, 2005.

13. Osman M, Alfano Y, Kamp S, et al: 5-year-follow-up of patients with clinically insignificant residual fragments after extracorporeal shockwave lithotripsy. European Urology 47:860-864, 2005.

14. Blomgren P, Connors B, Lingeman J, et al: Quantitation of shock wave lithotripsy-induced lesion in small and large pig kidneys. Anatomical Record 249:341, 1997.

15. Willis L, al e: Relationship between kidney size, renal injury and renal impairment induced by shock wave lithottripsy. J Am Soc Nephrol 10:1753, 1999.

16. Lane I: Dry extracorporeal shock-wave lithotripsy, in 21st American College of Veterinary Internal Medicine Forum, Charlotte, NC, June 2003.

17. Weisse CW, Berent AC. Interventional radiology in urinary diseases. In Bonagura J and Twedt D, Current Veterinary Therapy XIV, Saunders Elsevier 2009, pp 965-971.

17a. Adams LG: Nephroliths and ureteroliths: a new stone age. N Zeal Vet J 61:212,2013.

18. Siems J, Adams, LG, et al.: Ultrasound findings in 14 dogs following extracorporeal shock-wave lithotripsy for treatment of nephrolithiasis [abstr]. In: in Proceedings of the American College of Veterinary Radiology Chicago, p 11.

19. Daugherty M, Adams LG, al e: Acute pancreatitis in two dogs associated with shock wave lithotripsy (abstr). Journal of Veterinary Internal Medicine 18:441, 2004.

20. Delakas D, Karyotis I, Daskalopoulos G, et al: Independent predictors of failure of shcokwave lithotripsy for ureteral stones employing a second-generation lithotripter. Journal of Endourology 16:201, 2003.

21. Shiroyanagi Y, Yagisawa T, Nanri M, et al: factors associated with failure of extracorporeal shock wave lithotripsy for ureteral stones using Dronier lithotriptor U/50. International Journal of Urology 9:304, 2002.

22. Gonzales A, Labato M, Solano M, et al: Evaluation of the safety of extracorporeal shock-wave lithotripsy in cats (abstr). Journal of Veterinary Internal Medicine, 2002.

23. Adams LG, JC W, JA M, et al: In vitro evaluation of canine and feline urolith fragility by shock wave lithotripsy (abstr). Journal of Veterinary Internal Medicine 17:406, 2003.

24. Porpiglia F, Ghignone G, C F, et al: Nifedipine versus tamsulosin for the management of lower ureteral stones. Journal of Urology 172:568, 2004.

25. Achar E, Achar R, Paiva T, et al: Amitriptyline eliminates calculi through urinary tract smooth muscle relaxation. Kidney International 64:1356, 2003.

26. Berent AC,Weisse CW,Todd KL, et al: Use of locking-loop pigtail nephrostomy catheters in dogs and cats: 20 cases (2004-2009). J Am Vet Med Assoc 241:348, 2012.

Laser Lithotripsy for Treatment of Canine Urolithiasis

Ellen B. Davidson Domnick

Introduction

Uroliths are a common cause of hematuria, stranguria, and dysuria in dogs.[1,2] Obstructive uroliths, if left untreated, may cause azotemia, recurrent urinary tract infections, loss of kidney function, or death.[1-3] Surgical removal is the traditional treatment for removal of recurrent stones or obstructive stones in veterinary medicine.[2,4-6] Surgery in the carefully selected patient is relatively quick, relieves obstruction, and decreases or reverses loss of glomerular function. However, surgery is invasive and complications, including damage to healthy functioning tissue, perioperative hemorrhage, urethral or ureteral stricture, intra-abdominal adhesions, and urolith recurrence are common.

Nephrotomy may cause a temporary decrease in renal function and nephron loss in those animals with preexisting renal disease. Recurrence of calculi formation, adhesions, and urine leakage may occur after cystotomy.[5,6] Leakage of urine from the kidney, ureter or bladder causes uroperitoneum and metabolic, fluid, electrolyte, and acid-base abnormalities. Incomplete removal of calculi especially from the bladder is not uncommon. Because of the small size and irregular contour of some uroliths, complete removal of all stones can be difficult.[7,8] Flushing the bladder and urethra is not a reliable method to ensure complete removal of all calculi; in one study, uroliths were incompletely removed in 1 of 7 dogs and 1 of 5 cats following cystotomy.[9]

Complications following urethrotomy include hemorrhage, urine leakage, and possible urethral stricture; and is indicated only if obstructive uroliths cannot be hydropropulsed retrograde into the bladder for dissolution or removal.[5,7,10] The urethrotomy site may be closed or left to heal by 2nd intention, in which case hemorrhage occurs for 7 to 10 days. Chronic stricture formation following urethrotomy increases the risk of blockage during voiding of calculi. Other potential complications include scarring of the incision site, tissue irritation, urethrocutaneous fistulae, and diverticula formation. Permanent urethrostomy may be necessary if stricture occurs. Complications of urethrostomy include hemorrhage, recurrent urinary tract infections, and inguinal and scrotal scalding.[5]

Lithotripsy

In human urology, surgical removal of uroliths has been largely replaced by lithotripsy.[1,11] Lithotripsy, the act of breaking or fragmenting stones, uses the generation of shock waves or laser energy to fragment uroliths. There are two forms of lithotripsy that use shock waves to fragment the stone; electrohydraulic shock-wave lithotripsy (EHL) and extracorporeal shock wave lithotripsy (ESWL). All shock waves, when focused, fragment urinary stones by erosion and shattering.[12,13]

EHL uses the generation of sparks in a fluid medium to develop shock waves. The shock wave is generated at the tip of an insulated wire that is placed immediately adjacent to uroliths within the urinary tract. The shock wave passes through the body of a urolith and reflects back from its edge to pass back through the body of the stone. Many 1° and 2° shock waves are created, causing shearing forces that destroy the lattice of the urolith.[11,13] EHL has been used successfully in horses; successful ureteroscopic EHL was performed by perineal urethrostomy in a 3 yr. thoroughbred colt.[14] In an 18-year old thoroughbred gelding, a ballistic shock wave lithotriptor was used to break up an 8 cm. bladder calculus and by flushing out the sand-like residue under epidural anesthesia.[15]

In ESWL, shock waves are generated outside the body and directed or focused toward the urolith. The stone is localized during lithotripsy with ultrasonographic or fluoroscopic guidance. ESWL is standard therapy for renal and upper urinary tract calculi in humans, with over 75 to 90% of stones resolved

with lithotripsy.[12,13] Because of the relative immobility of the renal pelvis, ESWL is most applicable to renoliths that are relatively fixed as shock waves move through them. The relative mobility of the bladder and bladder stones makes ESWL less ideal for treatment of stones in the lower urinary tract.[16] Nephroliths and ureteroliths have been successfully treated in dogs with 1st and 2nd generation lithotriptors.[1,17] Expense, purchase, upkeep, and availability of ESWL have limited its use in small animals.[13,17] (See ESWL by Dr. I. Lane).

Laser lithotripsy, an alternative to other forms of shock wave lithotripsy, effectively eliminates uroliths in humans, horses, ruminants, pigs, and dogs.[18-32] Laser-induced shock wave lithotripsy transforms light energy into acoustic energy (photoacoustic) or thermal (photothermal) energy, depending on pulse duration.[21] The shock wave generated is large enough to fragment uroliths by photoacoustic or photothermal ablation.[21] During lithotripsy, laser energy is transmitted and directed to the urolith surface through a small diameter flexible optical fiber that allows the operator to directly visualize the urolith under endoscopic guidance. The development of fiberoptic cables has greatly increased therapeutic applications of the laser, as fiberoptics allow the laser delivery beam to be brought in contact with the stone.[26] The small fiber size of a laser generally between 300 to 600 microns in diameter (0.3 to 0.6 mm), allows it to be passed through instrument channels in newer generation flexible and rigid endoscopes, and limits retropulsion. Fiberoptics allow the operator to safely, effectively, and accurately deliver laser energy and fragment a stone with little damage to surrounding tissue damage.[31-33] In humans, laser lithotripsy is the 2nd most preferred method for urinary calculi removal after shock wave lithotripsy.[18,34-35]

A pulsed laser that can be delivered through fiberoptic cables is required. Pulsed laser energy is absorbed by water in the urolith, the resulting photothermal effect fragments the urolith, and fragments are actively flushed out with a flushing system attached to the endoscope's biopsy port. Any remaining stone fragments are left to be passed normograde during urination.[31] Because stones can be visualized endoscopically and the fiber is placed directly on the surface of the stone, the stone is consistently fragmented.[18,31] Laser lithotripsy is useful for patients at risk for hypertension or renal dysfunction, is non-invasive, protects renal function, and rapidly resolves clinical signs of obstruction.[26,36]

Lasers used in Lithotripsy

Both the Holmium: Yttrium Aluminum Garnet (Ho:YAG) and pulsed dye lasers can effectively fragment biliary and urinary stones.[22,26,37] but the dye laser energy required for urolith fragmentation may damage the optical fibers and fragmentation efficiency is dependent on urolith composition and color.[19] The pulsed dye laser has a wavelength of 504 nm, which is selectively absorbed by black or brown, the color of many uroliths. This is a disadvantage when treating "pale" uroliths such as cystine, because fragmentation may be ineffective for relatively colorless stones.[38] Pulsed dye laser lithotripsy is effective in fragmenting the most common uroliths of horses, calcium carbonate, and may be performed in standing horses with less surgical invasiveness and trauma to the urinary tract.[27] In male horses urethroliths are accessible at the distal urethra via a perineal urethrotomy or via a transurethroscopic approach. Transendoscopic pulsed dye laser lithotripsy was effective in the treatment of calcium carbonate urolithiasis in 2 adult geldings.[27] The principle disadvantages included cost of the procedure and the time delay required for use of the pulsed dye laser lithotriptor.

Success in fragmenting calcium carbonate uroliths in horses with Ho:YAG has been mixed; successful removal of calculi was reported in 5 horses with a combination of laser lithotripsy, lavage, basket snare removal, and digital manipulation.[39] In another report, the Ho:YAG failed to adequately fragment calculi, and pulsed dye lithotripsy or digital manipulation was necessary to remove the uroliths.[40]

Initial experience in human urology with the Ho:YAG laser has demonstrated its safety and that no excess hemorrhage, renal deterioration or trauma occurs.[25] Reported stone-free rates are 67 to 84% for renal calculi, with complications rates of < 1%.[25] Ho:YAG lithotripsy is effective for ureteral and renal calculi in morbidly obese patients.[26] Additionally, the photothermal effects of the Ho:YAG laser use are minimal; lesions are consistently < 1 mm.[25,26]

Advantages of the Ho:YAG laser for lithotripsy. The Ho:YAG laser is portable and rugged. The Ho:YAG laser precisely cuts with minimal damage to adjacent mucosal tissue. It offers fiber optic delivery, which is ideal for endoscopic use, and can treat tissue in a liquid environment such as the urinary tract. Protective eyewear is available for its infrared wavelength (2100 nm). Its laser wavelength is poorly absorbed in tissue, resulting in minimal damage to the adjacent urethral mucosa.[30-32] Its effect is independent of stone color.[38] Of all lasers, Ho:YAG produces the smallest fragments in all stone types. The reported efficacy of the Ho:YAG laser in fragmenting uroliths is 100% vs. 78 to 89%, for the pulsed dye laser.[38]

Laser Lithotripsy in Veterinary Medicine

The Ho:YAG laser effectively fragments urinary stones independent of composition, water content, or size.[32,41] Pulsed Ho:YAG laser energy fragments canine uroliths *in-vitro* without optical fiber damage. In an initial in vitro study all stones were successfully fragmented in less than 30 seconds.[30] This and other studies have shown that that higher pulse frequencies (10 to 40 Hertz [Hz]) and lower pulse energies ($\leq$ 1 joule[J]) were safer and more efficient for urolith fragmentation using Ho:YAG laser energy.[30,32,42]

In a subsequent in vivo experimental study, laser lithotripsy with the Ho:YAG laser successfully fragmented obstructive uroliths in the urethra of male dogs.[31] Mean time for adequate fragmentation was rapid, 166.7 seconds (range, 47 to 494.5 seconds). Minimal (< 30 mg) or no urolith material was evident within the urethra after lithotripsy. Urinary clinical signs related to lithotripsy resolved without further treatment in all dogs by day 5. Endoscopic evaluation of the urinary tract on day 10 revealed no mucosal lesions, stricture or narrowing of the urethra, or urolith remnants. No dog became obstructed during 30 days of observation.

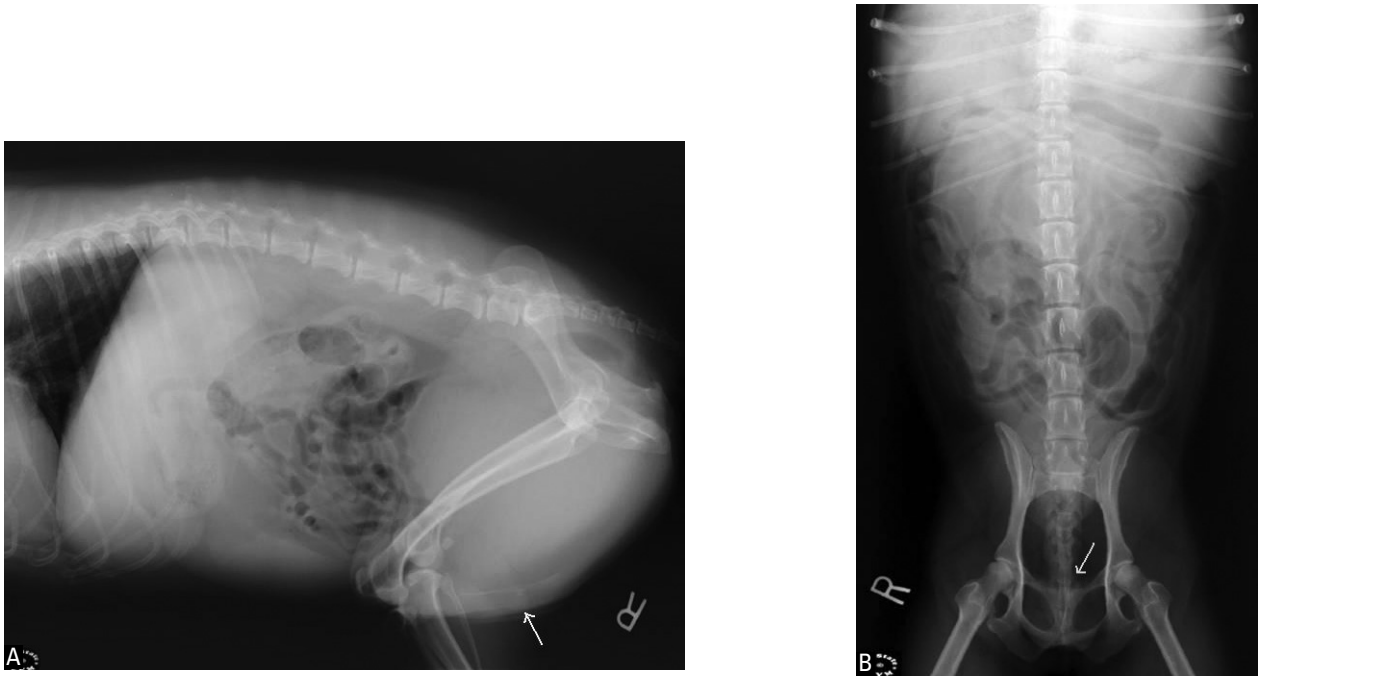


Figure 29-19. A. (lateral) and **B.** (Ventro Dorsal) radiogrpahic views of a dog with obstructive urethrolith formation (arrows).

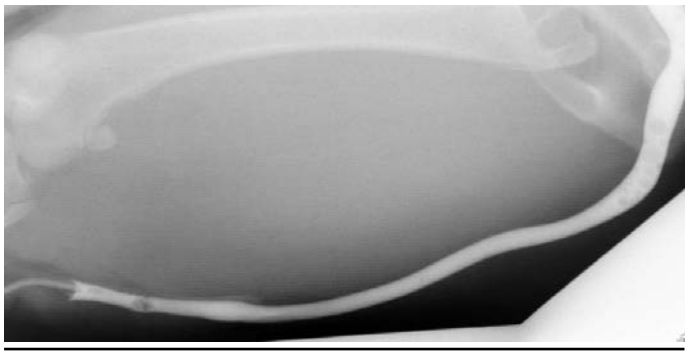


Figure 29-20. Pre-lithotripsy positive contrast cystourethrogram of the dog in Figure 29-19. Filling defect at the region of the os penis is evident. More proximal radiolucent apparent filling defects are air bubbles.

Laser lithotripsy has been performed in male dogs with spontaneously occurring urolithiasis that could not be relieved with catheterization or urohydropropulsion (Figures 29-19 to 29-21). Stone burden ranged from one to seven per dog, and stone types were calcium oxalate or magnesium ammonium phosphate. Both urolith types in this group of dogs were successfully fragmented in less than 130 seconds in all dogs, and no complications from the procedure have been reported to date (Table 29-3). Differences in stone density or composition does not appear to affect the efficiency of laser fragmentation. No recurrence of clinical signs of obstructive urolithiasis or stricture formation has occurred in four dogs; one dog developed recurrent calcium oxalate cystoliths 25 months after lithotripsy which was treated via cystotomy.

Lithotripsy Technique for Urethral Calculi

All dogs with urinary calculi should have complete imaging (radiography and ultrasound) of the entire urinary tract, laboratory analyses including urinalysis and urine culture, and urine function and clotting studies if necessary prior to lithotripsy.

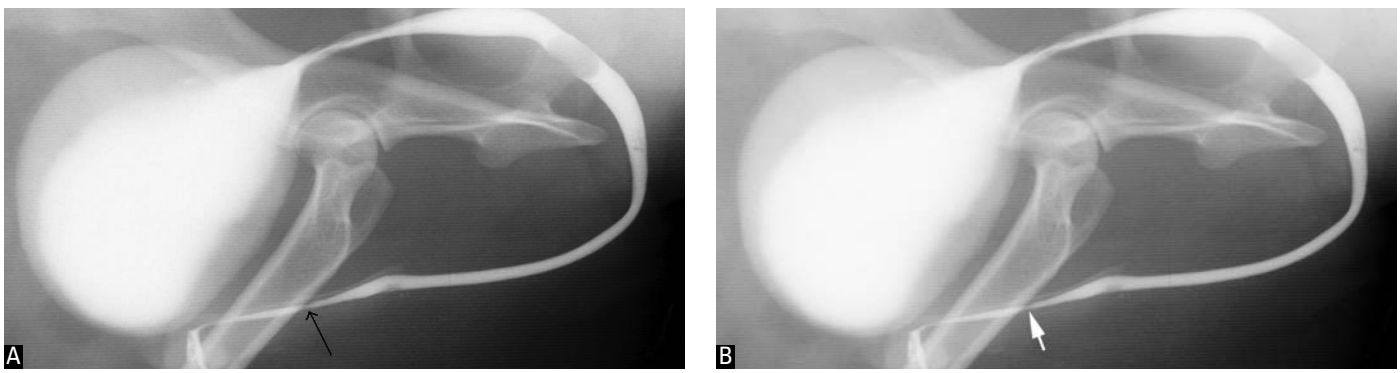


Figure 29-21. A. Post-lithrotripsy positive contrast cystourethrogram of the same dog. No filling defects are evident. There is mild narrowing of the distal urethra at the site where the stone was treated. This is likely due to mild spasming of the urethra from the lithotripsy procedure. **B.** Post. lithrotripsy positive contrast cystourethrogram of the same dog. No filling defects are evident. There is mild narrowing of the distal urethra at the site where the stone was treated (arrow) which is likely due to mild spasming of the urethra from the lithotripsy procedure.

Table 29-3. Results of Dogs undergoing Laser Lithotripsy

Dog	Signalment	Stone analysis	Laser time (seconds)	Laser settings (total energy)	Outcome
1	8.5 kg 9-year old male intact miniature Schnauzer	Stone content of 100% COM; shell of 100% COD	Multiple stones in bladder and at os penis 127.4 sec	637 J	Euthanized 26 months post-lithotripsy for unrelated illness; no recurrences of uroliths
2	3.9 kg, 3-year old male castrated Maltese	Could not collect fragments due to small size	1 stone lodged at os penis 44 sec	220 J	No episodes of dysuria, no urolith recurrence at 25 months
3	12.9 kg, 10 year-old male beagle	90% MAP hexahydrate (struvite) and 10% CPC stone forms	1 stone at os penis 77 sec	385 J	19 months following lithotripsy, the dog is urinating normally, no further evidence of obstructive urolithiasis.
4	11.9 kg, 10-year old male castrated Lhasa Apso	100% COM with a shell content of 20% COM and 80% COD	1 calculus at os penis, several small cystoliths 130.7 sec	653 J	No evidence of urinary tract disease or obstructive uroliths 28 months post-lithotripsy.
5	12 kg, 8 year-old male castrated Schnauzer	15% COM and 85% COD	1 calculus at os penis 9.8 sec	49 J	15 months post-lithotripsy, the RDVM performed cystotomy to remove 2 COM cystic calculi. The dog had been maintained on a diet designed for management of CO urolithiasis.

Key:
COM = calcium oxalate monohydrate
COD = calcium oxalate dihydrate
MAP = magnesium ammonium phosphate
RDVM = referring veterinarian
CPC = calcium phosphate carbonate

A 2.5 mm (7.5 French) (Karl Storz, Inc., Goleta, CA) or 2.8 mm (8.4 French) (Mitsubishi Endoscopy, Irvine, CA) flexible endoscope with an intraluminal channel is passed retrograde through the urethra to the level of the most distal urolith. A 320 um low-OH optical laser fiber (Sunrise Technologies, Fremont, CA) is passed through the operating channel until the aiming beam is visible extending from the tip of the endoscope. The fiber is directed onto the urolith surface and laser energy (sLase210 Ho:YAG laser, New Star Lasers, Auburn, CA) is applied in contact mode to the urolith surface until complete fragmentation occurs. Power settings are 5 Watt (W) power at 15 Hertz (Hz). Experience has shown that the total laser energy applied should be less than 1 J/pulse.[31] Continuous flushing with normal saline (0.9% NaCl) solution delivered through the biopsy/irrigation port of the endoscope is performed during lithotripsy. This provides excellent visualization and allows normograde and retrograde flushing of the stones.

Fragmentation of the stone is considered complete when the fragments are easily flushed out through the urethra and the fragments are visually smaller than the urethral lumen at the level of the obstruction. Urethral obstruction occurs consistently at the level of the proximal or mid-os penis. The urethral mucosa is examined endoscopically before scope removal to determine that there is no immediately discernable gross damage to the mucosa.

In my clinical experience, all canine urolith types fragment consistently independent of composition, but continual readjustment and attention to the aiming beam position on the stone as it fragments is critical. Experience with use of the Ho:YAG laser is important to minimize potential complications including collateral tissue damage from reflected photoacoustic energy and risk of retropulsing a large fragment into the urinary bladder. Continual readjustment and attention to the aiming beam position on the stone as it fragments is critical. Continual flushing of the urethra or bladder to clear debris and fragments, and dilate the urethra during laser lithotripsy is helpful. Even when flushing is performed gently and overfill of the bladder is not permitted, iatrogenic bladder rupture can occur.[43]

Lithotripsy Technique for Cystic Calculi

Despite advances in nutrition and antibiotic treatment, cystic calculi remain a common problem in dogs and cats.[7,8] Approximately 79 to 93% of all urinary calculi in dogs occur in the bladder.[44] Cystic calculi may cause recurrent urinary tract infections and obstruction. Traditionally, stones are removed by cystotomy, but surgical morbidity and cost of surgical removal are concerns especially when stones recur.[5] There is not a widespread useful alternative to surgical removal of calculi in dogs.[4,5] Minimally invasive alternatives, such as laparoscopic

cystotomy have been described, but are available on a limited basis.[45] ESWL has a high rate of residual stone fragments and is used primarily for ablation of ureteroliths or nephroliths because the relative mobility of the urinary bladder decreases its efficiency in fragmenting cystic calculi.[13]

Several recent studies have documented the efficacy of laser lithotripsy for the treatment of urethral and cystic calculi in dogs.[46,47,48] Lithotripsy using this technique is a minimally invasive procedure that appears to be a safe procedure with minimal complications. Depending upon the operator, anesthesia time can be longer than traditional surgical techniques such as cystotomy. Results of all three studies suggest that the use of laser lithotripsy is a safe and effective alternative to surgical removal of cystoliths and urethroliths in dogs (Table 29-3). At this time, laser lithotripsy is most available in academic or referral practices.

A brief description of cystic lithotripsy follows. A contrast urethrocystogram is performed prior to lithotripsy. In males, the dog is placed in dorsal recumbency and the prepuce and ventral abdomen are prepared aseptically. A 2.5 mm (7.5 Fr.) (Karl Storz, Inc., Goleta, CA) or 2.8 mm (8.4 Fr.) (Mitsubishi Endoscopy, Irvine, CA) flexible ureteroscope with an intraluminal channel is passed retrograde through the urethra to the bladder. In females, the dog is placed in dorsal recumbency with the hindquarters placed slightly beyond the edge of the table and elevated slightly. This allows the tail and hind limbs to remain out of the way and puts the dogs at a comfortable angle for the examiner.[49] A rigid 1.9 mm, 2.7 mm, or 4.0 mm cystoscope (Karl Storz Veterinary Endoscopy, Inc, Galeta, CA) is used for dogs < 10 kg, 10 to 20 kg, and 15 to 20 kg and above, respectively. The calculi are visualized and immobilized with an endoscopic basket (Securos endoscopic basket, Boston Scientific Inc., Boston MA) to grasp and immobilize each stone in preparation for fragmentation. Some stones do not need to be mobilized inside the basket; instead, lithotripsy is performed by immobilizing stones between the laser fiber and the bladder wall.

The remainder of the procedure is performed as for urethral lithotripsy. The entire bladder, with particular attention to the mucosa, should be examined endoscopically before scope removal to determine that there is no immediately discernable gross damage or large stone remnants. Random bladder biopsies may be performed after lithotripsy using a 3.5 mm endoscopic biopsy cup (apposing cup biopsy forceps, Karl Storz Veterinary Endoscopy, Goleta, CA).

Post Lithotripsy Recovery

Vital signs (temperature, pulse, respiration, and pain) are monitored routinely and patients generally are permitted water and food within 12 hours of the procedure. Dogs are monitored daily for gross hematuria, stranguria, and poilakiuria. Dogs frequently are poilakiuric initially. Mild to moderate hematuria and poilakiuria, if they occur, generally are self-limiting and resolve within 24 to 48 hours in affected dogs.[31] Similar clinical signs routinely occur in humans after laser or extracorporeal shock wave lithotripsy.[12,13,36,50] Concurrent cystotomies to retrieve bladder uroliths that are not accessible with the laser result in clinical signs of hematuria and stranguria for several days postoperatively.[5] Temporary urethral catheters in dogs are placed if moderate stranguria persists following lithotripsy. Catheterization is unnecessary in most cases, unless urethritis develops. In my experience, stranguria secondary to post-lithotripsy edema is more likely in dogs with chronic, multiple urethroliths.

Pronounced, prolonged stranguria or hematuria may indicate the presence of residual stones or more severe urethral mucosal damage. In those cases, additional imaging such as urethrography/cystography, endoscopic examination and retreatment may be necessary if the dog has evidence of obstructive urolithiasis (acute dysuria).

Remaining urolith fragments that are too small for further fragmentation or that retropulse proximally generally are voided normally within 24 hours.[31] Small (< 30 mg) fragments should pass easily during urination after lithotripsy. Large (> 100 mg) fragments may result in reobstruction from incomplete fragmentation. A fragment that retropulses into the bladder during urethral lithotripsy or is not located during bladder lithotripsy may later move distally and lodge in the urethra at the level of the os penis. In human lithotripsy procedures, intraoperative contrast fluoroscopy is routinely performed to confirm that no large fragments remain.[12] Retropulsion increases as fiber diameter and pulse energy increases therefore small fibers should be used.[50] Alternatively, stones that are fragmented and photomechanically retropulsed into the urinary bladder may be removed laparoscopically.[45] This would avoid laparotomy, but requires an additional procedure.

In dogs with large fragments, repeat lithotripsy to treat recurrent obstruction is an option, but waiting for reobstruction to occur may not be satisfactory and could result in complications from obstructive urolithiasis. Regardless, dogs with clinical signs of reobstruction may have urethral endoscopy and repeat lithotripsy if necessary. The effect of multiple lithotripsy sessions on the lower urinary tract of dogs is unknown. Repeat lithotripsy has not been reported in the veterinary literature. Confirmation of complete fragmentation with post-lithotripsy contrast studies and observation of normal urination is advised.

Histologic mucosal changes following lithotripsy in humans and dogs include temporary erythema, erosion, hemorrhage, or ulceration.[30,31,38,51] Depending upon the location and microscopic character of the lesions, causes include damage from the urolith as it was placed or lodged into the urethra, mechanical damage from the endoscope or grasper as it is directed into the urethra, or damage associated with the fragmentation and flushing of stone fragments.[38] Long-term deleterious effects on the urethral mucosa from repeated laser lithotripsy are unlikely.[52]

Lithotripsy for Treatment of Nephroliths

Surgical morbidity, effect on glomerular filtration rate, and cost of surgical removal of renoliths are important concerns in veterinary surgery.[4,5] To date, there is not a widespread alternative to nephrotomy or pyelolithotomy for removal of nephroliths in dogs. In human urology, surgical removal for renoliths and uteroliths has been superseded by minimally invasive procedures. Options for removal of stones in the renal pelvis include ESWL, percuta-

neous nephrolithotripsy (PCNL), intracorporeal or transureteral endoscopic retrieval, or laser lithotripsy.[12,22,25,26,51]

ESWL is the most common technique for removal of kidney stones in humans, but has a higher rate of resistant residual stone fragments.[25,50] In addition, some stones located in the lower pole of the pelvis are not amenable to ESWL.[47] ESWL has been reported on a limited basis in veterinary medicine and is available at some referral practices.[1,13,17] Future advancements in ESWL therapy in veterinary medicine may occur as lithotriptors become more available.

PCNL In humans, allows a minimally invasive approach to the renal pelvis and renolith fragmentation with fluoroscopic or ultrasound guidance.[54] Renoliths larger than 3 cm in diameter, staghorn-shaped stones, calcium oxalate monohydrate stones, and cystine stones that are relatively resistant to ESWL are indications for PCNL.[26,38] Prior to lithotripsy, a percutaneous pyelogram may be performed to locate the exact stone position and size. The intrarenal collecting system is accessed through a percutaneous nephrostomy tract. In this procedure, a hollow needle is passed into the renal pelvis under fluoroscopic or ultrasonographic visualization. A flexible guide wire is then passed through the hollow needle and manipulated through the ureter. The nephrostomy tract is formed by dilating the skin abdominal wall muscles, and renal tissues using progressively larger plastic dilators or a balloon catheter. After the tract has been adequately dilated, a hollow plastic sheath is placed into the tract into the renal pelvis. A rigid or flexible endoscope is passed into the pelvis and/or proximal ureter. Stones are retrieved with an endoscopic basket if very small. If they are larger, a Ho:YAG laser fiber is placed into the central operating channel of the endoscope and lithotripsy is performed. Laser energy delivered to the surface of the stone creates photothermal energy that reduces the stone to tiny fragments, the majority of which are washed out with the irrigant.[21,51] The cutaneous tract is left to heal by second intention.

Initial experience in humans with the Ho:YAG laser has demonstrated its safety. There is no evidence of decreased renal function after Ho:YAG lithotripsy.[25] In a study of 25 pediatric patients, only one had significant decrease in glomerular filtration rate (GFR) following Ho:YAG PCNL.[22] Additionally, only one of 18 patients in a retrospective study had decreased GFR > 20% (the threshold for significant decrease). There was no correlation between GFR and stone size, stone location, or energy.[47]

Reported stone free rates are 67 to 84% for renal calculi, with complications rates of < 1%.25 Ho:YAG lithotripsy is effective for ureteral and renal calculi in morbidly obese patients who are not candidates for ESWL. Additionally, the photothermal effects of the Ho: YAG laser are minimal; lesions were consistently less than one mm.[25] In the future, laser lithotripsy with PCNL may offer a non-invasive, cost-effective, rapid treatment option for dogs with nephroliths. Studies to evaluate and modify the technique for use in small animals are being performed.

Conclusion

Laser lithotripsy is a non-invasive, cost-effective, rapid treatment option for dogs with urinary calculi in the bladder and/or urethra. This is especially important for breeds (or individual dogs) that are predisposed to recurrent urolith formation. Techniques for laser fragmentation of obstructive uroliths in the urethra and bladder have been established. Further advancements in lithotripsy in veterinary patients may obviate the need for traditional surgery.

Until the complex and multifactorial causes of stone formation in dogs are elucidated and stone formation is preventable, the further development of minimally invasive treatment protocols that prevent the need for multiple surgical procedures has many advantages. Laser lithotripsy appears to have applications for treatment of urolithiasis, a common and potentially dangerous health problem in dogs. In particular, successful laser lithotripsy may reduce or prevent associated problems that affect animal urinary health such as urinary tract infections, acute dysuric obstruction, and hydroureter/hydronephrosis. Potential disadvantages of laser lithotripsy include patient and operator safety issues, cost,laser maintenance, and the training and experience required for successful stone fragmentation.

References

1. Block G, Adams LG, Widmer WR, et al: Use of extracorporeal shock wave lithotripsy for treatment of nephrolithiasis and ureterolithiasis in five dogs. *J Am Vet Med Assoc* 208:531, 1996.

2. Osborne CA, Lulich JP, Unger LK, et al: Canine and feline urolithiasis: relationship of etiopathogenesis with treatment and prevention *In*: Bojrab MJ, ed.: Disease Mechanisms in Small Animal Surgery. Philadelphia: Lea & Febinger, 1993, p 464.

3. Lulich JP, Osborne CA: Canine calcium oxalate uroliths *In*: Bonagura JD, Kirk RW, eds.: Current Veterinary Therapy XII, Philadelphia: Saunders, 1995, p 992.

4. Rawlings CA, Bjorling DE, Christie BA: Nephrolithiasis *In* Slatter D, ed.: Textbook of Small Animal Surgery, 2nd ed. Philadelphia: WB Saunders, 2003, p 1610.

5. Kyles AE, Aronsohn M, Stone EA: Complications of urogenital surgery *In*: Lipowitz AJ, Caywood DD, Newton CD, *et al,* eds.: Complications in Small Animal Surgery, Baltimore: Lea and Febiger, 1996, p 455.

6. Collins RL, Birchard SJ, Chew DJ, *et al*: Surgical treatment of urate calculi in Dalmatians: 38 cases (1980-1995) *J Am Vet Med Assoc* 1998; 213:833-837.

7. Lulich JP, Osborne CA, *et al*: Nonsurgical removal of uroliths in dogs and cats by voiding urohydropropulsion. *J Am Vet Med Assoc* 203:660, 1993.

8. Lulich JP, Osborne CA, *et al*. Management of canine calcium oxalate urolith recurrence. *Compend Contin Educ Pract Vet* 1998; 20: 178-189.

9. Lulich JP, Osborne CA, Polzin DP, et al: Incomplete removal of canine and feline urocystoliths by cystotomy. *J Vet Intern Med* 7:221, 1993.

10. Osborne CA, Lulich JP: Canine retrograde urohydropropulsion: lessons from 25 years of experience. *Vet Clin North Am: Small Anim Pract* 29:267, 1999.

11. Auge BK, Preminger GM: Update on shock wave lithotripsy technology. *Cur Opin Urol* 12:287, 2002.

12. Stoller ML: Extracorporeal shock wave lithotripsy: intraoperative considerations. *In*: Tanagho EA, McAninch JW, eds.: Smith's General Urology 14th ed. Norwalk:Appleton and Lange, 1995, p 307 .

13. Adams LG, Senior DF: Electrohydraulic and extracorporeal shock-wave lithotripsy. *Vet Clin North Am Small Anim Pract* 29:293, 1999.

14. Rodger LD, Carlson GP, Moran ME, et al: Resolution of a left ureteral

stone using electrohydraulic lithotripsy in a thoroughbred colt. *J Vet Intern Med*. 9:280, 1995.

15. Koenig J, Hurtig M, Pearce S, *et al*: Ballistic shock wave lithotripsy in an 18-year old thoroughbred gelding. *Can Vet J* 40:185, 1999.

16. Jou YC, Shen JH, Cheng MC, et al: Percutaneous nephrolithotomy with Ho:YAG laser and fiber guider- report of 349 cases. *Urol* 65:454, 2005.

17. Bailey G, Burk RL: Dry extracorporeal shock wave lithotripsy for treatment of ureterolithiasis and nephrolithiasis in a dog. *J Am Vet Med Assoc* 207:592, 1995.

18. Hofmann R32, Hartung R,33 Schmidt-Koiber H, *et al*: First clinical experience with a Q-switched neodymium:YAG laser for urinary calculi. *J Urol* 141:275, 1988.

19. Dretler SP, Watson G, Parrish JA, *et al*: Pulsed dye laser fragmentation of ureteral calculi: initial clinical experience. *J Urol* 137:386-389, 1987.

20. Watson G, Murray S, Dretler P, *et al*: The pulsed dye laser for fragmenting urinary calculi. *J Urol* 138:195, 1987.

21. Chan KF, Vassar GJ, Pfefer TJ, *et al*: Ho:YAG laser lithotripsy: a dominant photothermal ablative mechanism with chemical decomposition for urinary calculi. *Lasers Surg Med* 25:22, 1999.

22. Mor Y, Elmasry YE, Kellett MJ, *et al*: The role of percutaneous nephrolithotomy in the management of pediatric renal calculi. *Urol* 158:1319, 1997.

23. Lahme S, Bichler KH, Strohmaier WL, *et al*: Minimally invasive PCNL in patients with renal pelvic and calyceal stones. *Eur Urol* 20:619, 2001.

24. Zorcher T, Hochberger J, Schrott KM, *et al*: *In vitro* study concerning the efficiency of the frequency-doubled double-pulse Neodynium:YAG laser (FREDDY) for lithotripsy of calculi in the urinary tract. *Lasers Surg Med* 25:38, 1999.

25. Teichman JMH. Laser lithotripsy. *Curr Opin Urol* 12:305, 2002.

26. Higashihara E, Horie S, Takeuchi T, *et al*: Laser ureterolithotripsy with combined rigid and flexible ureteroscopy. *J Urol* 143:273, 1990.

27. Howard RD, Pleasant RS, May KA:Pulsed dye laser lithotripsy for treatment of urolithiasis in two geldings. *J Am Vet Med Assoc* 212:1600, 1998.

28. Halland, SK, House JK, George LW: Urethroscopy and laser lithotripsy for the diagnosis and treatment of obstructive urolithiasis in goats and pot-bellied pigs. *J Am Vet Med Assoc* 220:1831, 2002.

29. Streeter RN, Washburn KE, Higbee RG, *et al*: Laser lithotripsy of a urethral calculus via ischial urethrotomy in a steer. *J Am Vet Med Assoc* 219: 640, 2001.

30. Wynn VM, Davidson EB, Higbee RG, *et al*: In vitro assessment of Ho:YAG laser lithotripsy for the treatment of canine urolithiasis. Proc SPIE, Progress in Biomedical Optics and Imaging 4609:241, 2002.

31. Davidson EB, Ritchey JW, Higbee RD, *et al*: Laser lithotripsy for treatment of canine uroliths. *Vet Surg* 32:51, 2004.

32. Wynn VM, Davidson EB, Higbee RG, *et al*: In vitro effects of pulsed Holmium laser energy on canine uroliths and porcine cadaveric urethras. *Lasers Surg Med* 33:243, 2003.

33. Grasso M, Bagley D: Small diameter, actively deflectable, flexible utereropyeloscopy. *J Urol* 160:1648, 1998.

34. Psihramis KE, Buckspan MB: Laser lithotripsy in the treatment of ureteral calculi. *Can Med Assoc J* 142:833, 1990.

35. Bagley DH: Expanding role of ureteroscopy and laser lithotripsy for treatment of proximal ureteral and intrarenal calculi. *Curr Opin Urol* 12:270, 2002.

36. Bataille P, Pruna A, Cardon G, *et al*: Renal and hypertensive complications of extracorporeal lithotripsy. *Presse Med*. 29:34, 2000.

37. Kopecky KK, Hawes RH, Bogan ML, *et al*: Percutaneous pulsed-dye laser lithotripsy of gallbladder stones in swine. *Investig Radiol* 25: 627, 1990.

38. Matsuoka K, Iida S, Inoue M, et al: Endoscopic lithotripsy with the holmium:YAG laser. *Lasers Surg Med* 25:389, 1999.

39. Judy CE, Galuppo LD: Endoscopic assisted disruption of urinary calculi using a Holmium:YAG laser in standing horses. *Vet Surg* 31:245, 2002.

40. May KA, Pleasant RS, Howard RD, et al: Failure of holmium: yttrium-aluminum-garnet laser lithotripsy in two horses with calculi in the urinary bladder. *J Am Vet Med Assoc* 219:957, 2001.

41. Woods JP, Bartels KE, Stair EL, *et al*: Laser-induced shock wave lithotripsy of canine urocystoliths and nephroliths. *Proc SPIE Progress in Biomedical Optics* 2970: 227, 1997.

42. Spore SS, Teichman MH, Corbin NS, et al: Holmium:YAG lithotripsy: optimal power settings. *J Endourol* 13:559, 1999.

43. McCarthy TC, McDermaid SL: Cystoscopy. *Vet Clin North Am: Small Anim Pract* 20:1315, 1990.

44. Ling GV, Franti CE, Ruby AL, et al: Urolithiasis in dogs I: mineral prevalence and interrelations of mineral composition, age, and sex. Am J Vet Res 49: 624, 1998.

45. Rawlings CA, Mahaffey MB, Barsanti JA, et al: Use of laparoscopic-assisted cystoscopy for removal of urinary calculi in dogs. *J Am Vet Med Assoc* 222:759, 2003.

46. Adams LG, Berent AC, Moore GE, et al: Use of laser lithotripsy for fragmentation of uroliths in dogs: 73 cases (2005-2006). J Am Vet Med Assoc 232: 1680,2008.

47. Lulich JP, Osborne CA, Albasan H, et al: Efficacy and safety of laser lithotripsy in fragmentation of urocystoliths and urethroliths for removal in dogs. J Am Vet Med Assoc 234: 1279, 2009.

48. Bevan JM, Lulich JP, Albasan H, et al: Comparison of laser lithotripsy and cystotomy for the management of dogs with urolithiasis. J Am Vet Med Assoc 234:1286, 2009.

49. Senior DF, Sundstrom DA: Cystoscopy in female dogs. *Compend Contin Educ Small Anim Pract* 10:890, 1988.

50. Lee H, Ryan RT, Teichman JM, et al: Stone retropulsion during holmium:YAG lithotripsy. *J Urol* 169:881, 2003.

51. Vorreuther R, Corleis R, Klotz T, et al: Impact of shock wave pattern and cavitation bubble size on tissue damage during ureteroscopic electrohydraulic lithotripsy. *J Urol* 153:849, 1995.

52. Kostolich M, Bartels KE, Schafer S, *et al*: Ho:YAG laser ablation of alimentary tract mucosa. *In*: Proceedings of Lasers in Orthopedic, Dental, and Veterinary Medicine, Los Angeles, pp. 74, 1993.

53. Sundaram CP, Slatzman B: Extracorporeal shock wave lithotripsy: a comprehensive review. *Comp Ther* 24:332, 1998.

54. Irby PB, Schawartz BF, Stoller ML: Percutaneous access techniques in renal surgery. *Tech Urol* 5:29, 1999.

55. Fry TR. Laser safety *Vet Clinic North Am Small Anim Pract* 32:535, 2002.

Renal Transplantation in Companion Animals

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Introduction

Clinical renal transplantation in cats was performed successfully in 1984 by Dr. Clare Gregory and Dr. Ira Gourley at the University of California-Davis, School of Veterinary Medicine. The ability to successfully perform renal transplantation as treatment for renal failure in companion animals was due to a number of factors including the development of microsurgical techniques and the availability of microsurgical equipment in veterinary practice, the ability to use an allograft from an unrelated donor and the

administration of cyclosporine for immunosuppressive therapy in the dog and cat.[1-3]

Results published in 1992 evaluating the first 23 cases of feline renal transplantation, supported transplantation as a treatment option for cats in end stage renal failure. In that study, 70% of the cats were discharged from the transplant facility and the mean survival period was 12 months for all cats with the longest surviving for 31 months.[4] In 1996, a retrospective study evaluating 66 cases of feline renal transplantation (including the 23 cases that had been previously described) was published.[5] In that study, although the percentage of cats surviving to discharge was similar to the first report during the 9 year study period, there was an improvement in perioperative survival. Perioperative survival rate improved from 64% in the first 33 cats to 79% for the last 33 cats.[5] It is estimated that over 400 feline renal transplants have been performed since the procedure was first introduced in 1984. Although a retrospective study describing all cases that have been performed to date is not available, recent information from veterinary surgical centers active in tranplantation suggests that survival times are continuing to improve (Table 29-4). Improved survival may be related to more stringent case selection, as well as the clinician's ability to better recognize and treat complications both in the immediate postoperative period and long term. Cats are the predominant species to undergo transplantation and will be the focus of this chapter, however information will also be presented on canine transplantation since it is becoming more common at selected university hospitals.

Table 29-4. Feline Renal Transplant (University) Centers in the United States

University of Pennsylvania, School of Veterinary Medicine
Contact: Dr. Lillian R. Aronson

University of Wisconsin, School of Veterinary Medicine
Contact: Dr. John F. McAnulty

University of Georgia, School of Veterinary Medicine
Contact: Chad Schmeidt

Client Education

It is important for clients to realize that renal transplantation is a treatment option for animals in chronic renal failure, but is not a cure. Medical therapy including subcutaneous fluid therapy, low protein diets, phosphate binders, hormonal therapy including Erythropoietin and Darbopoietin, gastrointestinal protectants, and antihypertensive medication can often be discontinued following surgery however the pet will still need immunosuppressive therapy for life. Selection criteria for transplantation are rigorous and the owner needs to understand the risks of the procedure and that their cat may be turned down as a potential candidate if the cat fails any aspect of the medical screening process or if the cat has a fractious temperament. The cost of renal transplantation is high and additional veterinary visits postoperatively for monitoring of renal function and determining serum levels of cyclosporine are required. It is necessary for the owner to identify a veterinary hospital that can provide 24 hour care and a veterinarian who is willing to care for a renal transplant recipient. Finally, a critical aspect of any transplant program is donor adoption. The client must be willing to provide a lifelong home for the donor animal regardless of the outcome of the transplant procedure.

Evaluation of a Potential Recipient

Thorough screening, which is often performed by the referring veterinarian working with the transplant surgeon, is essential for a potential feline renal transplant recipient to decrease the incidence of morbidity and mortality that can occur following the surgical procedure. Although the ideal time to perform transplantation is not known, experienced clinicians suggest that the best candidate for renal transplantation is a cat in early decompensated renal failure.[6,7] Indications of decompensation include continued weight loss and worsening of anemia and azotemia in the face of medical management. Although attempts to alter the physical deterioration of animals with chronic renal failure have been reported to be unsuccessful, the placement of either an esophagostomy tube or percutaneous endoscopic gastrostomy (PEG) tube has been used successfully for up to 2 years for the medical management of some potential renal transplant candidates[6,7] (Personal communication, Mathews, KG). It is noted that the degree of azotemia, anemia, urine specific gravity and age, do not determine a suitable patient for transplantation. In one report, cats greater than 10 yrs of age had an increase in mortality, particularly during the first 6 months following surgery.[8] To date, the oldest cat that has had successful transplantation at our hospital was 18 years of age.

Both physical and biochemical parameters should be carefully evaluated to determine if a cat is suitable for transplantation. Current evaluation in our hospital includes laboratory testing (complete blood count/chemistry/blood type and crossmatch/thyroid evaluation), evaluation of the urinary tract (urinalysis, urine culture, urine protein:Cr ratio, abdominal radiographs, abdominal ultrasound), evaluation for cardiovascular disease (thoracic radiography, blood pressure electrocardiography, echocardiography, and infectious disease screening (FeLV/FIV, Toxoplasma titer, IgG and IgM) (Table 29-5).

Table 29-5. Pre-operative screening for a Potential Feline Renal Transplant Recipient

- Complete blood count
- Serum chemistry profile
- Blood type and cross-match
- Thyroid hormone evaluation (T4)
- Urinalysis, urine culture, urine protein:Cr ratio
- Abdominal radiography
- Abdominal ultrasonography
- Thoracic radiography
- Electrocardiography, echocardiography, blood pressure
- Feline leukemia virus, Feline immunodeficiency virus
- Toxoplasmosis titer, IgG and IgM

Evaluation of the Urinary Tract

Evaluation of the urinary tract to rule out underlying infection or neoplastic disease is essential prior to transplantation. Based on biopsy reports from cats that have been transplanted, the most common diagnosis of renal disease is chronic tubulointerstitial nephritis. Other diseases successfully treated by transplantation include polycystic kidney disease, membranous glomerulonephropathy, calcium oxalate urolithiasis and ethylene glycol toxicity.[6] If on abdominal ultrasound, renomegaly is identified and the cause is not polycystic kidneys or perinephric pseudocysts, then a fine needle aspirate or a biopsy is recommended to rule out Feline Infectious Peritonitis (FIP) or neoplasia. Animals diagnosed with a urinary tract infection should be treated with the appropriate antibiotic therapy based on culture and sensitivity prior to presentation. In patients with recurrent urinary tract infections or those that have recently been treated, but at the time of presentation have a negative urine culture, a Cyclosporine (CsA; Neoral, Sandoz Pharmaceuticals) challenge is indicated. The patient is administered Cyclosporine for approximately two weeks at the recommended dose for transplantation immunosupression. The urine is evaluated for the presence of an infection on at least 2 occasions; after therapeutic CsA blood levels have been obtained and at the end of the 2 week period. Although negative urine culture results will not guarantee that a patient will remain infection free after transplantation and chronic immunosupression, it can eliminate some cats with occult infections. Alternatively, all potential transplant candidates can be treated with CsA for 2 weeks prior to surgery to attempt to identify occult infection prior to transplantation.[7]

The incidence of cats with calcium oxalate (CaOx) urolithiasis and concurrent renal failure and subsequent presentation of the cat for renal transplantation, has been increasing. In a recent retrospective study, renal transplantation was a successful treatment option for cats whose underlying cause of renal failure was associated with CaOx urolithiasis.[9] No difference in long term outcome was found between a group of 13 stone formers and a control group of 49 cats whose underlying cause of renal failure was not related to stone disease. If hydronephrosis is present on abdominal ultrasound during the recipient screening process, a pyelocentesis and urine culture is recommended prior to transplantation to identify patients that may be harboring an infection. The author has identified five cats with obstructive CaOx urolithiasis that have had a negative urine culture from urine collected from the urinary bladder and a positive urine culture from urine collected by pyelocentesis (L.R. Aronson unpublished data 2005). Allograft rejection as well as an increase in morbidity and mortality can occur in an immunosupressed patient harboring an infection.

Cardiovascular Disease

Many cats presented for transplantation have systolic murmurs identified on physical examination. These murmurs may be secondary to the anemia of chronic renal failure and not represent significant heart disease.[6] Historically, because of complications associated with transplanting cats with hypertrophic cardiomyopathy, cats with underlying cardiac disease were not accepted into the program. In a recent study performed at the University of California-Davis evaluating cardiac abnormalities in 84 potential transplant recipients, only 22% were found to have a normal heart on echocardiographic examination. The most common abnormalities identified included both papillary muscle and septal muscle hypertrophy and it was suggested that these changes may be related to chronic uremia, hypertension, age or early changes of hypertrophic cardiomyopathy.[10] We have identified patients with similar changes on echocardiography that were unable to tolerate fluid therapy prior to transplantation. Four patients developed varying degrees of pulmonary edema and pleural and pericardial effusion. Following transplantation, fluid therapy was reinitiated without complication. In 2 cats, echocardiographic evaluation performed within 3 months following surgery revealed resolution of echocardiographic abnormalities. Potential candidates with diffuse hypertrophic cardiomyopathy or those with congestive heart failure are declined as candidates for renal transplantation in our hospital. In cats with less severe cardiac disease, a decision is made on a case to case basis.

Infectious Disease

If a cat has an active FIV infection or is FeLV positive, they are declined as candidates for transplantation. All potential transplant donors and recipients currently undergo serologic testing (IgG and IgM) for Toxoplasmosis. *Toxoplasma gondii* can cause significant morbidity and mortality in both human and veterinary immunocompromised patients. Most human transplant patients will display clinical signs within the first 3 months following surgery since this is the period of maximum immunosupression.[11] In a report describing 3 cats and 1 dog, disseminated toxoplasmosis occurred within 3 weeks to 6 months following transplantation.[12] As a matter of policy at our facility, we do not use seropositive donors for seronegative recipients, but we have successfully used a seropositive donor for a seropositive recipient. Seropositive recipients are placed on lifelong prophylactic Clindamycin (25 mg PO q12h) which is started in conjunction with immunosupression. Tribrissen has also been used in cats that did not tolerate Clindamycin. To date, 10 recipients with a positive IgG and/ or a positive IgM titer have been placed on prophylactic Clindamycin therapy. Two cats are currently alive 105 and 545 days following transplantation. Eight cats have died a median of 379 days following transplantation. Cause of death included, lymphosarcoma (3 cats), presumed antibiotic toxicity (1 cat), cardiomyopathy (1 cat), accidental avulsion of the allograft (1 cat), chronic pyelonephritis (1 cat) and allograft failure (1 cat). None of the cats died from an active *Toxoplasma gondii* infection (L.R. Aronson unpublished data 2005).

Although we have become more selective in case selection in recent years, with the availability of hemodialysis and the increasing experience of clinicians who manage these cases we have "pushed the envelope" by performing transplants on cases that may be considered questionable recipients. Definitive findings that preclude renal transplantation include cats with neoplastic disease, severe cardiac disease, FeLV positive status, active FIV infection, recurrent or existing urinary tract infection that fails medical therapy and/or a CsA challenge, uncontrolled hyperthyroidism and a fractious temperament. (Table 29-6). Although objective information associated with survival has been identified with regard to some aspects of the screening

Table 29-6. Tests results or conditions that rule out Tranplantation in the Cat

- Primary or metastatic neoplasia
- Severe cardiac disease
- FeLV positive status
- Active FIV infection
- Recurrent or existing urinary tract infection that fails medical therapy and/or a CsA challenge
- Uncontrolled hyperthyroidism
- Fractious temperament

Test results or conditions that May rule out Tranplantation in the Cat

- Inflammatory bowel disease
- Diabetic patients
- Patients with echocardiographic abnormalities that suggest they are unable to receive fluid therapy

process in recipients, some clinical uncertainties continue to pose challenges including animals with inflammatory bowel disease, diabetes mellitus, and those cats with echocardiographic abnormalities that are not able to receive fluid therapy without causing fluid overload (See Table 29-6).

Evaluation of a Potential Donor

Cats selected as kidney donors are in excellent health and are typically between 1 to 3 years of age. Standard evaluation includes a serum chemistry profile, complete blood count, urinalysis and culture, FeLV and FIV testing and a Toxoplasmosis titer (IgG and IgM). The feline kidney donor must also be blood-cross match compatible to the recipient and of a similar size. Additionally, CT angiography is performed on all of the potential donors to evaluate the renal vasculature as well as evaluate the renal parenchyma for any abnormalities (Table 29-6).[13] This screening technique has allowed us to identify potential donors unsuitable for donation including those with renal infarcts as well as the presence of multiple arteries. A suitable home is found for any donor that fails the screening process. In a study evaluating the long term effects of performing a unilateral nephrectomy in a healthy cat, 16 donors were followed between 24 and 67 months postoperatively.[14] Fifteen of the 16 cats were clinically normal and serum creatinine concentrations for these cats remained within the reference range. One cat was diagnosed with chronic renal insufficiency 52 months following surgery. Although renal donation does not appear to affect normal life expectancy, long term monitoring is recommended in these animals.

Preoperative Recipient Treatment

Preoperative care for the recipient varies depending on the stability of the animal. At some centers, hemodialysis is performed prior to surgery in cats with severe azotemia (BUN > 100 mg/dL, Cr > 8mg/dL).[8] In cases that do not require hemodialysis, the recipient is typically placed on intravenous fluid therapy of a balanced electrolyte solution at 1.5 to 2 times the daily maintenance requirements. In some cases, underlying cardiac disease may preclude this rate of fluid administration because of the risk of development of pulmonary edema and pleural effusion. Additionally, the calcium channel blocker amlodipine (Norvasc, Pfizer labs, 0.625 mg/cat PO q24h) may be indicated prior to surgery if the cat is hypertensive. Anemia is typically corrected with either whole blood transfusions or packed red cells with the goal of obtaining an endpoint packed cell volume of 30% prior to surgery. If the cat is stable on admission with respect to anemia, blood transfusions are administered at the time of surgery. The first unit that is administered is a unit previously collected from the cross-match compatible donor cat. It is important to note that some cats in chronic renal failure are not transfusable because of incompatabilities despite the fact that the cats are of the same blood type and have had no known exposure to blood products. If the patient is traveling a great distance to the transplant hospital, blood crossmatching should be performed prior to admission. A blood sample can be sent to the transplant hospital for cross-matching in order to identify a compatible kidney donor as well as identify 2 to 3 potential blood donors. Hormonal therapy including Erythropoietin or Darbopoietin can be administered if a delay is expected and can greatly reduce the need for blood products at the time of surgery. Although uncommon, the owner should be cautioned regarding the possibility of the development of antibodies to these drugs which can result in significant morbidity and potentially mortality in the postoperative period. If deemed necessary, phosphate binders and gastrointestinal protectants can be given and if the cat is anorectic, a nasogastric, esophagostomy or PEG tube may be placed prior to surgery to administer nutritional support.

Feline Immunosupression

Two protocols are currently being used for the feline renal transplant recipient. In the first protocol, a combination of the Calcineurin inhibitor, CsA and the glucocorticoid, prednisolone are used together for their synergistic effects. Because the dose of cyclosporine that cats often require for immunosupression is small, an oral liquid formulation is used so that the dose can be titrated accordingly for each individual cat. Currently, the oral liquid formulation, Neoral (100 mg/ml), is recommended. Neoral is a microemulsified formulation and is preferred over the other oral liquid formulation, Sandimmune (Novartis Pharmaceuticals), because of better gastrointestinal absorption allowing for more predictable and sustained blood concentrations of the drug.[6] Additionally, the dose of Neoral necessary to maintain therapeutic blood concentrations compared to Sandimmune is less, making the drug more economical for clients.

Depending on the transplant facility performing the procedure, CsA is typically begun 24 to 96h prior to transplantation. Depending on the cat's appetite, Neoral is administered at a dose of 1 to 4 mg/kg PO q12h. In the author's experience, cats that are anorexic or that are eating a minimal amount prior to surgery have a much lower drug requirement to obtain appropriate drug levels prior to surgery. A 12-hour whole-blood trough concentration is obtained one day prior to surgery to adjust the oral dose for the surgical procedure. A target 12-hour whole-blood trough concentration of 300 to 500 ng/ml prior to surgery

using the technique of high-pressure liquid chromatography (HPLC) is recommended.[15] This level is maintained for approximately 1 to 3 months following surgery and is then tapered to approximately 250 ng/ml for long term maintenance therapy. Prednisolone is administered beginning the morning of surgery. At our facility, prednisolone is started at a dose range of 0.5-1 mg/kg q12h orally for the first 3 months and then tapered over several weeks to q24h. Protocols for both CsA and prednisolone vary between transplantation facilities. Doses have ranged from 0.25 to 2.5 mg/kg PO q12h orally starting the morning of surgery and then tapering to 0.25 mg/kg PO q24h by 1 month following surgery.[2,3,15] Prednisolone is preferred over prednisone for immunosupression in the these patients. In an abstract evaluating the bioavailability and activity of these two drugs in cats, serum prednisolone levels were significantly greater for oral prednisolone than oral prednisone.[16] It was suggested that these differences may be related to a decreased hepatic conversion of prednisone to prednisolone in some cats or decreased gastrointestinal absorption of prednisone.

A second protocol allows for once daily administration of medication. With this protocol, ketoconazole (10 mg/kg PO q24h) is administered in addition to the CsA and prednisolone.[17,18] Following the addition of ketoconazole, to the immunosuppressive protocol, CsA and prednisolone are administered once a day and CsA doses are adjusted into the therapeutic range by measuring 24 hour whole blood trough levels. Ketoconazole is an antifugal agent that can affect the metabolism of CsA by inhibiting both intestinal and hepatic cytochrome P450 oxidase activity resulting in increased blood CsA concentrations.[18] This protocol may reduce the cost of immunosuppression following surgery as well as be more appealing for owners whose work schedule does not permit twice a day dosing of medication. If twice daily dosing is necessary, the ketoconazole dose can also be split and then added to twice daily regimens to reduce costs. Ketoconazole administration is discontinued if signs of hepatotoxicity are identified.

At our facility, high performance liquid chromatography (HPLC) is the method of choice for measurement of whole blood CsA concentrations. This technique measures only the parent compound and not the metabolites of CsA which can vary depending on the patients' metabolism.[19] Flurescent immunoassay methods using either monoclonal or polyclonal antibodies have also been used. Antibodies can cross-react with the metabolites of CsA resulting in higher and more variable CsA concentrations than results obtained using the HPLC method. Although the HPLC method is the preferred method for both human and veterinary patients, immunoassay methods can still be used. Using one immunoassay method (TDxFLx assay, Abbott Laboratories) in cats, an accurate estimation of the HPLC can be determined since the correlation between these 2 methods is very high in an individual cat.[19] Whole blood CsA levels will be 1.5 to 4.2 times higher than levels measured with the HPLC method.[17,19] In a study evaluating CsA disposition following intravenous and multi-dose oral administration in cats, substantial individual variation of oral absorption was identified and results suggest that evaluation of 2-hour CsA blood concentration may be a better measure for estimating drug exposure than the 12-hour whole-blood trough concentration.[20] More work in this area is necessary prior to changing current drug monitoring protocols. Since CsA has a bitter taste, the medication is placed into a gelatin capsule prior to administration. If the owner is unable to medicate the cat, they should be given empty gelatin capsules to practice with until they feel comfortable with the technique. The capsule sizes that we most commonly use range from #1 to #3 depending on the dosage. The prednisolone, as well as other medication that the cat is taking, can be added to the gelatin capsule.

Both in vitro and in vivo studies have been performed evaluating the effects of various novel immunosuppressants such as tacrolimus, sirolimus, mycophenolate mofetil and leflunomide in cats, they have not been evaluated in the clinical patient.[21,22] Although these drugs may be effective for renal transplantation in cats, they are not without complication in the human transplant patient. Currently no other alternative immunosuppressive protocols exist for cats that cannot take CsA and prednisolone.

Canine Immunosupression

Canine transplantation remains a challenge with regard to determining the best immunosuppressive therapy, particularly in unrelated donor and recipient pairs. The selection of a major histocompatibility complex (MHC) identical littermate as a donor has been shown to improve long term graft survival in the recipient.[6] Various immunosuppressive protocols are currently being used in both unrelated and related donor and recipient pairs with varying results. The combination of Neoral, prednisolone and azathioprine (Imuran, Glaxo Wellcome) has been found to successfully maintain renal allografts in both MHC match and mismatched donor and recipient pairs. In one study using 4 healthy, unrelated mongrel dogs, immunosupression using Neoral (20 mg/kg/day) combined with azathioprine (5 mg/kg PO q48h) and prednisolone (1 mg/kg/day) resulted in 2 dogs surviving the 100 day study period, 1 dog being euthanized for an intestinal intussusception and 1 dog being euthanized for a severe upper respiratory infection.[23] The current dosage of Neoral recommended for dogs is 2.5-5 mg/kg PO q12h to attain a 12 hour whole-blood trough concentration of 500 ng/ml and 3 to 5 mg/kg PO q48h for azathioprine.[6] Transplantation has also been successful in unrelated dogs with the addition of rabbit antidog antithymocyte serum to the CsA, azathioprine and prednisone regimen.[24] Finally, leflunomide has shown promise experimentally when combined with CsA. In a recent study evaluating MNA 715 (an immunomodulatory drug derived from leflunomide) and CsA in a mismatched dog transplant model, the combination of these 2 drugs significantly prolonged renal allograft survival and reduced the severity in histologic rejection.[25] MNA715 was administered at an initial loading dose of 4 mg/kg PO q24hr followed by a dose of 2 mg/kg PO q24hr.

Anesthetic Protocols for Recipient and Donor

The specific anesthetic protocol for these patients is not unique to this surgical procedure, however there are important concepts to be emphasized. An example of a donor and recipient anesthetic protocol that have been successfully used at our hospital is presented (Table 29-7). The reader is also referred to a recent publication on anesthetic management in feline renal

Table 29-7. University of Pennsylvania Anesthetic Protocol for Feline donor and recipient

IM Pre-op
- Butorphanol: 0.5 mg/kg
- Telazol: 3-4 mg/kg

Epidural
- Bupivicaine: 0.1 mg/kg
- Morphine: 0.15 mg/kg

Induction
- Oxymorphone: 0.1 mg/kg
- Midazalam: 0.5 mg/kg
- Lidocaine: 1 mg/kg
- Etomidate: 0.2 mg/kg +/- Glycopyrrolate/Atropine

Intra-operative
- Mannitol; 0.25 g/kg at time of incision and 1 g/kg before nephrectomy

Post-operative
- Buprenorphine 8 hours post induction: 0.02 mg/kg

Recipient

Epidural
- Bupivicaine: 0.1mg/kg
- Morphine: 0.15 mg/kg

Induction
- Oxymorphone: 0.1 mg/kg
- Midazolam: 0.5 mg/kg
- Lidocaine: 1 mg/kg
- Etomidate: 0.2 mg/kg +/- glycopyrrolate/atropine

Intra-operative Fentanyl infusion

Post-operative
- Buprenorphine 8 hours post induction: 0.02 mg/kg
- Hydralazine if needed for hypertension: 2.5 mg/4 kg cat SQ

transplantation.[26] At the time of anesthetic induction, both the donor and recipient cats are given cephalexin (22 mg/kg IV q2h). Additionally, an epidural injection is performed on both cats (Bupivicaine [0.1 mg/kg] and Morphine [0.15 mg/kg]) for analgesia. Both cats may be under anesthesia for as long as 4 to 6 hours and hypothermia is of serious concern and can be detrimental to these patients. A circulating warm air blanket is used throughout the procedure and continuous monitoring of esophageal temperatures is performed. In addition to cephalic catheters, an indwelling double lumen jugular catheter is placed into the recipient right jugular vein so that venous blood gases, the PCV and TP as well as the electrolytes can be monitored throughout surgery. The left side of the neck is preserved in animals where an esophagostomy tube may be placed. Additionally, at the time of anesthetic induction, the recipient is given a unit of cross-match compatible whole blood from the kidney donor followed by other cross-match compatible blood products as needed. The donor cat is administered mannitol on 2 occasions during the surgical procedure; 0.25 g/kg IV at the time of the abdominal incision and 1 g/kg 20 minutes prior to nephrectomy. Mannitol (0.5-0.1 g/kg IV) is occasionally administered to the recipient if there is concern regarding allograft perfusion following vascular anastomosis. Systemic arterial blood pressure is monitored regularly in both cats non-invasively via a Doppler technique and hypotension corrected by decreasing the concentration of inhalant anesthetic, or by the administration of fluid boluses, blood products or a continuous infusion of dopamine (5 ug/kg/min). Intraoperative hypertension can be treated successfully with the SQ administration of hydralazine (2.5 mg SQ for a 4 kg cat).

Renal Transplantation Surgery

Successful renal transplantation in the cat requires an operating microscope and surgical experience with microsurgical vascular and ureteral surgical procedures.

Feline Surgical Technique

In our hospital, 3 surgeons are required for each transplant procedure; 2 surgeons to operate on the donor and recipient and a third surgeon to close the donor following the nephrectomy. The donor cat is brought into the surgical suite approximately 45 minutes prior to the recipient and the donor kidney prepared for nephrectomy. At the time of initial incision, the donor is given a dose of mannitol (0.25 g/kg IV over 15 minutes). The alpha adrenergic agonist acepromazine (0.1 mg/kg IV) has also been recommended by some surgeons.[17] These drugs are used to minimize renal arterial spasms, improve renal blood flow and protect against renal tissue injury that can occur during the warm ischemia period. It is essential to harvest a donor kidney with a single renal artery. Many renal arteries bifurcate close to the kidney. A minimal length of 0.5 cm of a single renal artery is necessary for the arterial anastomosis.[6] The CT angiography that was performed on the donor prior to anesthesia not only provides important information regarding the renal vasculature, but also prevents delays between the donor nephrectomy and recipient anesthesia induction. The left kidney is preferred as a donor because it provides a longer renal vein than the right kidney. In most situations, if two renal veins are present, the smaller vein can be sacrificed. Prior to sacrificing a small vein, however, it is important for the surgeon to identify the ureteral vein and determine that it is not draining into the renal vein that is being sacrificed. The renal artery and vein are cleared of as much fat and adventitia as possible and the ureter is dissected free to the point where it enters the bladder serosa. Using sterile paper, templates are made of both the donor renal artery and vein to determine the size of the venotomy and aortotomy to be performed in the recipient. Harvesting the donor kidney is performed when the recipient is fully prepared to receive the kidney. Fifteen minutes prior to nephrectomy, a 2nd dose of mannitol (1.0 g/kg IV) is given to the donor cat.

An operating microscope is used for the majority of the recipient surgery. Following a full abdominal exploratory, the colon and ileum are tacked to the body wall using 3-0 chromic gut to aid in surgical exposure. Two surgical methods of renal trans-

plantation have been described. The first technique described transfers the transplanted kidney to the recipient's iliac vessels. In this technique, an end-to-end arterial anastomosis of the external iliac and renal artery and an end-to-side anastomosis of the external iliac vein and renal vein are performed.[2] Approximately 12% of cats having this procedure developed pelvic limb complications including pain, hypothermia, edema, paresis and paralysis.[5] These complications have been successfully prevented by changing the vascular surgical technique. In the revised procedure, the renal artery is anastomosed end-to-side to the caudal aorta (proximal to the caudal mesenteric artery), and the renal vein is anastomosed end-to-side to the caudal vena cava (Figure 29-22A and B).[27] Partial occlusion vascular clamps are used to obstruct blood flow in both the aorta and the caudal vena cava. Using the previously made templates from the donor vessels, windows are created in both the aorta and vena cava that match the size of the renal artery and vein, respectively. An aortotomy clamp is used to create the stoma in the aorta and adventitial scissors are used to create an oval defect in the vena cava. The aorta and vena cava are flushed with a heparinized saline solution. Two sutures of 8-0 nylon are placed at the cranial and caudal aspect of the aortotomy site. Sutures are not pre-placed in the venotomy.

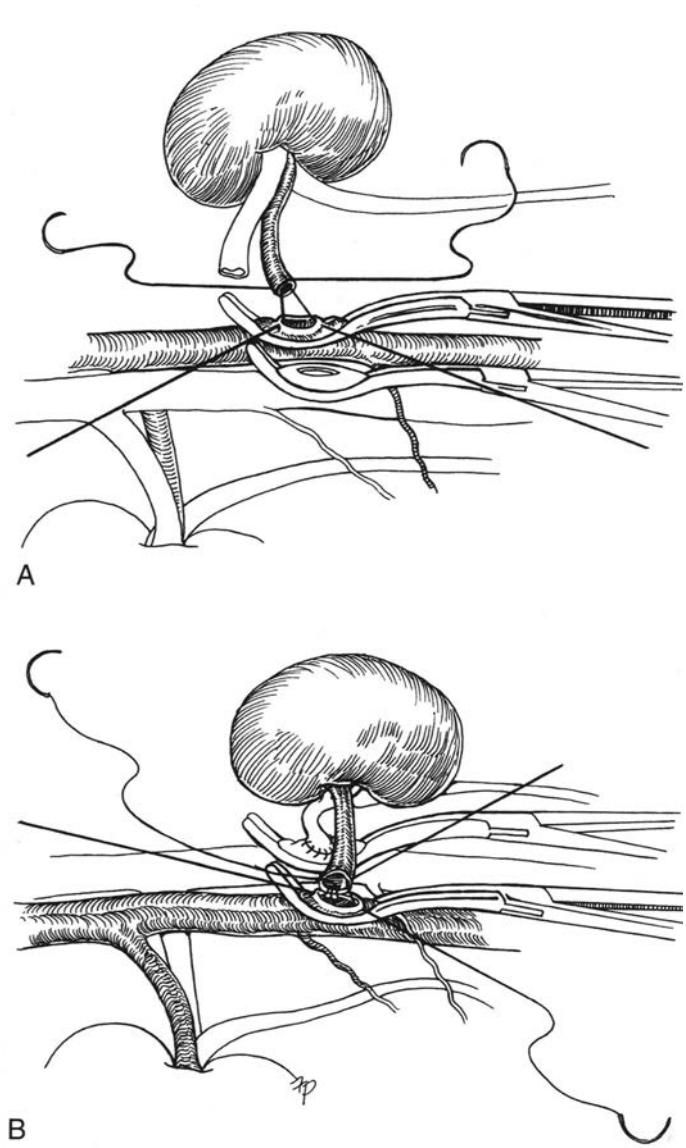


Figure 29-22. A and **B.** Transplantation of the renal allograft onto the recipients abdominal aorta and vena cava. The renal artery is anastomosed end to side to the aorta using 8-0 nylon and the renal vein is anastomosed end to side to the vena cava using 7-0 silk.

Following the second mannitol infusion in the donor, the graft is harvested and flushed with a phosphate-buffered sucrose preservation solution. Excess adventitia on the end of the renal artery is excised and the artery dilated. The renal artery is anastomosed to the aorta using 8-0 nylon in 2 rows of simple continuous sutures; one on the medial aspect and one on the lateral aspect of the artery. The renal vein is anastomosed to the vena cava using 7-0 silk. A back wall technique is used first to suture the portion of the renal vein closest to the renal artery. The anastomosis is completed once the second side of the vein is sutured using a continuous pattern. The venous clamp is removed first and then the arterial clamp. Some hemorrhage may occur but typically can be controlled with direct pressure. Significant leaks are repaired with the placement of additional single interrupted sutures. Occasionally, renal arterial spasm can occur following release of the vascular clamps. The application of topical lidocaine or acepromazine has been effective in some cases in eliminating this problem. Others recommend the systemic use of chlorpromazine or acepromazine for treating the vascular spasms that can occur and have found these drugs to be more effective than lidocaine.[17] In a comparison of the two surgical techniques, although not statistically significant, the graft warm ischemia and total surgical times were shorter using the arterial end-to-side technique compared to the iliac vessel technique. Additionally, pelvic limb complications were not identified using the revised technique.[27]

An alternative to performing the donor and recipient surgeries simultaneously is the use of hypothermic storage to preserve the donor kidney until the recipient surgery is performed. Following preparation of the donor kidney within the donor, a nephrectomy is performed and the graft flushed with a phosphate-buffered sucrose organ preservation solution.[17] To perform this technique, the renal artery is cannulated with an 18-gauge catheter, perfused with 25 to 50 ml of preservation solution at 100 cm water pressure and then placed in a stainless steel bowl which contains approximately 200 ml of preservation solution. The bowl is floated in an ice slush, the kidney agitated until cold to the touch and the bowl is covered with a sterile drape.[17,28] This technique is preferred by some surgeons because it reduces personnel and resources needed for the transplantation procedure and the cold preservation technique has been found to minimize ischemic injury that can occur to the kidney.

Once the vascular anastomosis is complete, a ureteroneocystotomy is performed. Three techniques have been described and are currently being performed at different surgical centers. I prefer the intravesicular mucosal apposition technique.[3] With this technique, a ventral midline cystotomy is performed. A mosquito hemostat is used to make a hole at the apex of the bladder and then the end of the ureter is grasped and brought directly into the bladder lumen. Tunneling of the ureter through the bladder wall is not performed (Figure 29-23). The bladder is

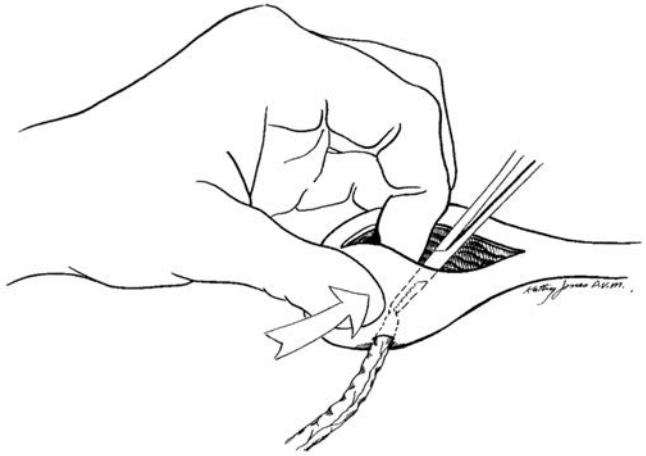


Figure 29-23. A ventral cystotomy is performed and the allograft ureter tunneled directly through the apex of the bladder using a mosquito forcep.

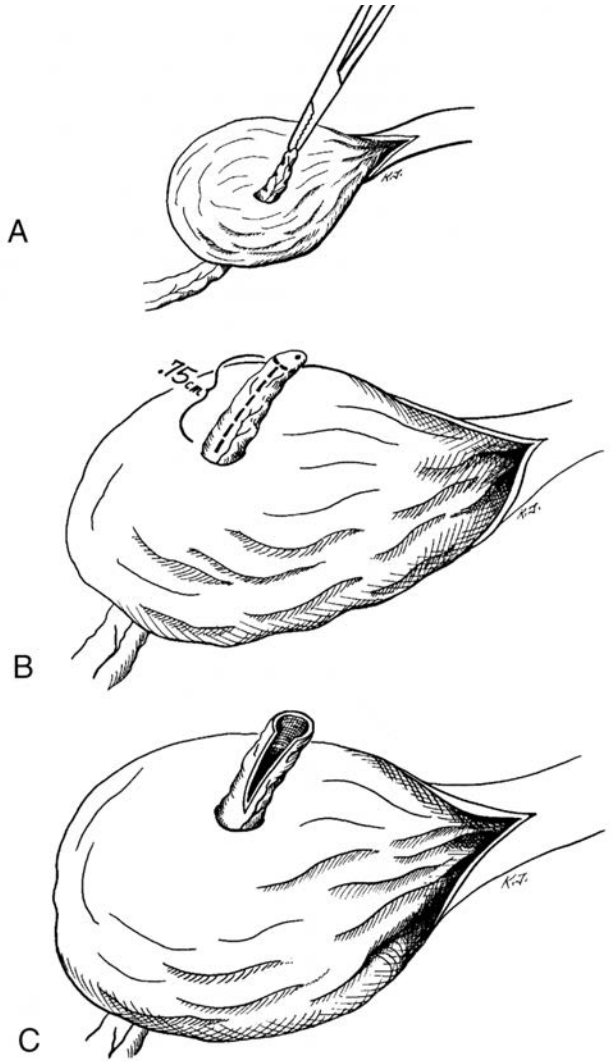


Figure 29-24. The bladder is everted for better exposure. The crushed end of the ureter is excised and the end of the ureter spatulated using straight microvascular scissors.

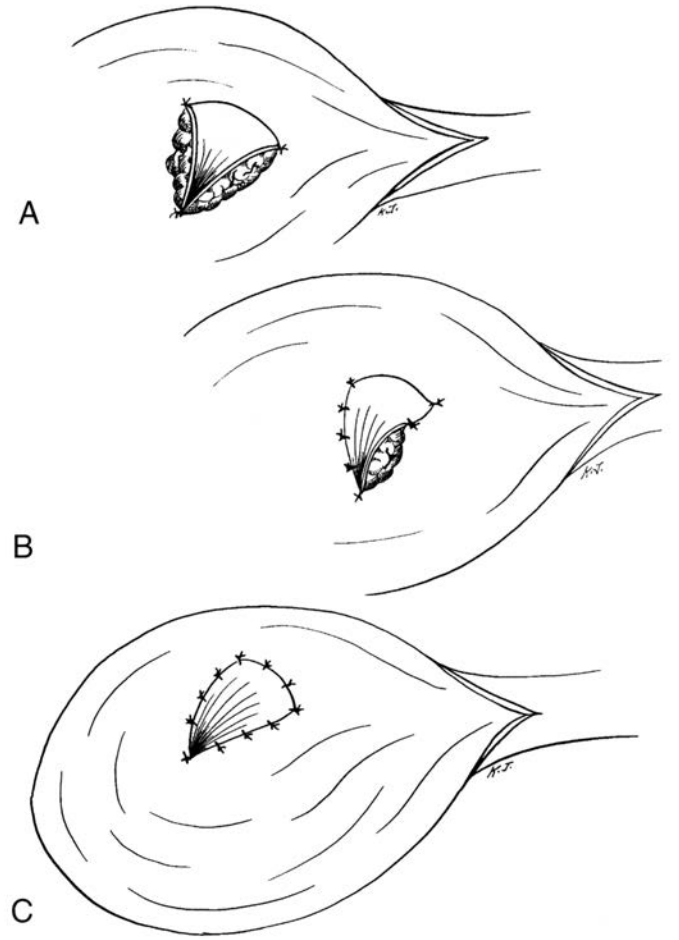


Figure 29-25. The ureteral mucosa is sutured in an interrupted pattern to the bladder mucosa using simple interrupted sutures of either 8-0 nylon or 8-0 vicryl. The first and most important suture is placed at the proximal end of the ureteral incision (point of the "V"). It is important that no periureteral fat is exposed once suturing is complete as this can lead to adhesions and granuloma formation potentially resulting in a ureteral obstruction. Once completed, the bladder is then closed routinely.

everted, the distal end of the ureter is excised, periureteral fat removed and then the end of the ureter is spatulated a distance of 0.5-0.75 cm (Figure 29-24). The ureteral mucosa is sutured to the bladder mucosa using either 8-0 vicryl or 8-0 nylon in a simple interrupted pattern. The first and most critical suture is placed at the proximal end of the ureteral incision (point of the "V") (Figure 29-25) It is important that no periureteral fat is exposed once suturing is complete as this can lead to adhesions and granuloma formation potentially resulting in a ureteral obstruction. A 5-0 polypropylene suture can be used to check for ureteral patency. Following completion of the anastomosis, the bladder is closed with absorbable suture in a single layer appositional pattern.

Two newer techniques for ureteral implantation, both extravesicular, have recently been described. In the first technique (Figure 29-26), a 1 cm incision is made through the seromuscular layer on the ventral surface of the bladder allowing the mucosa to bulge through the incision.[6,29] A smaller incision (3 to 4 mm) is made through the mucosal layer of the bladder at the caudal

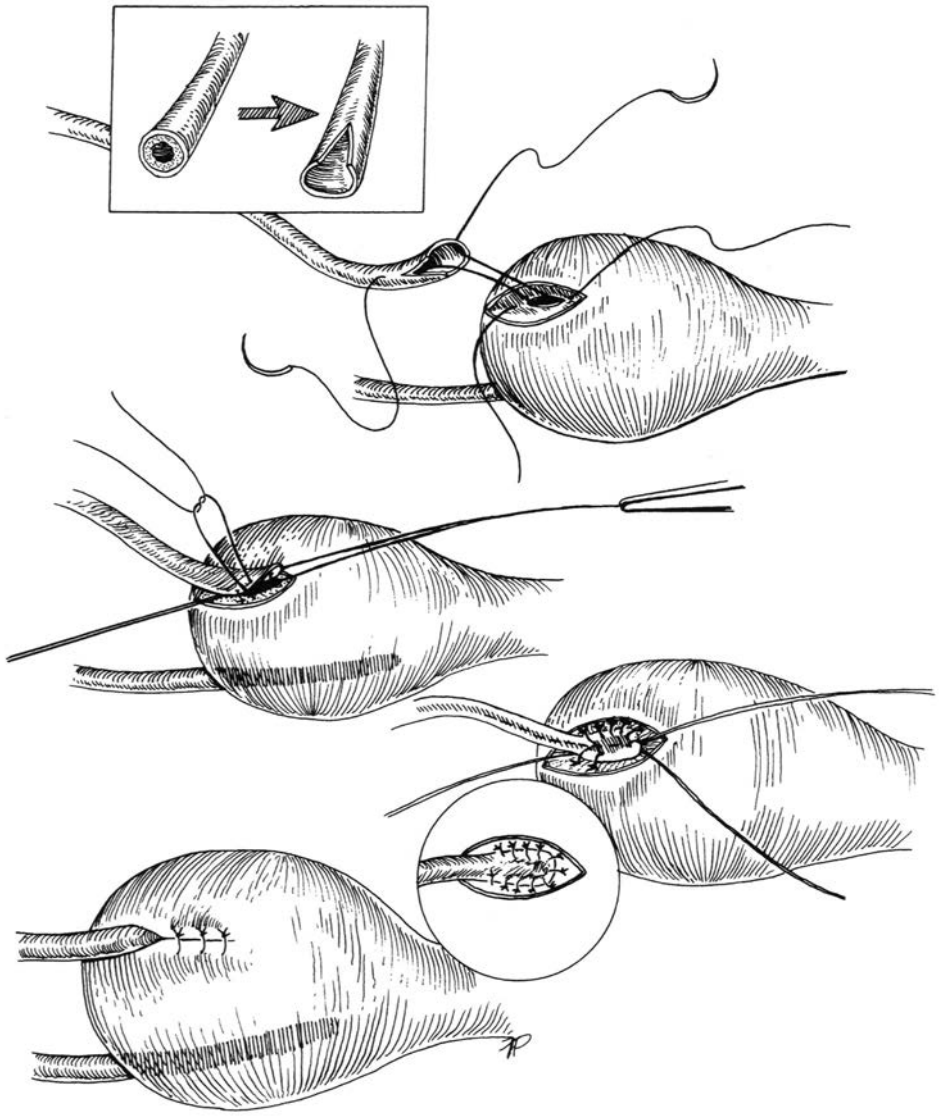


Figure 29-26. Extravesicular technique for ureteroneocystostomy. A 1 cm incision is made on the ventral surface of the bladder through the seromuscular layer allowing the mucosa to bulge through the incision. A smaller incision (3 to 4 mm) is made through the mucosal layer of the bladder at the caudal aspect of the seromuscular incision. The distal end of the ureter is spatulated and the ureteral mucosa is sutured to bladder mucosa using 8-0 nylon. The proximal and distal sutures are placed first. The seromuscular layer is closed over the ureter in a simple interrupted suture pattern.

aspect of the seromuscular incision. The distal end of the ureter is prepared as previously described. Ureteral mucosa is sutured to bladder mucosa using 8-0 vicryl or nylon. The proximal and distal sutures are placed first. Similar to the previous technique, 5-0 polypropylene suture can be used to check for ureteral patency. Once the ureteral anastomosis is complete, the seromuscular layer is apposed in a simple interrupted pattern over the ureter using 4-0 absorbable suture such as PDS. In the second technique, the entire ureter and ureteral papilla are harvested and sutured using an extravesicular technique.[30] A 2 mm cuff of bladder wall is isolated along with the distal end of the ureter. A 4 mm defect is made at the apex of the bladder and the ureteral papilla sutured in place using 8-0 Vicryl in a 2 layer pattern; mucosa to mucosa and seromuscular layer to seromuscular layer.

Prior to abdominal closure of the recipient, a biopsy of one of the native kidneys is taken (if not previously performed) and an esophagostomy tube placed if nutritional support is deemed necessary. Finally, the allograft is pexied to the abdominal wall. If the kidney is transplanted onto the aorta and vena cava, the adjacent body wall is incised and the incised edge sutured to the renal capsule using 6 interrupted sutures of 4-0 polypropylene. Another procedure involves the creation of a musculoperitoneal flap (based ventrally) which is elevated from the adjacent body wall and sutured to the renal capsule using 4-6 interrupted sutures of 5-0 polypropylene.[6] The pexy is critical to prevent allograft torsion on its vascular pedicle causing ischemia and subsequent graft loss. The native kidneys are usually left in situ to act as a reserve if graft function is delayed. If warranted, the kidneys can be removed at a later time. In cases of polycystic kidney disease, often one of the native kidneys needs to be removed at the time of the transplantation procedure in order to make room in the abdomen for the allograft.

Canine Surgical Technique

The surgical techniques described for renal transplantation in the dog are similar to those described for the cat with minor differences. Both the iliac vessel technique as well as anastomosing the renal vasculature to the caudal aorta and vena cava have been performed successfully in the dog and unlike the cat, magnification may not be necessary depending on the size of the patient.[6] Unlike cats, the iliac vessel technique is still being used both experimentally and clinically in the dog. The selected iliac artery is prepared for an end-to-end anastomosis to the renal artery and the external iliac vein is prepared for an end-to-side anastomosis to the renal vein. A bulldog vascular clamp is placed near the aortic bifurcation to occlude the iliac artery. The artery is subsequently ligated distally, severed and then flushed with heparinized saline solution. The end of the artery is dilated slightly and cleaned of any excess adventitia. The external iliac vein is isolated in the same region, tributary veins ligated and then 2 bulldog vascular clamps placed as far apart as possible (first distally and then proximally). A partial occlusion clamp can also be used. A venotomy in the external iliac vein is performed and then 2 rows of simple continuous sutures are used on the medial and lateral aspect of the renal vein and iliac vein as previously described for the cat. The renal artery and iliac artery are anastomosed using a simple interrupted pattern. Suture material used for the vascular anastomoses is 4-0 to 6-0 silk for the venous anastomosis and 5-0 to 8-0 nylon or polypropylene for the arterial anastomosis. Both intravesicular and extravesicular techniques for ureteroneocystostomy have been used successfully in canine transplantation. The renal capsule of the allograft is sutured to the abdominal body wall with simple interrupted sutures of 3-0 polypropylene, with a musculoperitoneal flap (based ventrally) using 3-0 polypropylene or by suturing the allograft capsule to the adjacent mesocolon with simple interrupted sutures of 3-0 polypropylene.[6,24]

Postoperative Care and Perioperative Complications

Important points of postoperative care in the transplant patient include minimizing stress and handling of the patient and treatment of hypothermia. The recipient is administered a balanced electrolyte solution with the volume adjusted depending on the cat's hydration status and oral intake of water. Blood transfusions should be given as needed. The cat is maintained on IV antibiotic therapy (cefazolin, 22 mg/kg IV q8h) until the intravenous catheter is removed and then the cat is maintained on oral amoxicillin combined with clavulenic acid (Clavamox, 62.5 mg PO q12h) until the feeding tube is removed. If the cat is Toxoplasma positive, Clindamycin (25 mg PO q12hr) is administered and continued for the lifetime of the cat. Postoperative pain has been controlled successfully using either hydromorphone (0.1-0.2 mg/kg IM or SQ q4-6h), buprenorphine (0.005-0.02 mg/kg IV q4-6h) or a constant rate infusion of butorphanol (0.1-0.5 mg/kg/h). An extended data base evaluating the packed cell volume, total protein, electrolytes, blood glucose and acid base status is initially evaluated 2 to 3 times daily and then tapered accordingly depending on the patient's stability. A renal chemistry panel is checked every 24 to 48 hours and a blood CsA level is checked every 3 to 4 days. The oral CsA dose is adjusted accordingly depending on postoperative blood levels. It has been the author's experience that CsA requirements typically decrease in the early postoperative period, likely associated with preoperative fasting of the patient and postoperative anorexia. The prednisolone dose is continued as previously described (0.5 to 1 mg/kg PO q12h). Voided urine is collected daily to assess urine specific gravity. Typically with appropriate pain control and improvement in azotemia, most cats start eating within 24 to 48 hours following the surgical procedure. In some cases in which continued anorexia is thought to be associated with altered gastric motility following surgery, metoclopramide administration (0.2 mg/kg SQ q6-8h) has been successful in improving a cat's appetite. If the cat remains anorexic, feeding is begun using the esophagostomy tube. Feeding is continued until the cat is eating and drinking and then tapered accordingly.

Patients are monitored for postoperative seizure activity every 1 to 2 hours for the first 3 days. During the 1990's, the most common complication reported in cats during the perioperative period was central nervous system (CNS) disorders including disorientation and seizures which occasionally progressed to a comatose state as well as respiratory and cardiac arrest.[31] In one report, the median time until onset of seizure activity was 24 hours following surgery.[5] Many variables were evaluated and showed no difference between affected and unaffected cats with respect to the degree of azotemia, magnesium and cholesterol levels, intraoperative blood pressure, osmolality, serum electrolyte and blood glucose concentration, erythropoietin and CsA administration.[7,31] In one study, postoperative hypertension was identified as a major contributing factor to postoperative seizure activity in the feline renal transplant recipient.[32] Additionally, the administration of antihypertensive therapy significantly reduced the seizure frequency and the morbidity and mortality associated with neurologic complications. Because of these findings, during the first 48 to 72 hours, indirect blood pressure is monitored every 1 to 2 hours for the development of hypertension. If the systolic blood pressure is equal to or exceeds 170 mmHg, hydralazine (Sidmack Laboratories, 2.5 mg SQ) is administered. The hydralazine dose can be repeated if the systolic pressure hasn't decreased within 15 minutes. If the cat is refractory to hydralazine, acepromazine (0.005-0.01 mg/kg IV) has been used successfully. It is important to note that the cause of CNS disorders in human transplant patients is thought to be multifactorial, and since there appears to be a difference between transplant centers in the incidence of hypertension and CNS disorders, the occurrence of CNS disorders in cats following renal transplantation remains a challenge.[17] Postoperative hypotension may also produce complications. Systolic blood pressure should be maintained at equal to or greater than 100 mmHg. Sustained hypotension can be a serious problem leading to poor graft perfusion. These patients need to be treated aggressively to prevent acute tubular necrosis and delayed graft function.

If transplant surgery is technically successful, azotemia typically resolves and the cat improves clinically within the first few days following surgery. If improvement is not identified during this time or if improvement in renal function as well as the clinical status of the patient is initially identified, but then worsens, an

ultrasonographic examination of the allograft is warranted. The allograft should be evaluated for any signs of hydronephrosis and hydroureter as well as renal blood flow. If ureteral obstruction is suspected, the cat is anesthetized and the allograft ureter evaluated. In some cases, the ureter may need to be re-implanted into the urinary bladder. If graft perfusion is adequate and no hydronephrosis/hydroureter exists, delayed graft function may be occurring. Typically, if perfusion remains adequate, improvement in graft function often occurs within the first few weeks following surgery. The author suspected delayed graft function in one cat and significant improvement didn't occur for approximately 6 to 8 weeks postoperatively. This cat experienced prolonged episodes of hypotension during surgery as well as in the immediate postoperative period.

Normally, without major complication, the recipient is transferred from the intensive care unit to the renal transplantation ward within a few days following surgery. Patients are discharged when graft function appears adequate and CsA blood levels are stable. If otherwise stable, cats with a delay in function of their graft can also be discharged. Medical management can be continued in this subset of patients until graft function returns to normal. If the transplanted kidney fails to function, the kidney should be biopsied prior to attempting retransplantation of the patient.

Long-Term Management and Complications

Following discharge, both cats should be evaluated by the primary care veterinarian once a week for the first 4 to 6 weeks initially and then extended to monthly intervals if the cat is clinically stable. During each exam, a renal panel, packed cell volume, total protein, a cyclosporine level and a urinalysis of a free-catch urine sample is performed. Body weight should be monitored regularly. It is recommended that a complete blood count and serum chemistry panel be performed every 3 to 4 months and an echocardiography performed every 6 to 12 months if the cat had been diagnosed with underlying cardiac disease prior to transplantation. The feeding tube can be removed at suture removal if oral intake of food and water is appropriate.

There is seemingly little correlation between the oral dose of cyclosporine and the blood level that will be achieved in an individual animal. Cats of similar weight on identical doses of CsA may vary markedly in blood levels achieved. Because of individual patient variability in the absorption of oral cyclosporine and its metabolism, it is essential that blood levels are monitored regularly to maintain therapeutic concentrations and minimize side effects from toxicity. As previously described, CsA trough levels are maintained for approximately 1 to 3 months following surgery at 300 to 500 ng/ml and then tapered to approximately 250 ng/ml for maintenance therapy. Although rare, a fatal side effect of CsA therapy, hemolytic uremic syndrome (HUS), has been identified in the cat.[33] Patients develop hemolytic anemia, thrombocytopenia with rapid deterioration of renal function secondary to glomerular and renal arteriolar platelet and fibrin thrombi. Unfortunately, the disease typically has not manifested itself until after the transplant procedure and the mortality rate has been 100%.

If renal function remains normal following transplantation, the anemia associated with renal failure should resolve within 3-4 weeks after surgery.[34] If graft function remains adequate, but the anemia persists, iron supplementation should be considered.

Renal complications following transplantation have included renal rejection, hemolytic uremic syndrome, oxalate nephrosis and renal failure. Both acute and chronic rejection have been described in the cat. Acute rejection with loss of function of the affected organ can occur at any time, but is most common within the first 1 to 2 months following surgery. Acute rejection is often associated with poor owner compliance in administration of required medication. Some cats that are experiencing a rejection episode may be lethargic, depressed, anorexic and PU/PD and thus prompt a visit to a veterinarian while in other cats, clinical signs may be minimal. For this reason, weekly blood sampling is critical during this time period to detect any changes in serum creatinine concentration. Histopathologic, sonographic, and scintigraphic examination of allograft rejection in cats has recently been described.[35,36] In one study, allograft histopathology revealed significant interstitial inflammation and tubulitis with varying degrees of intimal arteritis.[35] A significant increase in cross sectional area of the kidney on ultrasound examination has been identified in cats during a rejection episode.[36] Although normal allograft enlargement is expected during the first week postoperatively, a gradual decline in size should then occur. Allograft rejection should be suspected if renal enlargement persists or progresses beyond 7 days. Additionally, a subjective increase in echogenicity and a decrease in corticomedullary demarcation may be identified in allografts undergoing rejection.[36] Neither resistive index nor glomerular filtration rate were sensitive indicators in normal grafts and those undergoing allograft rejection.[36-38] Prior to initiating treatment for rejection, a urine sediment should be evaluated to rule out obvious infection and an abdominal ultrasound performed of the allograft to rule out ureteral obstruction.

Treatment for a possible rejection episode should not be delayed and these tests should only be performed prior to initiating therapy if in house capabilities are available. Acute rejection episodes are treated with intravenous administration of cyclosporine (6.6 mg/kg q24h given over 4 to 6h) and prednisolone sodium succinate (Solu Delta Cortef, Upjohn, 10 mg/kg IV q12h). Each milliliter of the IV cyclosporine is diluted with 20 to 100 ml of either 0.9% NaCl or 5% Dextrose (not Lactated Ringer's solution). Because CsA is light sensitive, the IV fluid lines should be covered. Following the completion of the CsA infusion, the cat is continued on IV fluid therapy. The infusion of CsA can be repeated, however if the creatinine concentration does not improve within 24 to 48 hours, other causes for the azotemia should be investigated. Chronic rejection is characterized by a gradual loss of organ function over months to years, often without a known episode of rejection. Kidneys undergoing chronic rejection show severe narrowing of numerous arteries and thickening of the glomerular capillary basement membrane. Unfortunately, the cause of chronic rejection is undetermined. As described previously, HUS is a rare, but fatal complication in the feline renal transplant recipient. Three feline transplant recipients were dignosed with HUS secondary to cyclosporine therapy.[33]

Results of a recent study suggest that transplantation is a treatment option for cats with calcium oxalate (CaOx) urolithiasis. No difference in long term outcome was found between a group of 13 cats with CaOx calculi and a control group of 49 cats whose underlying cause of renal failure was not related to calculi formation.[9] Although formation of calculi in the allograft did not significantly reduce survival, the power of the study was low and there was a trend towards lower survival rates in cats that formed calculi. Four of the 5 cats that formed calculi following surgery had calculi attached to the nylon suture used to perform the ureteroneocystostomy and two cats that formed calculi after surgery were diagnosed with a urinary tract infection. We speculate and recommend that the use of absorbable suture material for performing the ureteroneocystostomy and a more thorough screening for urinary tract infection be performed in these cats.

Another potential cause for the recurrence of azotemia in the first few months postoperatively in the feline renal transplant recipient is the development of retroperitoneal fibrosis.[39] The cause is unknown but may be associated with operative trauma, infection, the presence of foreign material, inadequate immunosupression, hemorrhage or urine leakage during the transplant procedure. Ultrasound examination of the kidney reveals hydronephrosis with or without hydroureter and occasionally, a capsule can be identified surrounding the allograft. Surgery has been successful in relieving the obstruction and restoring normal renal function.

Finally, similar to humans following transplantation, complications occur secondary to chronic immunosuppressive therapy. Cats and dogs are more susceptible to bacterial and fungal infections as well as opportunistic infections such as the reactivation of latent *Toxoplasma gondii* infection.[12] Bacterial urinary tract infections in the transplant patient cause direct morbidity and mortality due to the infection itself, and may also activate the rejection process. Two cats have developed fatal Mycobacterium infections following chronic immunosuppressive therapy; one cat had systemic disease and the other cat had septic arthritis.[40,(personal communication, Aronson 2005)] Transplant recipients are also more susceptible to various forms of neoplasia and diabetes. Decreased immune surveillance, activation of latent oncogenic viruses such as the Epstein Barr virus and chronic antigenic stimulation are thought to put human patients at increased risk for various forms of neoplasia.[7] The prevalence of neoplasia in cats following renal transplantation has been reported from 9.5 to 14% with lymphoma being the most common type reported.[41]

Conclusion

Renal transplantation offers a unique method of treatment for renal failure in cats. Currently, approximately 90 to 95% of cats recover from surgery sufficiently to be discharged to the owner and approximately 70% of these cases are alive and clinically doing well 1 year after transplant. Transplant success in the canine is considerably less than the feline unless matched donors and recipients are used. Survival times have steadily improved as more animals have been treated and careful screening of recipients is performed, and early recognition of problems and complications has improved. Clients interested in renal transplantation for their pet need to understand the risks of surgery and recovery and that substantial ongoing care is necessary for the life of the animal.

References

1. Gregory CR, Gourley IM, Taylor NJ, et al. Preliminary results of clinical renal allograft transplantation in the dog and cat. J Vet Intern Med 1:53, 1987.

2. Gregory CR, Gourley IM. Organ transplantation in clinical veterinary practice. In:Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1993, 95.

3. Gregory CR. Renal transplantation. In: Bojrab MJ, 4th ed. Current techniques in small animal surgery. Williams and Wilkins, 1998,434.

4. Gregory CR, Gourley IM, Kochin EJ, et al. Renal transplantation for treatment of end-stage renal failure in cats. J Am Vet Med Assoc 201:285,1992.

5. Mathews KG, Gregory CR. Renal transplants in cats : 66 cases (1987-1996). J Am Vet Med Assoc 211:1432, 1997.

6. Gregory CR, Bernsteen L. Organ transplantation in clinical veterinary practice. In:Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 2000,p 122.

7. Mathews KG. Renal transplantation in the management of chronic renal failure. In: August J, ed. Consultation in feline internal medicine 4. Philadelphia: WB Saunders, 2001, p 319.

8. Adin CA, Gregory CR, Kyles AE, et al. Diagnostic predictors and survival after renal transplantation in cats. Vet Surg 30:515, 2001.

9. Aronson LR, Kyles AE, Preston A, Drobatz K, Gregory CR. Renal transplantation in cats diagnosed with calcium oxalate urolithiasis:19 cases (1997-2004). J Am Vet Med Assoc. Accepted with revisions.

10. Adin DB, Thomas WP, Adin CA, et al. Echoardiographic evaluation of cats with chronic renal filure. Absrtact, ACVIM Proceedings, May 25, 2000, p714.

11. Renoult E, Georges E, Biava MF, et al. Toxoplasmosis in kidney transplant recipients:report of six cases and review. Clin Infect Dis 24:625,1997.

12. Bernsteen L, Gregory CR, Aronson LR, et al. Acute toxoplasmosis following renal transplantation in three cats and a dog. J Am Vet Med Assoc 215:1123, 1999.

13. Bouma JL, Aronson LR, Keith DM, et al. Use of computed tomography renal angiography for screening feline renal transplant donors. Vet Radiol & Ultrasound 44:636, 2003.

14. Lirtzman RA, Gregory CR. Long-term renal and hematological effects of uninephrectomy in healthy feline kidney donors. J Am Vet Med Assoc 207:1044,1995.

15. Bernsteen L, Gregory CR, Kyles AE, et al. Renal transplantation in cats. Clin Tech in Sm Anim Prac 15:40, 2000.

16. Graham-Mize CA, Rosser EJ. Bioavailability and activity of prednisone and prednisolone in the feline patient. Dermatology Abstracts 2004;15:9.

17. Katayama M, McAnulty JF. Renal transplantation in cats: Techniques, complications, and immunosupression. Comp Cont Educ Pract Vet 24:874, 2002.

18. McAnulty JF, Lensmeyer GL. The effects of ketoconazole on the pharmacokinetics of cyclosporine A in cats. Vet Surg 28:448,1999.

19. McAnulty JF, Lensmeyer GL. Comparison of high performance liquid chromatography and immunoassay methods for measurement of cyclosporine A blood concentrations after feline kidney transplantation. Vet Surg 27:589,1998.

20. Mehl ML, Kyles AE, Craigmill AL, et al. Disposition of cyclosporine after intravenous and multi-dose oral administration in cats. J Vet Pharmacol 26:349, 2003.

21. Kyles AE, Gregory CR, Craigmill AL. Comparison of thee in vitro antiproliferative effects of five immunosuppressive drugs on lymphocytes in whole blood from cats. Am J Vet Res 61:906,2000.

22. Kyles AE, Gregory CR, Craigmill AL. Pharmacokinetics of tacrolimus after multidose oral administration and efficacy in the prevention of allograft rejection in cats with renal transplants. Am J Vet Res 64:926,2003.

23. Bernsteen L, Gregory CR, Kyles AE, et al. Microemulsified cyclosporine based immunosupression for the prevention of acute renal allograft rejection in unrelated dogs: preliminary experimental study. Vet Surg 32:219,2003.

24. Mathews KA, Holmberg DL, Miller CW. Kidney transplantation in dogs with naturally occurring end stage renal disease. J Am An Hosp Assoc 36:294,2000.

25. Kyles AE, Gregory CR, Griffey SM, et al. An evaluation of combined immunosupression with MNA 715 and microemulsified cyclosporine on renal allograft rejection in mismatched mongrel dogs. Vet Surg 31:358, 2002.

26. Valverde CR, Gregory CR, Ilkew JE. Anesthetic management in feline renal transplantation. Vet Anaes & Analgesia 29:117,2002.

27. Bernsteen L, Gregory CR, Pollard RE, et al. Comparison of two surgical techniques for renal transplantation in cats. Vet Surg 28:417, 1999.

28. McAnulty JF. Hypothermic storage of feline kidneys for transplantation. Vet Surg 27:312, 1998.

29. Mehl ML, Kyles AE, Pollard R, et al. Comparison of 3 techniques for ureteroneocystostomy in cats. Vet Surg 34:114, 2005.

30. Hardie RJ, Schmiedt CW, Phillips L. Ureteral papilla implantation for neoureterocystostomy in cats. 14th annual ACVS Symposium, October 7-9, 2004.

31. Gregory CR, Mathews KG, Aronson LR, et al.Central nervous system disorders following renal transplantation in cats. Vet Surg 26:386, 1997.

32. Kyles AE, Gregory CR, Wooldridge JD, et al. Management of hypertension controls postoperative neurological disorders after renal transplantation in cats. Vet Surg 28:436, 1999.

33. Aronson LR, Gregory CR. Possible hemolytic uremic syndrome in three cats after renal transplantation and cyclosporine therapy. Vet Surg 28:135, 1999.

34. Aronson LR, Preston A, Bhalereo DP, et al. Evaluation of erythropoiesis and changes in serum erythropoietin concentration in cats after renal transplantation. Am J Vet Res 64:1248, 2003.

35. Kyles AE, Gregory CR, Griffey SM, et al.Evaluation of the clinical and histological features of renal allograft rejection in cats. Vet Surg 31:49, 2002.

36. Halling KB, Graham JP, Newell SP, et al. Sonographic and scintigraphic evaluation of acute renal allograft rejection in cats. Vet Rad and Ultrasound 44:707, 2003.

37. Newell SM, Ellison GW, Graham JP, et al. Scintigraphic, sonographic, and histologic evaluation of renal autotransplantation in cats. Am J Vet Res 60:775, 1999.

38. Pollard R, Nyland TG, Bernsteen L, et al. Ultrasonagraphic evaluation of renal autograpfts in normal cats. Vet Rad and Ultrasound 40:380, 1999.

39. Aronson LR. Retroperitoneal fibrosis in four cats following renal transplantation. J Am Vet Med Assoc 221: 984, 2002.

40. Griffin A, Newton AL, Aronson LR, et al. Disseminated Mycobacterium avium complex infection following renal transplantation in a cat. J Am Vet Med Assoc 222:1097, 2003.

41. Wooldridge J, Gregory CR, Mathews KG, et al. The prevalence of malignant neoplasia in feline renal transplant recipients. Vet Surg 31: 94, 20002.

Management of Ureteral Ectopia

Mary A. McLoughlin

Introduction

Ureteral ectopia is a complex congenital abnormality of the urinary system frequently resulting in urinary incontinence. Distal displacement of one or both ureteral orifice(s) to sites within the bladder neck, urethra, vagina or vestibule has been described in small animal patients. *Intermittent, continual or positional urinary incontinence* is the most common clinical symptom reported in both juvenile and adult patients diagnosed with ureteral ectopia. Ureteral ectopia is diagnosed with significantly greater frequency in females compared to males in all affected species. Ureteral ectopia is reported in both purebred and mix-breed dogs. It has been documented with greater frequency in specific breeds including Labrador retriever, Golden retriever, Siberian husky, Newfoundland, Skye terrier, West Highland white terrier, Wire-haired fox terrier, Soft-Coated Wheaten terrier as well as Standard and Miniature poodles. The specific etiology of this developmental anomaly remains unclear and a genetic basis has not yet been established.

Two types of ectopic ureters are recognized in veterinary patients based on the anatomic structure and pathway of the distal ureter. Extramural ureters exit the kidney and completely bypass the bladder opening directly into the proximal, middle or distal urethra, uterus, vagina or vestibule. The incidence of extramural ectopic ureters is rare. Intramural ectopic ureters attach to the serosal surface of the bladder in the expected dorsolateral anatomical position, yet fail to open into the bladder lumen at the tip of the trigone. Intramural ectopic ureters tunnel submucosally through the trigonal region to open at sites within or distal to the bladder neck. Intramural ectopic ureters are the most common type of ectopic ureters identified in both male and female dogs. Additional anatomic variations of the distal ureteral segment include multiple fenestrations, ureteral troughs, dilation, branched ureters and associated ureteroceles. Urinary incontinence since birth or following ovariohysterectomy is the most frequently reported clinical symptom in patients diagnosed with ureteral ectopia. Normal voiding patterns may also be observed in these patients. The cause of urinary incontinence is considered multifactorial. It can result from urine outflow distal to the bladder neck and urethral sphincter mechanism,or functional and/or structural abnormalities of the vesicourethral junction and urethra resulting in primary sphincter mechanism incompetence. The degree of urinary incontinence and patterns of urination cannot be used to confirm the diagnosis of ureteral ectopia nor determine if unilateral or bilateral disease exists.

Diagnosis

Ureteral ectopia is the most common cause of urinary incontinence in young female dogs. However, it should also be considered as a rule-out for patients with history of incontinence after ovariohysterectomy. Physical examination is often normal with the exception of moist or urine stained hair in the perivulvar or prepucial region.

Perivulvar or prepucial dermatitis secondary to urine scalding may be observed. Careful abdominal palpation is performed to discern marked abnormalities in kidney size that can result from hydronephrosis or dysplasia. Results of hematological and serum biochemical evaluations are often normal unless associated abnormalities of the upper urinary tract that diminish renal function exist. Urinary tract infections are frequently identified resulting from ascending bacterial pathogens.

The specific diagnosis of ureteral ectopia is based on identification of one or both ureteral orifice(s) in a distally displaced position. Uroendoscopy or direct visualization at surgery is considered to be the "gold standard" for the diagnosis of ureteral ectopia in female dogs. Direct visualization of the lumenal surface of the lower urinary and reproductive tracts using a rigid or flexible endoscope has dramatically improved our ability to accurately diagnose and classify ectopic ureters and identify associated abnormalities in a minimally invasive manner. Radiographic imaging techniques including intravenous urography (IVU) with or without fluoroscopy, vaginocystography, contrast enhanced computed tomography (CT) and ultrasonography may also provide a valuable method of diagnosis as well as providing valuable information regarding structure and function of the urinary tract. Specific identification of the ureteral orifice with imaging techniques can be difficult or obscured by contrast accumulation in the urinary bladder resulting in a potential false positive or false negative diagnosis.

Surgical Techniques

The goal of surgical treatment of ureteral ectopia is resolution of urinary incontinence and re-establishment of anatomical integrity of the lower urinary system. The specific surgical correction of ureteral ectopia is based upon location and morphology of the ectopic ureter(s), and associated abnormalities of the urogenital tract. A variety of urologic abnormalities have been reported associated with ureteral ectopia including renal dysplasia, renal agenesis, hydronephrosis, hydroureter, tortuous ureter and presence of a septal remnant at the opening of the cranial vaginal vault. Evaluation of renal structure and function is an essential part of the surgical planning. Ultrasonographic evaluation of the upper urinary structures combined with either contrast radiography (IVU) or differential renal nuclear scintigraphy is performed to characterize renal function. Nephroureterectomy is performed when a kidney is determined to be nonfunctional. Renal biopsy and culture are recommended if structural abnormalities of a functional kidney are noted.

Ureteral Reimplantation

Extramural ectopic ureters may result in persistent incontinence because the ureteral orifice is positioned distal to the bladder neck and urethral sphincter mechanism (Figure 29-27A). Repositioning the ureteral orifice directly into the bladder may restore urinary continence provided additional functional or structural abnormalities of the urethral sphincter mechanism do not exist.

The urinary bladder and proximal urethra are exposed and isolated. The distal aspect of the extramural ectopic ureter is isolated at the site of attachment to the dorsolateral surface of the vesicourethral junction, urethra, uterus or vagina. The extramural ureter is ligated at its distal point of attachment with 3/0 absorbable suture material and the ureter transected cranial to the ligature (Figure 29-27B). The surgeon should gently isolate the distal 1/3 of the ureter from the ureteral fascia and retroperitoneal space avoiding disruption of the ureteral arterial blood supply located longitudinally within the fascial attachment. The site of ureteral reimplantation is determined by examining bladder size and position without traction and relative to ureteral length. Ureteral reimplantation can be performed at any site within the bladder between the apex and the tip of the trigone however it is critical to avoid tension at the vesicoureteral anastomosis. A ventral midline cystotomy is performed and a small mucosal incision or defect created at the proposed site of ureteral reimplantation. A mosquito hemostat is passed through the mucosal incision at an oblique angle to exit the serosal surface of the bladder. The surgeon then gently guides the ureter through the bladder wall defect (Figure 29-27C). Once positioned within the bladder lumen, the terminal .25 cm of the ureter is excised and discarded. If the ureteral orifice is extremely small, magnification should be used to accurately place the ureterovesicular anastomotic sutures. Alternatively, the terminal end (4

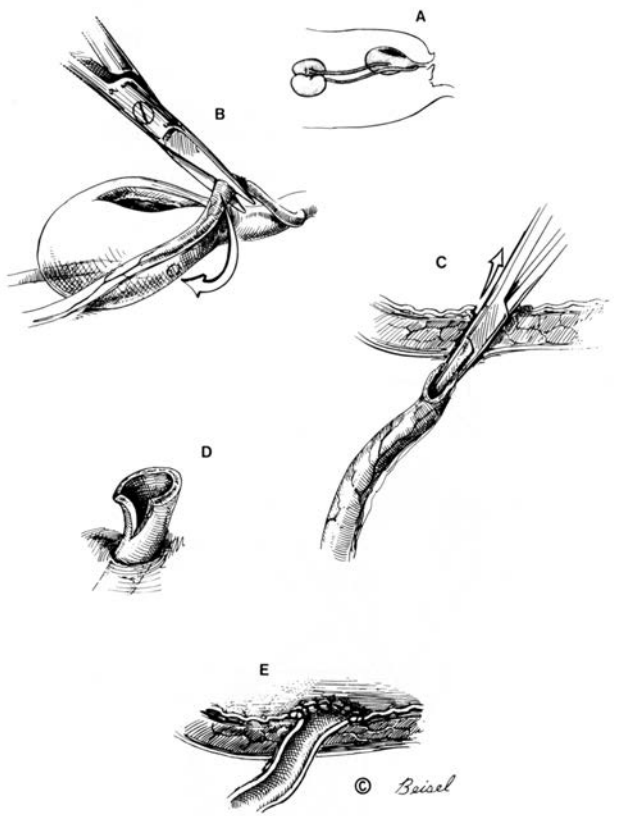


Figure 29-27. A. Reimplantation of an extramural ectopic ureter. **B.** A caudal ventral midline celiotomy to expose the bladder and ureters. The extramural ureter is isolated at its distal point of attachement, ligated and transected. A ventral midline cystotomy is performed. **C.** A mosquito hemostat is passed thru a small mucosal incision within the bladder and passed thru the bladder wall. The transected ureter is gently guided through the bladder wall. **D.** The terminal .25 cm. of the ureter are excised and discarded. If necessary, a 4-6 mm longitudinal incision can be made with small metzenbaum scissors to widen the orifice facilitating vesicoureteral anastomosis. **E.** Vesicoureteral anastomosis is performed placing simple interrupted sutures in the ureteral mucosa and bladder mucosa.

to 6 mm) of the ureter can be incised longitudinally with small metzenbaum scissors to spatulate or widen the orifice to facilitate the intravesicular anastomosis (Figure 29-27D). Intravesicular ureteral anastomosis is accomplished by suturing the ureteral mucosa to the incised edges of the bladder mucosa using 4 to 6 interrupted 5-0 absorbable, monofilament sutures (Figure 29-27E). The bladder is closed in a routine manner with a 4-0 absorbable monofilament suture material in a one or two layer closure.

Neoureterostomy and Urethral/Trigonal Reconstruction

Urinary incontinence caused by an intramural ectopic ureter is attributed to both the ectopic position of the ureteral orifice and/or malformation or dysfunction of the proximal urethral sphincter mechanism by the submucosal ureter. Historically, surgical repair of intramural ectopic ureters has focused on the creation of a new ureteral opening within the bladder lumen and ligation of the distal submucosal ureteral remnant. Persistent or recurrent urinary incontinence after surgery has been frequently reported after this surgery. To restore the functional anatomy of the internal urethral sphincter mechanism in an effort to improve continence after surgery, the terminal segment of the intramural ureter is resected from the surrounding tissues of the bladder neck and urethra. Surgical apposition of the urethral mucosa and smooth muscle layers of the remaining defect are performed to realign the smooth muscle layer of the internal urethral sphincter mechanism.

A ventral midline cystotomy and urethrotomy is performed to expose the trigone and intramural ureter(s). Most displaced ureteral orifices are visualized distally within the bladder neck or urethra (Figure 29-28A). However, if a displaced ureteral orifice is located distally beyond the extent of this approach, a small incision can be made through the urethral mucosa into the lumen of the submucosal ureter to create an orifice avoiding the surgical morbidity of pelvic osteotomy. An appropriate sized (5,8 or 10 French) soft urethral catheter is passed retrograde through each displaced ureteral orifice (Figure 29-28B). With the catheter in place, the ureter is sharply dissected from the surrounding urethral tissues including the mucosa, submucosa and muscularis using small metzenbaum scissors. Surgical dissection through the seromuscular layer on the dorsal aspect of the urethra should be avoided. Primary closure of the mucosal/submucosal defect created by dissection in the bladder neck and urethra is performed using 4 or 5-0 synthetic absorbable, monofilament suture material in a continuous pattern. Closure of the urethral mucosa including a deep bite of the underlying smooth muscle layer is performed. Hemorrhage is controlled by placement of the suture pattern to close the defect. It may be necessary to dissect a portion of the submucosal ureter followed immediately by closure of the defect to control hemorrhage before continuing with the complete dissection (Figure 29-28C). The ectopic ureter is completely dissected from its submucosal position distally to the site where the ureter passes through the bladder wall. The ureteral remnant is transected approximately .5 cm from the site where the ureter passes through the bladder wall. To create a new permanent ureteral opening within the bladder, the ureteral mucosa is sutured to the bladder mucosa using 5-0 absorbable suture in an interrupted pattern (Figure 29-28D). An appropriate size soft urethral catheter can be passed from the bladder lumen distally to exit the vulva. The tip of an appropriate size balloon tipped urinary catheter is carefully sutured to the tip of the red rubber catheter protruding from the vulva with a silk suture. The urethral catheter is withdrawn into the bladder lumen to facilitate the passage of the balloon tipped catheter through the urethra during surgery. The urethral catheter is detached and discarded and the catheter balloon inflated with saline. The cystotomy and urethrotomy are closed

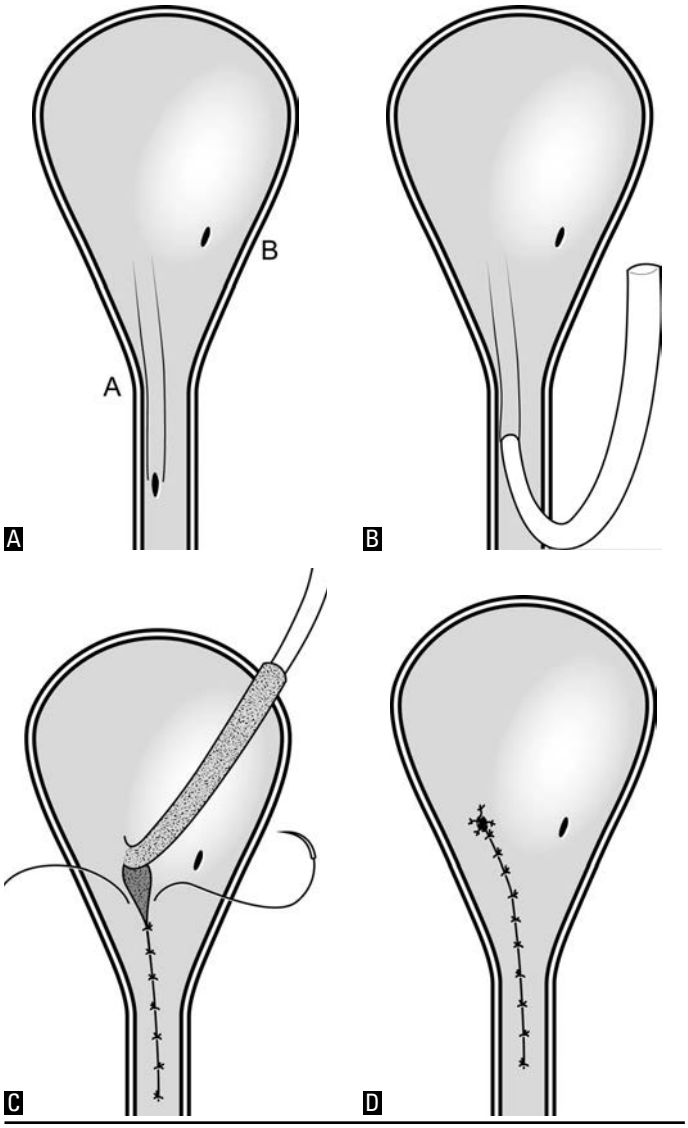


Figure 29-28. A. Neoureterostomy and trigonal and urethral reconstruction. A ventral midline cystotomy and urethrotomy expose the displaced ureteral orifice. **B.** The ectopic ureteral orifice is catheterized with an appropriate sized urethral catheter. **C.** The ureter is sharply dissected from the surrounding urethral tissues. Closure of the remaining defect in the bladder neck and proximal urethra is performed using a continuous or interrupted suture pattern. **D.** The ectopic ureteral remnant is completely dissected from its submucosal position distally to the site where the ureter passes through the bladder wall. The ureteral remnant is transected approximately .5 cm from the site where the ureter passes through the bladder wall. To create a new permanent ureteral opening within the bladder, the ureteral mucosa is sutured to the bladder mucosa.

using 4-0 absorbable monofilament suture in a single or double layer continuous or interrupted pattern.

The urinary catheter and a closed urine collection system should be maintained for 24 to 48 hours after surgery. Following removal of the urethral catheter, stranguria may be noted. Administration of NSAID therapy can be considered if renal function is normal.

Nephroureterectomy

Removal of a nonfunctional, dysplastic or hydronephrotic kidney with a severely dilated ectopic ureter is indicated as a salvage procedure provided renal function in the contralateral kidney is normal. Aerobic bacteriologic cultures from the renal pelvis should be obtained if a urinary tract infection is diagnosed prior to surgery or pyelonephritis is suspected. Perform a ventral midline celiotomy from xyphoid to pubis. Gently free the kidney from its retroperitoneal attachments and reflect it medially to expose the vascular pedicle and ureter at the dorsal aspect of the renal hilus. Bluntly dissect the perirenal fat from the renal hilus to expose the vascular pedicle. Isolate and doubly ligate the renal artery and vein individually with an appropriate sized silk suture. An additional transfixation suture is placed through the renal artery and the renal artery and vein transected. Sharply dissect the ureter from the ureteral fascia and retroperitoneal space to its termination. The ureter is ligated at its most distal point of attachment with a 3-0 absorbable suture and transected cranial to the ligature. *Nephroureterectomy without the removal of the associated intramural ureteral remnant will likely result in continued incontinence after surgery.* A ventral midline cystotomy and urethrotomy is performed to identify and remove the submucosal remnant of the ectopic ureter as previously described.

Post-Surgical Considerations

Mild to moderate ureteral dilation occurs following surgical manipulation of the ureter and generally resolves within 4 to 6 weeks after surgery. However, moderate to severe hydroureter, present prior to surgery, is most likely a developmental response of the ureter to increased lower urinary tract outflow pressure. Successful surgical correction of ureteral ectopia may improve but will not completely resolve the hydroureter in this situation.

Persistent urinary incontinence is the most common complication after surgical repair of unilateral or bilateral ureteral ectopia. Urinary incontinence has been reported to occur in 44 to 67% of patients undergoing either ureteral reimplantation, neoureterostomy or ureteronephrectomy alone. Patients with continuous or recurrent symptoms of urinary incontinence should be completely evaluated for additional causes of incontinence including urinary tract infection,other congenital abnormalities of the urogenital tract and primary sphincter mechanism incompetence. Aerobic bacteriologic cultures of urine samples obtained via cystocentesis should be performed and appropriate antibiotic therapy administered based on results of antibiotic sensitivity testing. Alpha-adrenergic drugs such as phenylpropanolamine, ephedrine sulfate and oxybutinin have been used successfully to manage some patients with mild urinary incontinence after surgery. An additional consideration for patients with unrelenting urinary incontinence after appropriate surgical correction of the ureteral ectopia, is the use of endoscopically placed urethral submucosal bulking agents such as bovine collagen to treat the sphincter mechanism incompetence.

Editor's Note: Until recently, surgical correction has been the primary treatment for ectopic ureter. Surgical correction is challenging and a high degree of technical skill is required. Surgical time, patient pain, and required hospitalization are potential disadvantages. Cystoscopic laser ablation performed by minimally invasive techniques has shown promising results. Cystoscopic capability and laser access are required. Consultation with an internist at a referral center is recommended.

Suggested Readings

Cannizzo K.A., McLoughlin M.A., Mattoon J., Chew D.J., Samii V.F., DiBartola S.P.; Transurethral cystoscopy and intravenous pyelography for the diagnosis of ectopic ureters in 25 female dogs. (1992-2000). J Amer Vet Med Assoc 223:475, 2003.

Dean P.W., Bjorab M.J., Constantinescu G.M.: Canine ectopic ureter. Compend Contin Educ Pract Vet 10(2):146, 1988.

Lane I.F., Lappin M.R., Seim H.B.: Evaluation of results of preoperative urodynamic measurements in nine dogs with ectopic ureters. J Am Vet Med Assoc 206:1348, 1995.

Leveille R., Atilola M.A.: Retrograde vaginocystography: A contrast study for evaluation of bitches with urinary incontinence. Compend Contin Educ Pract Vet 13:934, 1991.

McLaughlin R., Miller C.W.: Urinary incontinence after surgical repair of ureteral ectopia in dogs. Vet Surg 20:100, 1991.

McLoughlin M. A., Chew D.J.: Diagnosis and surgical management of ectopic ureters. Clin Tech Sm Anim Pract 15:17, 2000.

Mason L.K., Stone E.A., Biery D.N., et al.: Surgery of ectopic ureters: Pre- and postoperative radiographic morphology. J Am Anim Hosp Assoc 26:73, 1990.

Stone E.A., Mason L.K.: Surgery of ectopic ureters: Types, method of correction, and postoperative results. J Am Anim Hosp Assoc 26:81, 1990.

Samii V.F., McLoughlin M.A., Mattoon J.S., Drost W.T., Chew D.J.: Digital fluoroscopic excretory urography, helical computed tomography and cystoscopy in 24 dogs with suspected ureteral ectopia. J Vet Int Med 2004:18:271-281.

Sutherland-Smith J., Jerram R.M., Walker A. M., Warman C.G.A.: Ectopic ureters and ureteroceles in dogs: presentation, cause and diagnosis. Compend Contin Educ Pract Vet 4:303, 2004.

Sutherland-Smith J., Jerram R.M., Walker A. M., Warman C.G.A.: Ectopic ureters and ureteroceles in dogs: treatment. Compend Contin Educ Pract Vet 4:311, 2004.

Chapter 30

Urinary Bladder

Cystotomy and Partial Cystectomy

Elizabeth Arnold Stone and Andrew F. Kyles

Introduction

Cystotomy is indicated to remove cystic and urethral calculi, to approach ectopic ureters, to examine the interior surface of the bladder for tumors, polyps, and ulcers, to remove blood clots, sloughed urothelium, or foreign bodies, and to repair some types of bladder rupture. Partial cystectomy is indicated to excise bladder neoplasms, polyps, ulcers, patent urachus, urachal diverticula, and infected urachal remnants. Total cystectomy has been used as a treatment for malignant tumors that are extensive or that involve the trigone and ureters. Various surgical techniques for urine diversion after partial cystectomy with or without the creation of a urine reservoir have been described, but all are associated with significant postoperative morbidity. Alternatives to total cystectomy include palliative treatment by placement of a permanent cystostomy catheter, chemotherapy,and radiation therapy.

Depending on the indication, preoperative assessment before cystotomy or cystectomy should include evaluation of renal function, urinalysis, and quantitative bacteriologic culture and diagnostic imaging of the bladder using survey radiography, contrast cystography, or ultrasonography.

Surgical Technique

Cystotomy

A caudal midline incision is made in female dogs and cats. In the male dog, a paraprepucial incision is used; the skin incision curves lateral to the prepuce, the prepuce is retracted laterally, and a midline abdominal incision is made through the linea alba.

A ventral cystotomy incision is recommended because it provides better access to the trigone, ureteral openings, and proximal urethra than a dorsal incision, and the risk of adhesions or leakage is similar with either location of the incision.[1] The bladder is isolated from the abdomen with moistened laparotomy sponges or towels. A retention suture is placed at the cranial end of the bladder, and a second suture is placed at the caudal end of the planned incision. The length of the incision is determined by the size of the calculi or by the extent of the planned exploration of the bladder interior. The bladder is emptied by cystocentesis using a 22-gauge needle and syringe (Figure 30-1). A stab incision is made into the bladder with a scalpel. The incision is extended cranially and caudally with scissors (Figure 30-2). Retention sutures can be placed lateral to the incision to help open the bladder and to allow inspection of the interior (Figure 30-3).

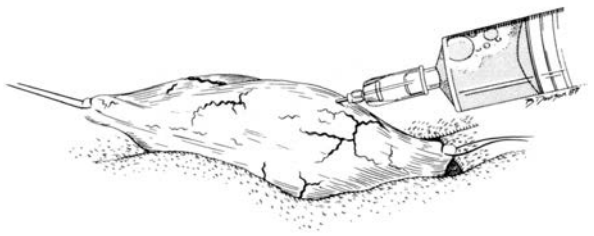


Figure 30-1. Retention sutures are placed cranial and caudal to the ends of the proposed cystotomy incision. Urine is removed by cystocentesis.

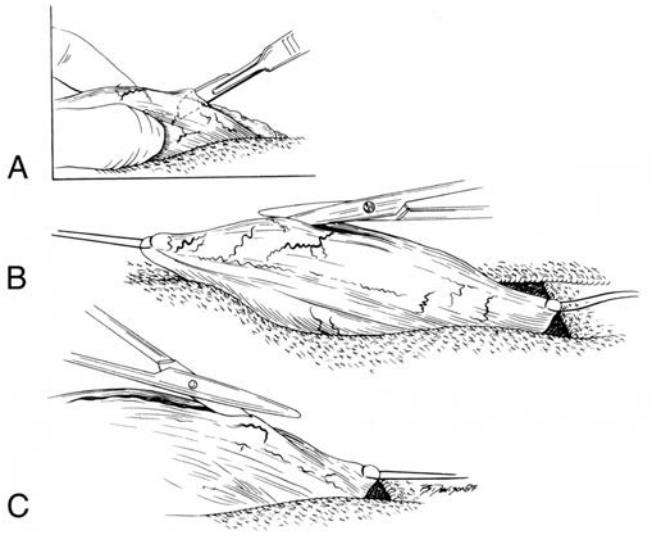


Figure 30-2. *A.* A stab incision is made into the bladder. *B.* and *C.* The incision is extended cranially and caudally with scissors.

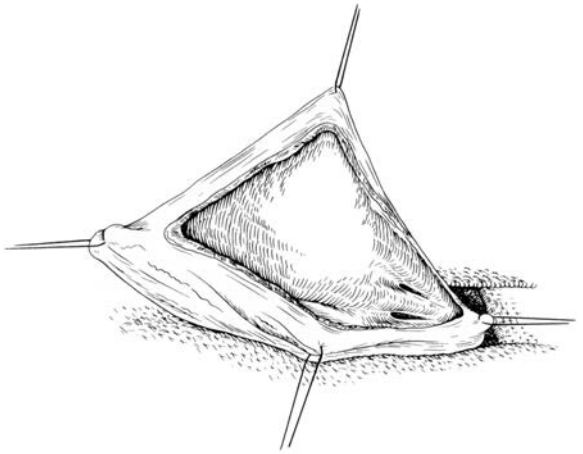


Figure 30-3. Retention sutures are placed on each side of the incision and the interior of the bladder is inspected.

Calculi are removed with a bladder spoon or forceps. Passing a urethral catheter and flushing the urethra from the bladder and from the urethral opening alternately can often dislodge urethral calculi. The bladder lining is inspected, and abnormal appearing areas are sampled for biopsy. The ureteral openings can be identified in the trigone and catheterized if necessary. The bladder is flushed with warm saline before closure.

The bladder is closed in one layer with absorbable suture material. An inverting pattern (e.g., Cushing) or simple continuous is used in a bladder of normal thickness, and a simple interrupted pattern is used in a thickened bladder wall (Figure 30-4). The suture material should not enter the lumen of the bladder, but should incorporate the submucosal layer. The bladder closure can be tested by injecting saline to distend the bladder and evaluating the incision for leakage. The abdomen is lavaged with warm saline and is closed routinely.

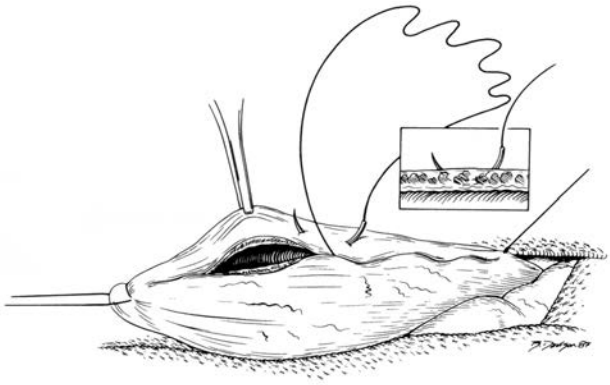


Figure 30-4. The bladder is closed in a single layer inverting pattern. In a thickened bladder wall, a simple interrupted appositional pattern is preferred.

Partial Cystectomy

Up to 75% of the urinary bladder can be excised and the remaining tissue closed around a 5 mL Foley catheter bulb. A return to normal bladder volume and function within 3 months is anticipated.

If bladder neoplasia is suspected, the bladder wall is gently palpated and a cystotomy incision is made at least 2 cm away from the bladder mass. The mucosal surface of the bladder is inspected for additional tumors. The mass should not be manipulated during the cystectomy. The bladder wall with the mass is excised with a 1 to 2 cm margin of grossly normal tissue. Care is taken to preserve as much of the blood supply to the bladder as possible. It is preferable to preserve the trigone with the ureters intact, but if necessary, the ureters can be reimplanted into another location in the residual bladder. After tumor excision, gloves and drapes should be changed and new instruments used to close the bladder and abdomen, to prevent tumor seeding.[2] Closure of the bladder incision is similar to the cystotomy closure described previously. Placement of simple interrupted sutures may facilitate apposition of the bladder remnant.

Postoperative Management

The patient should be allowed to urinate frequently. If this is not possible, the bladder should be kept empty for 2 to 3 days by intermittent catheterization or with an indwelling urethral catheter connected to a closed urine collection system. Following cystotomy, retrieved calculi are submitted for quantitative mineral analysis, and appropriate medical management is initiated to help prevent urolith recurrence. Following partial cystectomy, an indwelling urinary catheter should be placed if more than 50% of the urinary bladder is excised. Excised tissue should be submitted for pathologic examination. With suspected bladder neoplasms, evaluation of the tissue margin is facilitated by pinning the specimen flat to a corkboard and marking the edges of the excised tissue with India ink before fixing in formalin.

References

1. Desch JP II, Wagner SD. Urinary bladder incisions in dogs: comparison of ventral and dorsal. Vet Surg 1986:15:153-158.

2. Blake EH III, Ellison, GW, Roberts JF, et al. Biomechanical and histologic comparison of single-layer continuous Cushing and simple continuous appositional cystotomy closure by use of poliglecaprone 25 in rats with experimentally induced inflammation of the urinary bladder. Am J Vet Res 2006; 67:686-692.

3. Gilson SD, Stone EA. Surgically induced tumor seeding in eight dogs and two cats. J Am Vet Med Assoc 1990:11:1811-1815.

Cystostomy Tube Placement

Julie D. Smith

Introduction

Cystostomy tube placement is a method of diverting urine from its normal bladder and urethral flow. Clinical indications for cystostomy tube placement include temporary and permanent urine bypass of the urethra. Temporary bypass is indicated in patients with urethral obstruction due to urethral calculi, inflammation, or neoplasia. Temporary bypass may also be indicated in patients with bladder atonia while awaiting response to medication and for temporary urinary diversion after urethral surgery. Permanent cystostomy tubes can be used as palliative treatment for bladder neck or urethral neoplasia.

Latex or mushroom tipped or Foley urinary catheters have been used most commonly as cystostomy tubes. Low profile cystostomy tubes are more expensive but are less cumbersome and less prone to accidental removal. They are also more suitable for long term use.

Preoperative Management

In a patient with suspected urethral obstruction, placement of a transurethral catheter should be attempted. If a transurethral catheter cannot be passed, urethral obstruction can be temporarily bypassed by placement of a cystostomy tube. The tube can be placed quickly and with minimal anesthetic compromise to the patient. This placement allows for drainage of urine while awaiting more definitive diagnostic procedures or for stabilization of a critically ill animal before instituting more definitive therapy.

If urethral or prostatic neoplasia is causing significant urethral obstruction, a cystostomy tube can be placed through a

minilaparotomy or during a staging laparotomy. The cystostomy tube can be used as permanent palliative therapy, or it can be placed while awaiting response to more definitive therapy, such as chemotherapy or radiation.

Surgical Technique

A minilaparotomy (1 to 2 cm skin incision) is made in the caudal third of the abdomen. Usually, the bladder is easily palpable, and the incision is made over the bladder (Figure 30-5A). The incision can be made on the midline through the linea alba, or paramedian through the abdominal body wall. In male dogs, it is often easier to make a paramedian incision lateral to the prepuce, or alternatively, the prepuce can be retracted laterally to make a midline incision. The bladder is exteriorized, and two retention sutures are placed to allow for retraction (Figure 30-5B).

A pursestring suture using synthetic absorbable suture is placed through the serosa and muscular layers of the bladder wall in the ventral portion of the exteriorized bladder. When a ventral midline approach is used, the tube is placed through a separate paramedian incision in the body wall; when a minilaparotomy is performed, the tube can be placed through the primary body wall incision. A stab incision is made into the bladder within the pursestring (Figure 30-5C), and the cystostomy tube is introduced

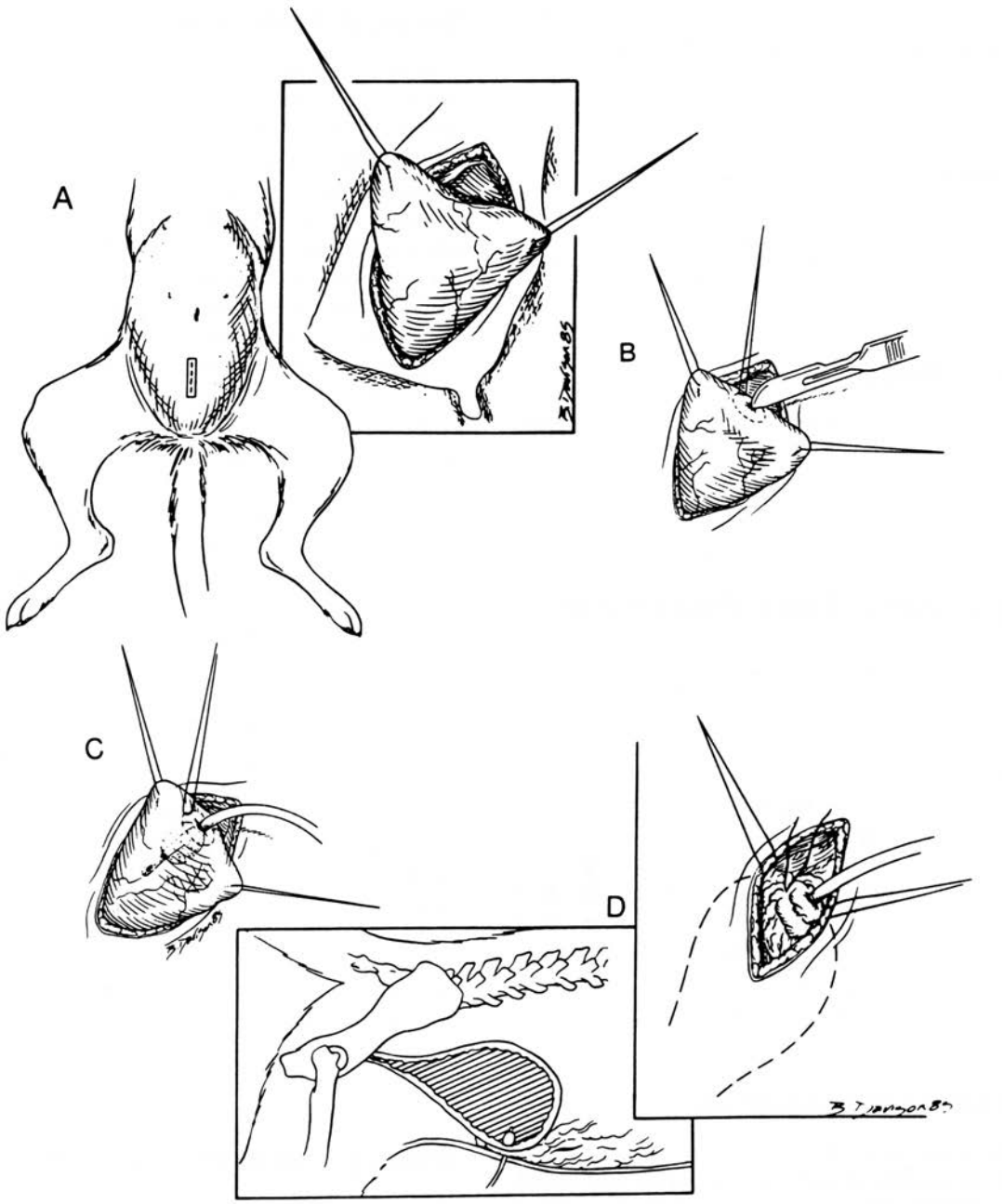


Figure 30-5. Cystostomy tube placement. **A.** Site of the skin incision. **B.** Exteriorized bladder held by retention sutures. **C.** Placement of the pursestring suture and stab incision into the bladder wall. **D.** Insertion of a Foley catheter into the bladder after passage through body wall. **E.** Omentum incorporated around the catheter to help secure the pexy of the bladder. **F.** Sagittal section with catheter in placed, with optional omentum wrapped around the cystostomy tube.

into the bladder (Figure 30-5D). A Foley catheter (8 or 12-French) is recommended for temporary bypass, and the catheter balloon is inflated with sterile saline. If the catheter is to remain in place for weeks to months, a mushroom-tip (Pezzar) urinary catheter or a low-profile cystostomy tube is recommended. The omentum can be incorporated around the catheter (Figure 30-5E), or the retention sutures can be placed between the bladder and the body wall to help secure the "pexy" of the bladder. The incisions in the body wall and skin are closed around the catheter, and the catheter is secured to the skin (Figure 30-5F). The catheter is connected to a closed drainage system, or alternatively, the bladder can be intermittently drained. The catheter can be safely removed after 7 to 14 days, allowing for a strong adhesion to form between the bladder and body wall. After tube removal, urine leaks from the stoma for 1 to 3 days: the stoma is allowed to heal by second intention.

Postoperative Management

After urine flow is restored by temporary bypass of the obstructed urethra, fluid therapy is continued to correct dehydration, azotemia, and electrolyte and acid-base disturbances. Urine output is carefully monitored by continuous, closed-system drainage in the critically ill patient.

If the cystostomy tube was placed to remain for a longer period (i.e., urethral neoplasia, bladder atonia), the clients can be taught to drain the patient's bladder intermittently with a syringe. The cystostomy tube should be protected from self-mutilation by the patient with an Elizabethan collar or side brace if necessary. Low-profile tubes offer an advantage over Pezzar or Foley catheters since they are less likely to become dislodged due to inadvertent snagging of the tube on various objects.

Over time, the presence of the cystostomy tube will cause a urinary tract infection. Prophylactic antibiotics are not recommended, because of the potential development of a resistant bacterial urinary tract infection or fungal infection. After removal of the tube, the urine should be cultured, and appropriate antibiotics should be administered. If the catheter is to remain in place permanently, the administration of antibiotics should be carefully considered only if the animal is showing systemic signs or discomfort from the urinary infection.

Suggested Readings

Smith JD, Stone EA, Gilson SD: Placement of a permanent cystostomy catheter to relieve urine outflow obstruction in dogs with transitional cell carcinoma. J Am Vet Med Assoc 206:496, 1995.

Stiffler KS, Stevenson MA, Cornell KK, et al. Clinical use of low-profile cystostomy tubes in four dogs and a cat. J Am Vet Med Assoc 223:325, 2003.

Stone EA, Barsanti JA. Surgical therapy for urethral obstruction in dogs. In: Stone EA, Barsanti JA, eds. Urologic surgery of the dog and cat. Philadelphia: Lea & Febriger, 1992.

Bray JP, Ronan SD, Burton CA. Minimally invasive inguinal approach for tube cystostomy. Vet Surg 38 (3): 411, 2009.

Colposuspension for Urinary Incontinence

Elizabeth Arnold Stone

Introduction

Urethral sphincter mechanism incompetence is a common cause of urinary incontinence in the bitch. It can occur as a congenital or an acquired condition and has multifactorial origin. Among factors contributing to the pathophysiology of the condition is a caudally located bladder neck and proximal urethra ("pelvic bladder"), a common finding in bitches with urethral sphincter mechanism incompetence. The caudally located bladder neck may predispose to incontinence during increases in intra-abdominal pressure when this pressure acts on the intra-abdominal bladder but is transmitted less efficiently to the extra-abdominal intra-pelvic proximal urethra. A competent urethra maintains urinary continence under these conditions, but in a bitch with urethral sphincter mechanism incompetence, such disparity in pressure transmission can result in urinary incontinence. Thus, bitches, with this combination of disorders, leak urine at times of abdominal pressure increases, particularly when they are recumbent.

Indication

In a bitch with a "pelvic bladder", colposuspension may alleviate urinary incontinence associated with urethral sphincter mechanism incompetence by moving the lower urogenital tract cranially, thereby positioning the bladder neck and urethra within the abdomen. After the procedure, increased intra-abdominal pressure is transmitted simultaneously to the bladder and to the bladder neck and proximal urethra. In this way, increases in intravesical pressure resulting from raised intra-abdominal pressure may be counteracted by simultaneous increases in urethral resistance.

Urethral sphincter mechanism incompetence is a multifactorial condition and colposuspension corrects only one of the factors. Thus, colposuspension is not expected to cure all animals. In a study of 150 bitches, approximately 50% were completely continent, with the degree and frequency of incontinence significantly reduced in a further 40%. The severity of the incontinence remained unaltered in 10% of bitches.[1] In another study, 55% of "spay-related" urinary incontinent bitches were completely dry, requiring no medical treatment, two months after surgery. However, less than 14% remained continent at 1 year with no treatment. With the addition of medication (usually phenylpropanolamine), 36% had complete control and another 41% were greatly improved 1 year after surgery.[3]

Our approach is to perform surgery in affected younger bitches (less than 8 years of age) as the first form of treatment in the hope that long term medical therapy and their potential side effects can be avoided. Colposuspension is delayed in juvenile bitches with congenital urethral sphincter mechanism incompetence until after the first estrus because more than half of such animals become continent after their first heat. Animals with severe

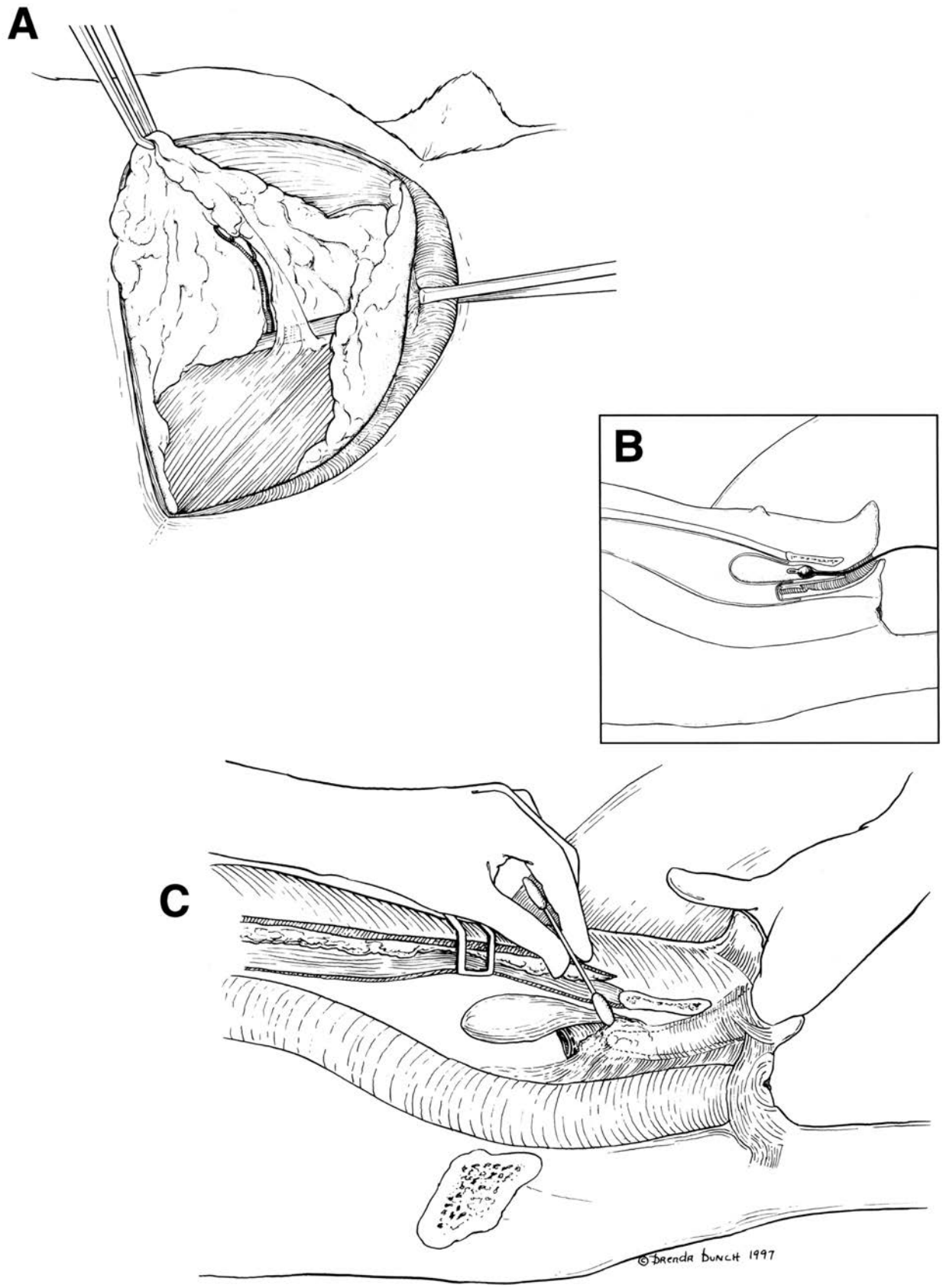


Figure 30-6. A. Prepubic fat and fascia separated by blunt and sharp dissection on both sides of the midline at the level of the prepubic brim. **B.** A finger inserted into the vagina helps to clear out fat and fascia. **C.** The vaginal wall is exposed by using a dry swab to clean off the overlying fat and fascia in a caudolateral direction. **D.** Technique repeated on the other side of the vagina (see text). **E.** Sutures are passed through the abdominal wall caudal to the tendon, in and out of the vaginal wall, and back out of the abdominal wall cranial to the tendon. **F.** Sutures are placed around the prepubic tendon, depending on the size of the bitch and the position of the external pudendal vessels laterally. The optimal number of sutures in medium or large dogs is two.

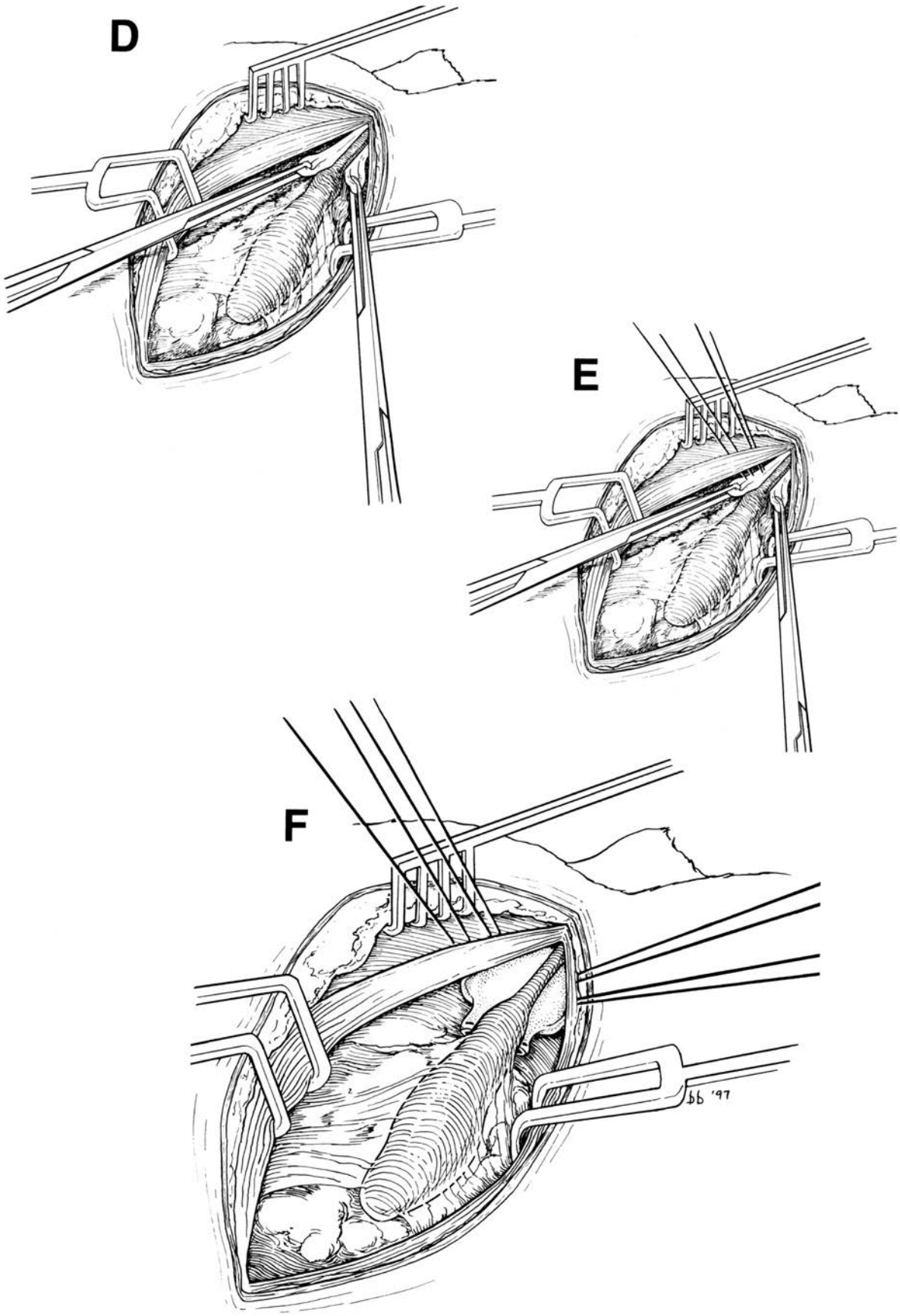


Figure 30-6 (continued). D. Technique repeated on the other side of the vagina (see text). **E.** Sutures are passed through the abdominal wall caudal to the tendon, in and out of the vaginal wall, and back out of the abdominal wall cranial to the tendon. **F.** Sutures are placed around the prepubic tendon, depending on the size of the bitch and the position of the external pudendal vessels laterally. The optimal number of sutures in medium or large dogs is two.

congenital urethral hypoplasia may be unsuitable for colposuspension. In such animals, the bladder neck cannot be returned to abdominal position by colposuspension. Fortunately, such severe urethral hypoplasia is rare, and its treatment is described elsewhere.[2] In older bitches, colposuspension is reserved for animals that have failed to respond to medical therapy.

Surgical Technique

After general anesthesia is induced, the bitch is placed in dorsal recumbency with the hind limbs flexed. The ventral abdominal skin and vagina are prepared for aseptic surgery, the vagina by douching with dilute aqueous povidone iodine solution. An 8 French (smaller bitches less than 35 kg) or a 10 French (larger bitches more than 35 kg). Foley catheter is inserted through the urethra into the bladder, and the cuff is inflated. The catheter is then gently withdrawn until the cuff rests in the bladder neck. The presence of the catheter facilitates identification of the urethra and bladder neck during surgery.

A midline, caudal abdominal approach is made. The prepubic fat and fascia are separated by careful blunt and sharp dissection on both sides of the midline at the level of the pubic brim, and the prepubic tendons and external pudendal vessels are identified (Figure 30-6A). These vessels must be avoided during subsequent placement of sutures around the prepubic tendon.

The midline incision is continued through the linea alba of the abdominal muscle wall and extends caudally to the pubic brim. Self retaining (Gosset or Balfour) retractors are used to hold the rectus abdominis muscle edges apart, and the bladder is identified. Cranial traction on the bladder allows the intrapelvic bladder neck to be pulled into the abdomen and identified by the presence of the inflated Foley catheter cuff. Seeing the bladder neck and proximal urethra is often difficult because of the presence of local retroperitoneal fat.

The vagina is displaced cranially and is cleared of fat and fascia on both sides of the urethra. This is most easily accomplished by inserting a finger into the vagina (Figure 30-6B and C). The urethra is palpated through the ventral vaginal wall and is displaced to the bitch's left. Using the finger in the vagina, the vaginal wall on the right side of the urethra is pushed cranially and ventrally toward the caudal end of the abdominal incision. The vaginal wall is exposed by using a dry swab to clean off the overlying fat and fascia in a caudolateral direction (Figure 30-6C). The bladder neck can be seen as a swelling because of the Foley catheter cuff in the bladder. The vaginal wall is grasped with Allis tissue forceps. The technique is repeated on the other side of the vagina (Figure 30-6D). The surgeon then changes gloves, and the vulva is covered with a large sterile swab or surgical drape throughout the remainder of the procedure.

When the surgeon's finger and the patient's vagina are of incompatible sizes (very large or very small bitches or those with gross vaginal strictures or septa), the vagina has to be located by blunt and sharp dissection of the overlying fat and fascia on either side of the urethra, grasped with tissue forceps, and then pulled cranially. This is more difficult than the use of a finger in the vagina, and, fortunately, most bitches with urethral sphincter mechanism incompetence are of a size compatible with one's finger. It is sometimes helpful in extremely large or small bitches to identify the vagina by inserting a Poole suction tip or a closed Carmalt clamp.

The vagina must now be anchored cranially to maintain the bladder neck in an intra-abdominal position. The vagina is sutured to the prepubic tendon on each side of and approximately 1 to 1.5 cm away from the midline. The sutures (monofilament nylon) are passed through the abdominal wall caudal to the tendon, in and out of the vaginal wall (as far laterally as possible), and back out of the abdominal wall cranial to the tendon, avoiding any abnormal twisting of the vaginal wall (Figure 30-6E). The sutures may enter the vaginal lumen during this procedure, hence the need to prepare the vagina for aseptic surgery.

One or two sutures are placed around the prepubic tendon, depending on the size of the bitch and the position of the external pudendal vessels laterally. Most affected bitches are medium to large breeds, and the optimum number of sutures is two around each tendon (Figure 30-6F). Number 0 nylon is suitable for most bitches, but No. 1 nylon should be used in very large breeds. On the rare occasions when colposuspension is performed in small or toy breeds, it may only be possible to place one suture through each side of the vagina and around each prepubic tendon.

Before the sutures are tied, they are pulled tight to ensure that, after they are tied, the urethra will not be compressed against the pubis by an arch of vagina (See Figure 30-6F). Compression on the urethra may result in postoperative dysuria. The surgeon should be able to insert the tip of a blunt instrument such as Mayo scissors or Carmalt forceps easily between the urethra and the vaginal arch and pubis. If the urethra is compressed, the sutures should be repositioned. This is rarely a problem when the sutures have been placed as far laterally on the vagina as possible. After the sutures are properly placed, they are tied, the Foley catheter is removed, and the abdomen is closed routinely.

Postoperative Care

Preoperative, perioperative, and postoperative analgesics are used routinely. These are not usually required after the first 24 hours. Antibiotic therapy (e.g., amoxicillin) is used for 10 days postoperatively as a precaution to minimize the risk of peritonitis in case colposuspension sutures have entered the vaginal lumen. We have never encountered this complication. The use of a rectal thermometer to take the animal's temperature postoperatively is avoided because some bitches are sensitive in this area for a few days after surgery. In some bitches, local subcutaneous tissue swelling occurs, presumably because of the small dead spaces left after dissection to expose the prepubic tendons. Such swelling is not a problem and resolves spontaneously within 5 to 7 days. The animal is closely observed for signs of dysuria and to determine whether the incontinence has resolved. In most successful cases, the response is immediate, although some bitches remain incontinent for weeks before becoming continent. Skin sutures are removed routinely 7 to 10 days after the surgical procedure.

Possible Complications

Because the surgical procedure involves trauma to intrapelvic structures, some animals are stimulated to strain, usually immediately after recovery from general anesthesia. This can be controlled by the administration of appropriate analgesics. Rarely, some bitches find the first postoperative defecation uncomfortable if the feces are firm and bulky. This problem can be controlled with stool softeners.

Dysuria may occur immediately postoperatively. This complication is rare (approximately 5% of dogs in our experience) and may be caused by vaginal stimulation by the surgical procedure leading to suppression of the micturition reflex or reflex dyssynergia. Clinical observations and the response to diazepam suggest that reflex voluntary dyssynergia is the most likely cause of dysuria after colposuspension. It may be exacerbated by recent estrogen therapy, and so any estrogen therapy should cease at least 1 month before the operation. Voluntary dyssynergia usually responds to diazepam at a dose of 0.2 mg/kg by mouth two or three times daily. An indwelling urinary catheter can be used for a few days if necessary in the few animals that are unable to urinate at all. A further potential cause of dysuria is compression of the urethra against the pubis by the vagina. Care should be taken during surgery to avoid placement of vaginal sutures too close to the urethra.

Bitches that are allowed to be active after colposuspension may tear the sutures from the vagina. This is more likely to happen if these animals are allowed to jump, and owners should be advised of the necessity to restrict the exercise of their animals to leash walks only for 1 month postoperatively.

"Hymen" formation with accumulation of vaginal secretions causing dysuria or dyschezia is a rare, longer-term complication of colposuspension. This complication is caused by breakdown of a pre-existing vestibulovaginal stricture during the operation and subsequent healing of apposing raw areas of vagina to form a barrier across the vaginal lumen. It can be treated by breaking down the "hymen".

Acknowledgment

We wish to thank Brenda Bunch, MA, of the College of Veterinary Medicine, North Carolina State University, for drawing the illustrations.

References

1. Holt PE. Long-term evaluation of colposuspension in the treatment of urinary incontinence due to incompetence of the urethral sphincter mechanism in the bitch. Vet Rec 1990;127:537-542.

2. Holt PE. Surgical management of congenital urethral sphincter mechanism incompetence in eight female cats and a bitch, Vet Surg 1993;22:98-104.

3. Rawlings CA, Barsanti JA, Mahaffey MB, et al. Evaluation of colposuspension for treatment of incontinence in spayed female dogs. J Am Vet Med Assoc 2001;219:770-775.

Suggested Readings

Gregory SP. Review of developments in the understanding of the pathophysiology of urethral sphincter mechanism incompetence in the bitch. Br Vet J 1994;150:135-150.

Holt PE. Urinary incontinence in the bitch due to sphincter mechanism incompetence: surgical treatment. J Small Anim Pract 1985;26:237-246.

Chapter 31

Urethra

Surgical Management of Urethral Calculi in the Dog

Don R. Waldron

Introduction

Passage of urinary bladder calculi from the urinary bladder into the urethra may result in partial or complete urinary obstruction especially in the male dog. Calculi may lodge anywhere in the urethra but most commonly cause obstruction by lodging at the base of the os penis. The urethra at this level is narrow and does not distend owing to the presence of the os. Urethral calculi are less common in females as urethral distensability allows passage of the calculi in many cases. Dogs with partial or total urethral obstruction strain to urinate and pass little or no urine. Depending upon the duration of obstruction, the animal may be anxious, depressed or weak and the urinary bladder is usually distended. If the animal is azotemic and prolonged obstruction has occurred, vomiting and hypothermia may be present.

Preoperative Management

Complete urethral obstruction causes postrenal uremia that results in electrolyte and acid-base imbalance. Hyperkalemia and metabolic acidosis are the most likely abnormailities. The goals of therapy are correction of any fluid or acid-base imbalance by intravenous fluid administration and relief of urethral obstruction. Normal saline (0.9%) is the fluid of choice although Ringer's may also be used.

Urethral obstruction is relieved by catheterization or a combination of cystocentesis and catheterization. Tranquilization or sedation with narcotics or ketamine/diazepam, or propofol may be necessary during efforts to establish urethral patency. In some cases, general anesthesia is preferred especially if the animal is metabolically normal. A urinary catheter is advanced to the level of obstruction and sterile saline infused under pressure in an effort to hydropulse the stones retrograde into the urinary bladder. Liberal lubrication of the catheter and inclusion of sterile lubricant within the fluid may assist in dislodging the obstructing calculi. The veterinarian or assistant may assist in urethral dilation by performing a digital rectal exam and occluding the pelvic urethra simultaneously with fluid infusion. Sudden release of digital urethral occlusion may allow calculi hydropulsion. If initial efforts are unsuccessful, cystocentesis to relieve bladder and urethral pressure may permit successful hydropulsion. Some veterinarians report successful flushing of stones distally out the end of the penis by the method described and quick withdrawal of the catheter. It is imperative to maintain digital urethral occlusion proximally to flush stones distally. If attempts to move the calculi by catheterization techniques are unsuccessful, the veterinarian may attempt to bypass the obstructing calculi with a smaller catheter to relieve bladder distension.

Once successful passage of the catheter to the bladder has been achieved, the catheter is attached to a closed fluid/urine collection system .

Surgical Techniques

Prescrotal Urethrotomy

In most cases, urethral calculi are successfully hydropulsed to the urinary bladder allowing cystotomy and calculi removal as an elective procedure when the patient is able to undergo anesthesia and surgery safely. Urethrotomy is performed most often at the base of the os penis to remove obstructing calculi when hydropulsion fails to flush the calculi into the bladder. Alternatively, a scrotal urethrostomy may be performed as a permanent urinary diversion procedure, this procedure requires neutering the patient (see Scrotal urethrostomy).

To perform prescrotal urethrotomy, a skin incision is made from the base of the os penis to just cranial to the base of the scrotum (Figure 31-1A). Subcutaneous tissue is sharply incised permitting identification of the retractor penis muscle which overlies the purplish colored corpus spongiosum. The retractor penis muscle is mobilized and retracted laterally. The surgeon grasps the urethra between the thumb and forefinger and elevates the urethra from the incision, this maneuver decreases hemorrhage as the corpus spongiosum and urethra are longitudinally incised directly over the obstructing calculi with a number 15 scalpel blade (Figure 31-1B). All obstructing calculi are removed by flushing or grasping calculi with a mosquito hemostat. Removal of all calculi, and patency of the urethra, is assured by successful passage of a urinary catheter to the urinary bladder proximally and distally through the penile urethra.

Surgical closure of the urethrotomy may be performed or the urethra and skin incisions allowed to heal by second intention (Figure 31-1C). If the urethra has been damaged by catheterization or calculi second intention healing is recommended. Suture closure of the urethra with 4/0 monocryl or polydioxanone on a tapered needle with simple interrupted sutures will reduce hemorrhage postoperatively but requires increased operative time. Gentle tissue handling and meticulous technique are recommended to decrease the chance of postoperative urethral stricture formation. Care is taken to appose the mucosal edges precisely. The subcutaneous tissue and skin are closed routinely. An indwelling urinary catheter is not routinely placed whether suture closure or second intention healing is selected. The incidence of urethral stricture following suture closure or second intention healing of the urethra has not been reported in clinical patients but appears to be low when urethral tissue is healthy and well vascularized.

Postoperative Management

Urine output, hydration status, renal function and electrolyte concentrations are closely monitored for 24 to 48 hours postoperatively. Post-obstructive diuresis may cause dehydration and electrolyte abnormalities including hypokalemia. If suture closure is not performed the dog will urinate from the urethral incision for 10 to 14 days as the wound heals. Bleeding from

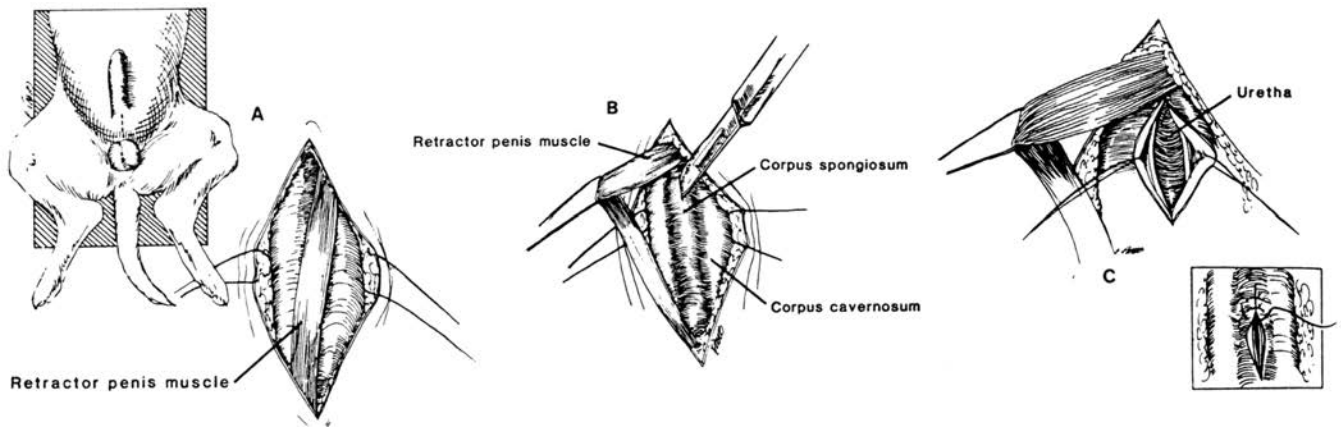


Figure 31-1. Prescrotal urethrotomy. **A.** Site of skin incision and dissection of subcutaneous tissue to the retractor penile muscle. **B.** Longitudinal incision into the corpus spongiosum and urethra after lateral retraction of the retractor penis muscle. **C.** Retention sutures in the corpus cavernosum and exposure of the urethral interior. After removal of uroliths, the urethrotomy can be left open or closed in a simple interrupted pattern (inset). (From Stone EA. Urologic surgery: an update. In: Breitschwerdt, EB, ed. Contemporary issues in small animal practice. Vol. 4. Nephrology and urology. New York: Churchill Livingstone, 1986.)

the urethra occurs concurrently with urination especially in the first few days following surgery if second intention healing is selected. Hemorrhage does not typically reach serious levels but does increase hospitalization time. Should stricture occur, scrotal urethrostomy is recommended.

Editor's Note: Laser lithotripsy of urethral calculi can be an effective mode of therapy for relieving obstruction without surgery. Cystoscopic capability and laser access are required.

Scrotal Urethrostomy

Daniel D. Smeak

Introduction

Scrotal urethrostomy is the procedure of choice in the canine when creation of a permanent urethral orifice distal to the pelvic urethra is necessary. Scrotal urethrostomy has several advantages over prescrotal, prepubic, or perineal urethrostomy. The membranous urethra in the region of the scrotum is larger and more distensible than the prescrotal urethra. These characteristics reduce the risk of stricture formation and calculi pass more readily through the stoma following urethrostomy. The urethra in the scrotal area is also more superficial and surrounded by less cavernous tissue than in the perineal region (Figure 31-2). Surgical exposure is easier, there is less tension on the urethrostomy, and the risk of hemorrhage or urine extravasation into periurethral tissues is reduced. Scrotal urethrostomy diverts urine directly downward and away from perineal skin. Skin surrounding the urethrostomy is kept dry and this reduces the risk of intractable dermatitis from urine scalding.[1] Most urethral calculi are readily removed from the distal urethra or flushed back to the bladder by scrotal urethrostomy. I do not recommend a urethrostomy in the prescrotal region since urine expelled from the stoma often becomes misdirected and tends to soil the skin of the scrotum, inguinal region, and medial thighs and this area tends to stricture more readily than urethrostomies performed in the scrotal region.[1,2] If castration is objectionable to the owner or the lesion is more proximal, however, other urethrostomy locations should be considered.[3,4]

Indications

Scrotal urethrostomy is indicated for the following conditions: (a) recurrent urethral calculi that are not responsive to appropriate medical therapy; (b) acute calculi obstruction in dogs anticipated having recurrent episodes (e.g., metabolic stone formers); (c) severe distal urethral wounds secondary to penile or os penis trauma; (d) urethral stricture distal to the scrotum from trauma or previous urethral surgery; and (e) diseases requiring amputation of the penis or prepuce and formation of a more proximal urethral stoma (e.g., extensive neoplasia in the region, penile strangulation, certain congenital diseases such as severe hypospadias, and deficiency in penile or preputial length).[1] Because a permanent stoma that bypasses the normal opening of the urethra may increase the risk of ascending urocystitis, a urethrostomy should not be performed unless due consideration is given to the indications and complications of the procedure.[5,6]

If both urethral and bladder calculi are found in dogs requiring scrotal urethrostomy, I prefer to perform the urethrostomy first. After the urethrostomy stoma is created, the surgeon can flush any remaining (more proximally located) calculi back into the bladder, and then perform a cystotomy. This allows both normograde and antegrade urethral irrigation during cystotomy to ensure that all urethral calculi have been removed. If the cystotomy is completed first, any urinary stones remaining in the proximal urethra often cannot be removed via the scrotal urethrostomy, and are then flushed back into the bladder during retrograde irrigation.

A modified urethrostomy technique is described here because the standard simple interrupted scrotal urethrostomy technique often results in unacceptable bleeding and bruising complications.[6] In a retrospective study of dogs undergoing standard scrotal urethrostomy, active hemorrhage (requiring patient hospitalization) was noted an average of 4.2 days following surgery; in some patients bleeding persisted up to 10 days.[6]

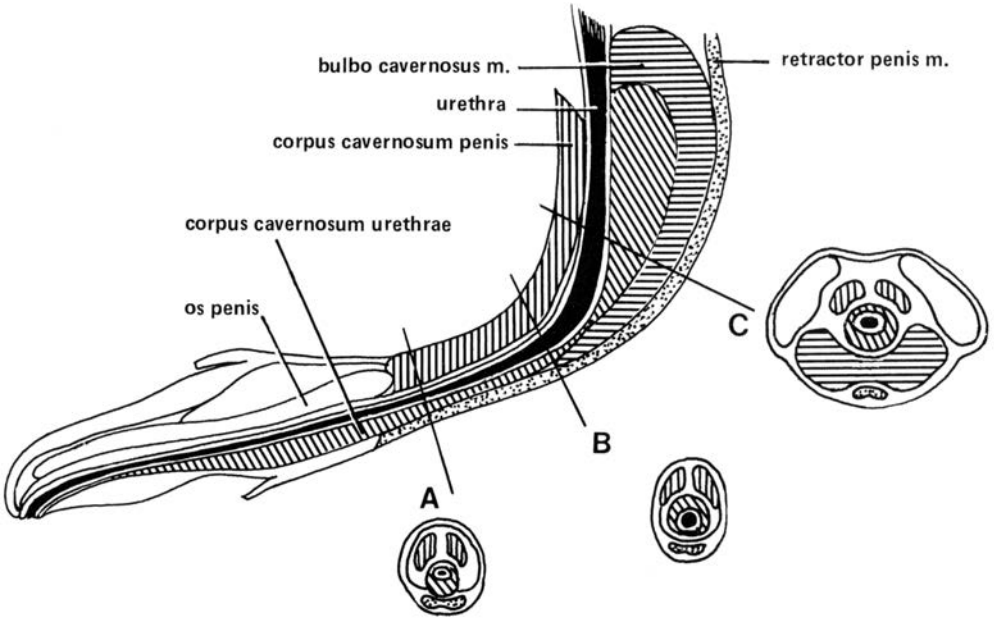


Figure 31-2. Schematic diagram showing cross sections of the penis and urethra in the prepubic *A.* scrotal *B.*, and perineal *C.* locations. The urethra in the prescrotal and scrotal area is more superficial and is surrounded by less cavernous tissue than the perineal area. The scrotal urethra is more distensible and larger in diameter than the prepubic urethra, allowing easier passage of calculi and reducing the risk of postoperative stricture formation.

The following modified scrotal urethrostomy technique uses a continuous suture pattern and a three-needle bite sequence for urethrostomy closure.[5] In my experience, this modification has dramatically reduced active bleeding, bleeding after urination, and bruising postoperatively. Furthermore, no stricture or suture line breakdown has been observed to date. This closure is also faster to perform.

The rationale for the modified technique is several fold. Simple continuous suture patterns produce a better seal by apposing tissues more completely. Continuous suture patterns require fewer knots, and irritation from "prickly" knot ears is reduced. Needle bites are placed closer together and this also improves urethra-to-skin apposition. *Incorporation of a bite of tunica albuginea adds additional strength to the incision line and helps seal incised cavernous edges* (see surgical technique). When the needle is passed outward from the urethra to skin, better apposition of cut surfaces results. All these advantages, I believe, help reduce suture line breakdown and hemorrhage.

Surgical Technique

The surgeon must obtain the owner's consent for the animal's castration before performing scrotal urethrostomy in intact dogs. Metabolic disturbances are stabilized in the obstructed patient preoperatively. I prefer to give an epidural administration of a narcotic to help alleviate pain in the immediate perioperative period. While the patient is under general anesthesia, the surgeon places the patient in dorsal recumbency with the rear limbs gently abducted and secured caudally. The proposed surgery site including the scrotum is clipped and scrubbed routinely and is draped for aseptic surgery. An elliptic full-thickness skin incision is made around the base of the scrotum. Hemostasis is maintained and the isolated scrotal skin is discarded (Figure 31-3). Enough skin should be left on the lateral aspect of the incision so no tension is placed on the urethrostomy during closure or with rear limb abduction. If there is any doubt, ample scrotal skin should be preserved and any redundant skin can be removed later in the procedure. If the dog is sexually intact, the testicles and spermatic cords are isolated and the dog is neutered in a routine manner (Figure 31-4). The underlying connective tissue is dissected to expose the paired retractor penis muscles, which appear as a thin brownish-tan band on the ventral surface of the penile shaft. The surgeon sharply dissects and mobilizes the retractor penis muscles, and

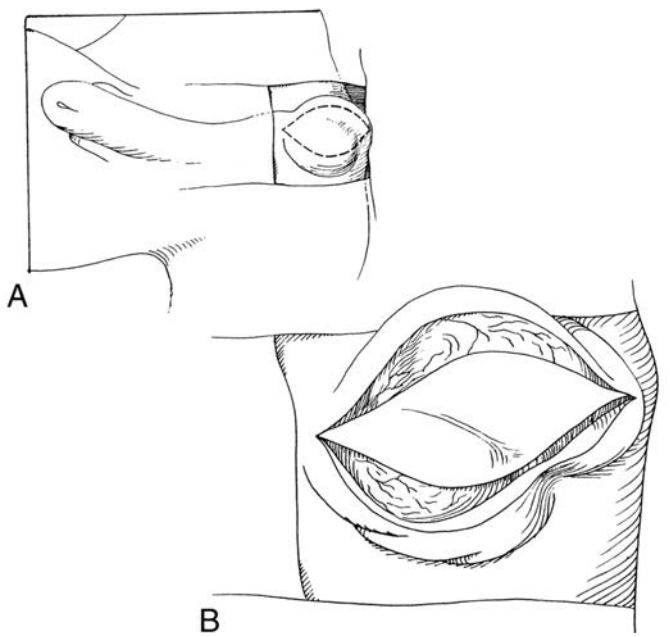


Figure 31-3. A. and **B.** An elliptical incision is made at the base of the scrotum. Enough lateral skin is retained to allow tension-free closure of the urethrostomy. Redundant skin can be resected later in the procedure.

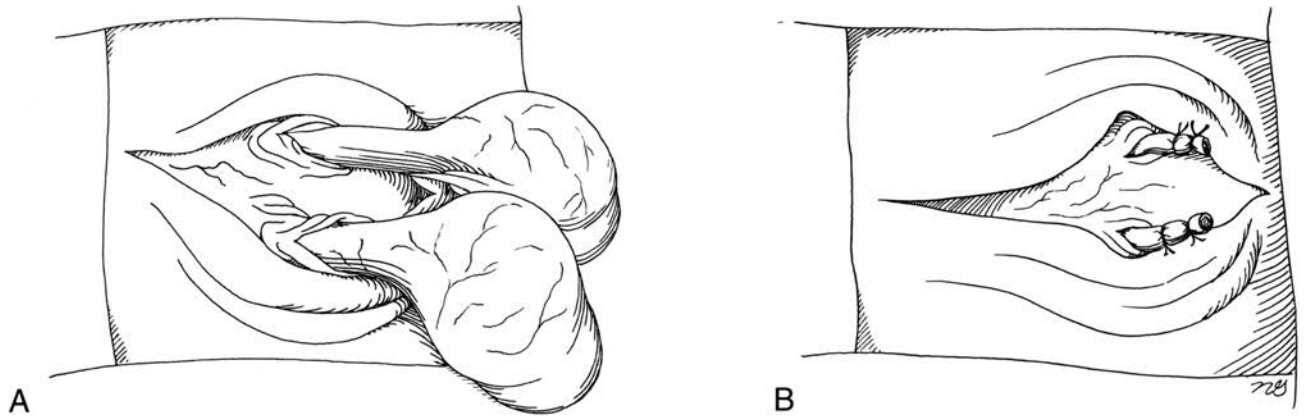


Figure 31-4. A and **B.** The isolated scrotal skin is removed, and castration is performed.

retracts them laterally to expose the bluish corpus spongiosum urethrae (Figure 31-5). An appropriately sized red rubber urinary catheter is inserted retrograde from the normal penile opening, if possible, to outline and distend the urethra. The ventral midline of the urethra is sharply incised over the catheter with a #15 Bard-Parker scalpel blade. If a catheter cannot be inserted, the incision must be made carefully to avoid accidental laceration of the dorsal urethral surface. Blunt tenotomy or iris scissors are used to enlarge the urethral incision to 2.5 to 4 cm in length (approximately five to eight times the diameter of the urethra) to ensure sufficient urethral lumen size after healing is complete. The incision length appears excessive at first but after complete healing of the urethrostomy, the opening is approximately 2/3 to 1/2 the original length. The surgeon should stay directly on midline with scissors to reduce intra-operative and postoperative hemorrhage from cavernous periurethral tissue. Intra-operative hemorrhage is controlled with direct digital pressure. Electrocoagulation should not be used in tissues in the immediate vicinity of the urethrostomy site. The caudal limit of the incision is chosen to ensure that the new urethral stoma will allow urine to be diverted directly ventral from the ischial arch (Figure 31-6). A monofilament, nonabsorbable suture material (size 4-0 or 5-0) is selected for the urethrostomy because this material incites little inflammatory response and has minimal tissue drag. A taper-cut swaged-on needle is preferred to reduce the size of the needle tract through the cavernous tissue.

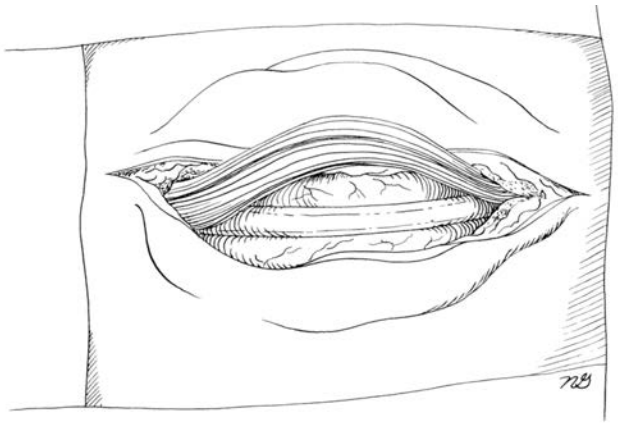


Figure 31-5. A urinary catheter is placed retrograde from the penile orifice to help to identify the urethra. The retractor penis muscles are retracted laterally and the ventral midline of the urethra is visalized.

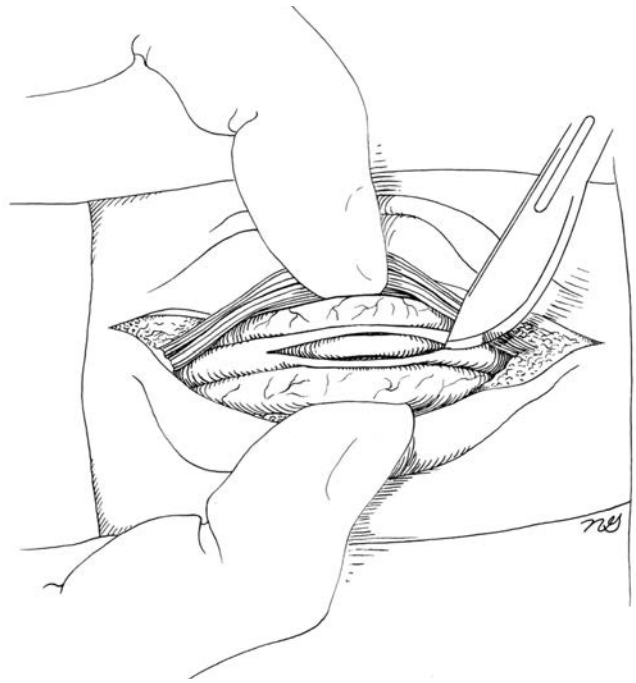


Figure 31-6. The ventral midline of the urethra is incised for 2.5 to 4 cm while immobilizing the penile shaft between the thumb and forefinger. The incision extends far enough caudally to ensure that direct ventral urine drainage can occur from the level of the ischial arch.

In addition, this needle can be inserted through the skin without difficulty and is less likely to cut friable urethral mucosa.

Sutures should appose the skin and urethral mucosa accurately, to avoid possible stricture formation. When excess tension is present, the surgeon should try to adduct the patient's rear limbs before attempting closure. A deep suture line should be placed from the subdermal layer to the tunica albuginea if additional tension relief is necessary before closure of the skin and urethra.

The needle is inserted in an outward direction from the urethral lumen to the skin for best apposition. The first suture is placed from the corner of the caudal urethral incision to the corner of the caudal skin incision. Each suture pass comprises three tissue bites. The sequence begins with a 2 mm bite of urethral mucosa. Next, the needle is passed through a 2 mm bite of

fibrous tunica albuginea and, finally a 2 to 3 mm split-thickness bite of skin (Figure 31-7). A simple continuous suture line is used, with tissue bites 2 to 3 mm apart beginning caudally and working cranially (Figure 31-8). The urethral mucosa and skin margins are grasped gently and only when necessary to avoid excessive inflammation, which can lead to dehiscence and stricture. The urethral mucosa and skin are approximated without gapping. The suture line should not be tight and each suture pass should have even tension. After the first side of the urethrostomy is closed, a separate simple continuous suture closure completes the new stoma. The surgeon should excise any redundant skin in the cranial aspect of the incision to create a cosmetic closure. If the cranial aspect of the skin incision extends beyond the urethral incision, it is closed with simple interrupted sutures.

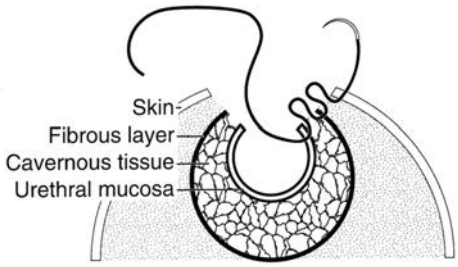


Figure 31-7. Three-needle bite sequence for closure of urethra to skin. The needle is inserted first through the urethral mucosa, followed by the tunica albuginea, and then a split-thickness bite of skin. The incised cavernous tissue is sealed between the urethral mucosa and tunica albuginea.

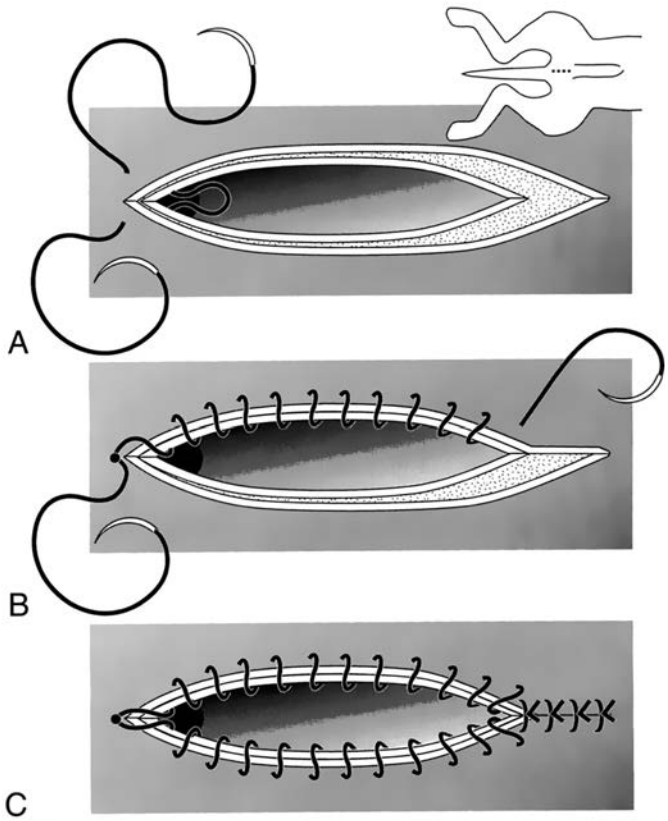


Figure 31-8. Suture the urethral mucosa to the skin beginning at the caudal aspect of the wound and continuing cranially. Place subsequent sutures in continuous fashion to complete one side of the urethrostomy. Another continuous line on the opposite side of the incision completes the procedure. Routinely close any remaining skin outside the urethrostomy.

Postoperative Considerations

Creation of a urethrostomy will not cure urinary tract infection or remove the source of urinary calculi. It can be expected that any procedure that shortens the functional length of the urethra such as urethrostomy, increases the risk of urinary tract infection.[3] Strict aseptic procedures should be adopted during stoma inspection and urethral catheterization to reduce this risk. Since the urethrostomy is located distal to the pelvic urethra (the area that controls urethral flow) there is no concern about creating incontinence following surgery. Owners should understand that urethrostomy reduces but does not completely eliminate the risk of urethral obstruction by calculi. If obstruction occurs, these patients are usually readily managed by catheterization and hydropropulsion of the calculi.

An Elizabethan collar or side body brace is placed on all dogs immediately after urethrostomy until healing is complete; or about 2 to 3 days after suture removal. The incision area is kept clean but blood clots are not removed unless they obstruct urine flow. A film of petrolatum jelly is applied to the skin around the urethrostomy site once or twice daily until postoperative swelling is reduced (3 to 5 days) to reduce urine scalding of surrounding skin. Topical anesthetic agents (5% Xylocaine ointment, Astra Pharmaceutical Prod., Inc., Westborough, MA 01581) can be applied to the exposed urethra if the patient is showing discomfort during urination. Minor bleeding can be treated with application of direct pressure over the urethrostomy site and cold compresses. On rare occasions, if bleeding from the stoma is profuse and localized, additional sutures may be placed in gaps between the urethra and skin. Sedatives can also be used to reduce bleeding if the patient is hyper-excitable. Exercise is strictly limited because any episodes of excitement, could lead to excessive hemorrhage from the urethrostomy, and to reduce motion and tension at the stoma to reduce the risk of dehiscence. Dogs are usually hospitalized for the first two days since owners are often concerned about mild postoperative hemorrhage that is usually present especially during and just after urination. Urine samples collected via cystocentesis should be cultured routinely after antibiotics are discontinued to determine if urinary tract infection is present. Urinary calculi are submitted for quantitative analysis and the patient treated with appropriate antibiotic, dietary, and medical therapy once calculus type is known. Urine voiding habits should be monitored indefinitely to identify early signs of obstruction or infection. Nonsteroidal anti-inflammatory drugs are used judiciously for 3 to 5 days after surgery to help reduce inflammation and pain.

Sutures are removed 10 to 12 days following the surgical procedure. Removal of a continuous suture line is more difficult than removal of simple interrupted sutures placed in the urethra. Migrating epithelium often partially covers exposed suture and sedation is necessary to remove sutures without causing pain and trauma.

Swollen, bruised, and painful areas of skin surrounding the urethrostomy may signal leakage of urine into the subcutaneous tissues. Placement of an indwelling soft urinary catheter is indicated in these dogs for three to five days, or until the edges of the urethrostomy are sealed. In general, catheters should be avoided because they increase the risk of urinary tract infection and may increase the risk of stricture. Dehiscence of the urethrostomy should be repaired primarily, without tension, using the materials and suturing techniques described previously if the tissues are healthy; otherwise allow the area is allowed to heal by second intention and either reconstruct the strictured stoma or divert urine through a more proximal urethrostomy site.

References

1. Smeak DD, Newton JD: Canine scrotal urethrostomy, *in* Bojrab MJ, ed.: Current Techniques in Small Animal Surgery (ed 4) Baltimore, MD: Williams & Wilkins, 1998, pp 465-468.

2. Bellah JR: Problems of the urethra: surgical approaches. *Prob Vet Med* 1:17-35, 1989.

3. Dean PW, Hedlund CS, Lewis DD, et al: Canine urethrotomy and urethrostomy. *Comp Contin Ed Pract Vet* 12:1541-1554, 1990.

4. Smeak DD: Urethrotomy and urethrostomy in the dog, *Clin Tech in Small Anim Prac* 15:25, 2000.

5. Newton JD, Smeak DD: Simple continuous closure of canine scrotal urethrostomy: results in 20 dogs. *J Am Anim Hosp Assoc* 32:531-534, 1996.

6. Bilbrey S, Birchard SJ, Smeak DD: Scrotal urethrostomy: a retrospective review of 38 dogs (1973-1988). *J Am Anim Hosp Assoc* 27:560-564, 1991.

Perineal Urethrostomy in the Cat

M. Joseph Bojrab and Gheorghe M. Constantinescu

Feline urologic syndrome (FUS), a synonym for lower urinary tract disease in the feline, can result from various single, multiple and interacting, or unrelated etiologic factors. Factors implicated in the development of FUS are infectious agents such as viruses and bacteria, diet, and urachal anomalies, especially bladder diverticula.

Crystalluria is a common clinical finding in cats and is characterized by microscopic precipitates in the urine. The most prevalent crystal type is struvite (magnesium ammonium phosphate). In normal cats, these crystals are passed in the urine during normal micturition. Urine from cats with FUS contains crystals that coalesce with a matrix of mucus and debris, to form a macroscopic semisolid mass, or concretion. Crystal formation is enhanced in an alkaline pH and is inhibited in a more acidic pH.

Urethral obstruction has been associated with concretions and urethral plugs. Other causes of urethral obstruction are strictures, lesions of the prostate gland, and extraluminal masses that compress the urethral lumen. Obstruction of the urethra by plugs occurs commonly in male cats but infrequently in females. The explanation for this difference resides in the anatomic differences in urethral structure between the sexes. The urethra in the male cat is long and narrow, whereas it is short and wide in the female.

Crystals composing a concretion have razor-sharp edges, which protrude from the concretion margins. In the male cat, at the root of the penis just proximal to the bulbourethral glands, the urethral lumen diameter narrows, creating a funnel effect. As a concretion passes down the urethra, it may become lodged at this point. Initially, the cat can usually force a concretion through the penile urethra by straining. This action, however, forces the sharp edges of the crystals into the urethral mucosa, resulting in multiple lacerations. This trauma results in hemorrhage, urethral inflammation, edema, and swelling, which decrease the urethral diameter even further. Passage of another concretion through the urethra results in an obstruction that cannot be dislodged by the animal. This situation requires emergency treatment to remove the urethral obstruction and reestablish urine flow.

Diagnosis

The diagnosis of FUS is based on history, clinical signs, and palpation of a large, firm, tense bladder. The history may include urination in unusual locations along with increased frequency in attempts to urinate. This increased frequency may be mistaken for tenesmus by the client. Frequent licking at the genital area and occasional hematuria may also be present. With progression of the condition, the cat may become depressed, listless, or comatose. Prolonged obstruction results in hyperkalemia, which can lead to cardiac irregularities and subsequent death.

Medical Treatment

The first step in emergency treatment of urethral obstruction is to relieve obstruction. This can be done by catheterization of the urethra, which in the severely depressed or comatose patient can be accomplished without the use of anesthetics. If attempts to dislodge the obstruction are likely to result in additional urethral damage or to induce urinary tract infection, pharmacologic restraint should be considered. An ultrashort acting anesthetic should be selected for sedation since the cat may have metabolic abnormalities. Anesthetics must be given cautiously, because effective doses in patients with postrenal azotemia tend to be lower than in animals with normal renal function.

To relieve the obstruction, concretions lodged in the distal penis are first milked out by gently rolling the penis between the thumb and forefinger. Additionally, massaging the urethra through the animal's rectum may help to dislodge abdominal or pelvic urethral concretions. Voiding is then induced by gentle urinary bladder palpation. If urethral massage and bladder expression fail to dislodge the obstruction, retrograde urethral flushing is attempted to dislodge the concretion into the bladder by hydropropulsion.

The penis is exposed, washed, and a 3.5-French open-ended tomcat catheter, lubricated with a sterile gel, is placed into the distal urethra. Once the catheter has been placed, the prepuce is grasped digitally and is retracted caudodorsally, so the urethra

is parallel to the vertebral column. A 12-mL syringe containing sterile saline or lactated Ringer's solution is then connected to the catheter by an assistant. Subsequently, fluid is forced through the catheter while the catheter is gently advanced; the catheter should remain parallel to the spine during this maneuver. This technique should force the concretion into the bladder. The catheter is then advanced into the bladder, which is then repeatedly flushed and emptied to remove as much debris as possible. This catheter is then removed and is replaced with a 5-French catheter cut to a length of 6 cm. This catheter is positioned so the tip is just past the root of the penis. This reduces the possibility of ascending cystitis. The catheter is sutured in place and is removed in 5 days. If urethral patency cannot be restored by this method, one should suspect a mural or periurethral lesion with or without an associated urethral plug.

Antibiotics are given for 30 days; three different drugs are used for 10 days each. The cat's diet is changed to Prescription Diet Feline Multicare (Hills Packing Company, Topeka, KS). This diet is low in magnesium and tends to acidify the urine, thus decreasing crystal formation. The food should be salted to increase fluid intake and to promote diuresis, to flush out urinary bacteria and precipitates. Instead of salting the food, the owner may administer a 1-g salt tablet orally once a day. If obstruction recurs, perineal urethrostomy is indicated.

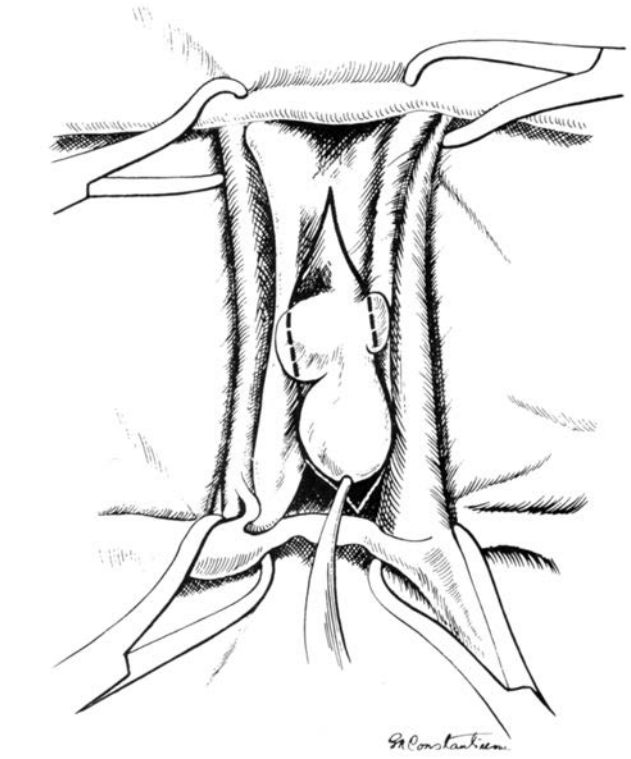


Figure 31-9. After the perineal area is draped and a urinary catheter is placed, an elliptic incision is made around the scrotum and prepuce.

Perineal Urethrostomy

Preoperative Considerations

Cats who have had urinary tract obstruction are poor anesthetic risks. Diuresis after unblocking is indicated. Induction of anesthesia with an ultrashort-acting anesthetic agent followed by maintenance with a gas anesthetic is recommended.

Surgical Technique

The animal is prepared for aseptic surgery. The hair is clipped from the entire perineal area including the base of the tail. A pursestring suture is placed in the anus, and a 3.5-French open-ended tomcat catheter is placed. The animal is positioned on the surgery table in ventral recumbency with the hind legs draped over the end of a titled table. The tail is taped over the dorsal midline of the back, and the genital area is draped.

An elliptic incision starting halfway between the anus and scrotum is made around the scrotum and prepuce (Figure 31-9). If the animal is sexually intact, castration is performed. After the penis with accompanying prepuce and remaining scrotum are retracted dorsally, ventral dissection is begun with Metzenbaum scissors (Figure 31-10). All preliminary dissection is done ventrally until the bilateral ischiocavernosus muscles are located and cut with scissors at their urethral attachments (Figure 31-11). This technique frees the penis and allows the visualization of a ventral penile fibrous band from the pelvic diaphragm located on the midline between the penis and the ischial arch. This structure is then cut, further freeing the penis.

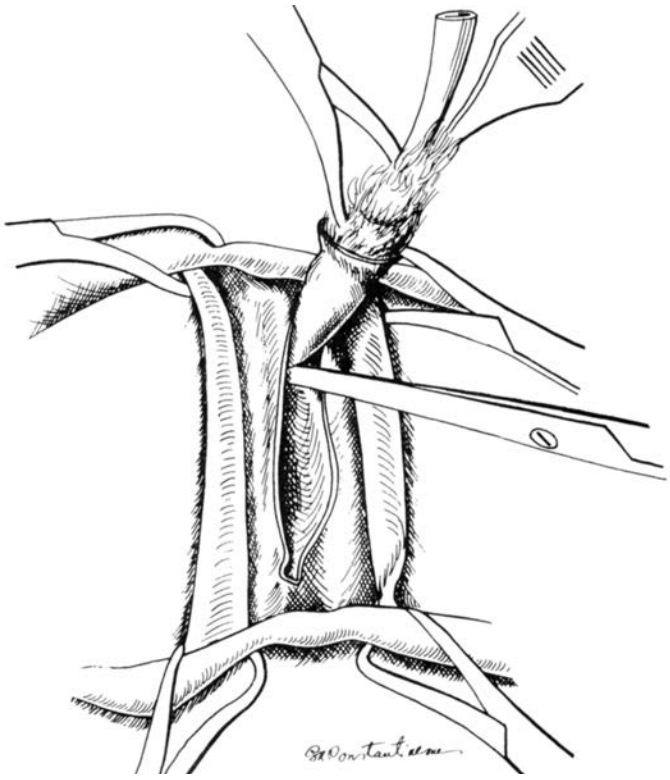


Figure 31-10. The penis and prepuce are retracted dorsally, and ventral dissection is begun.

At this point, dorsal dissection is begun. All dorsal dissection is accomplished close to the urethra. Metzenbaum scissors are

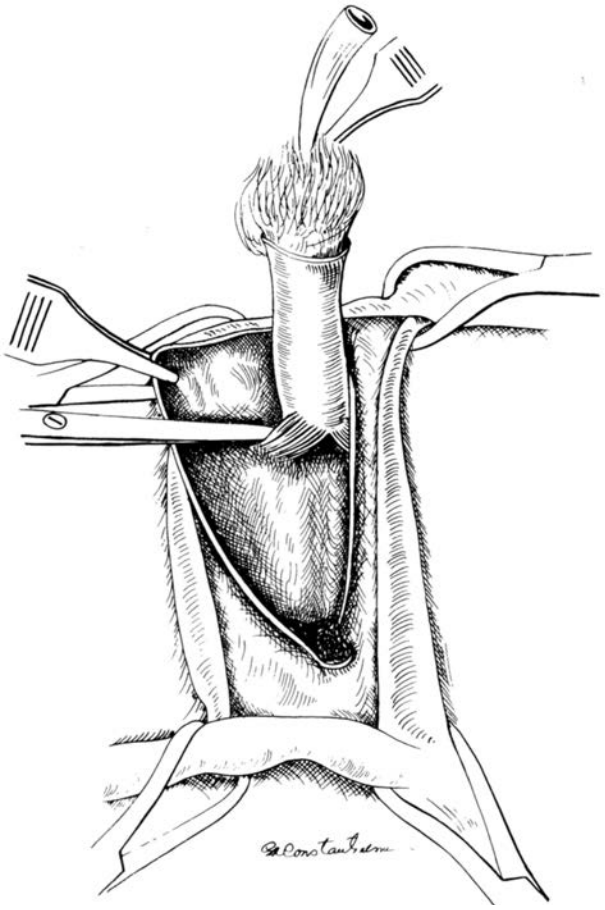


Figure 31-11. The ischiocavernosus muscle is identified and is cut with scissors close to the penile attachment.

used to cut and bluntly dissect the attachments circumferentially, further freeing the urethra and allowing it to be retracted caudally. The dorsal white V-shaped uterus masculinus is now visible and is cut close to the urethra (Figure 31-12). Care must be exercised during the entire dissection not to damage the rectum (dorsally) and the nerves that innervate the rectum and bladder neck. Such damage is avoided by keeping all dissection close to the urethra.

The dissected penis is grasped in the surgeon's left hand, with the index finger under the penile crus. A No. 10 scalpel is used to incise over the catheter on the dorsal midline of the urethra (Figure 31-13). The incision is carried into the lumen. The incision is extended 1 cm cranial and 2 cm caudal to the crus of the penis. Extension of the pelvic urethral incision more than 1cm cranial to the crus leads to severe incisional invagination when the incision is sutured. A 1-cm incision in the pelvic urethra is adequate to provide the enlarged opening needed. The catheter is removed, and forceps are inserted into the pelvic urethra (Figure 31-14). The incision is now ready for suturing.

We recommend using 4-0 polydioxanone or polypropylene (Ethicon, Inc., Somerville, NJ) with a swaged-on taper-cut needle for urethral suturing. The first suture is placed to approximate the most dorsal skin edges. The next suture, which begins the urethral suturing, picks up one skin edge and then passes through the dorsal roof of the urethra just cranial to the most cranial incision edge and then through the other skin edge (Figure 31-15A). When

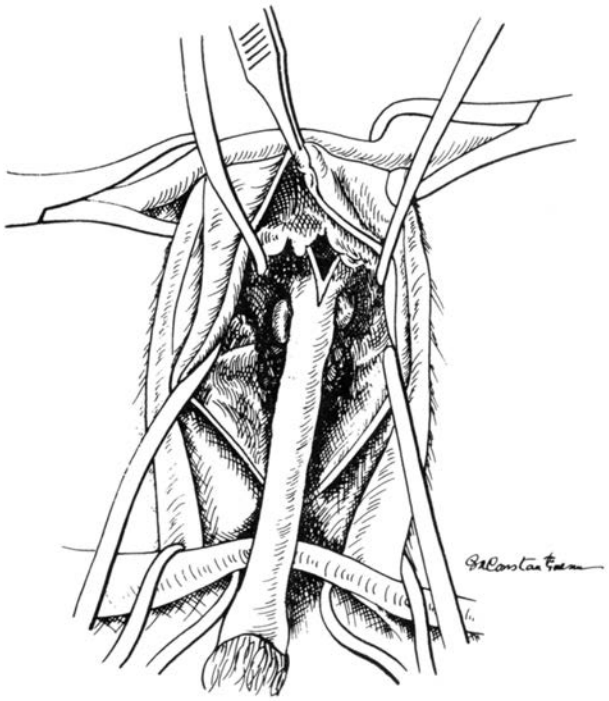


Figure 31-12. Urethral dissection is completed by transecting the V-shaped uterus masculinus close to the urethra.

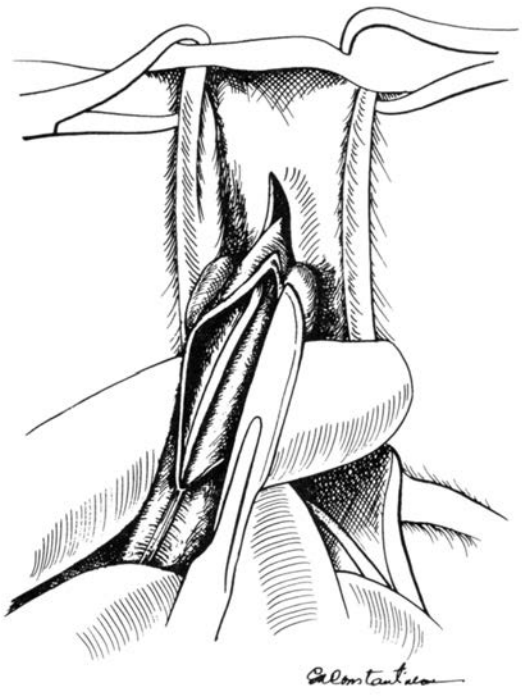


Figure 31-13. The urethra is incised into the lumen with a No. 10 scalpel.

this suture is tied, the roof of the urethra is pulled up to the skin edge, thus lifting the urethra to the surface. Suturing is continued down the skin incision on each side, including the cut edge of the urethral mucosa in each stitch (Figure 31-15B). It is important also to include the edge of the corpus spongiosum (corpus cavernosum urethrae) within these urethral edge stitches to help control hemorrhage from the cut edge of the corpus spongiosum.

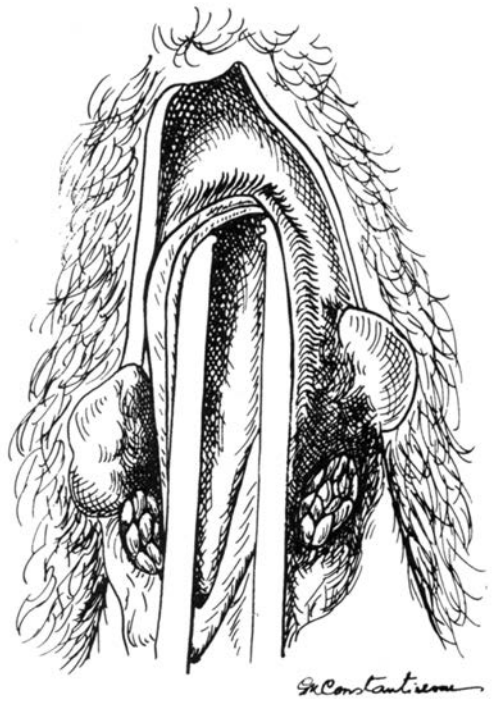


Figure 31-14. After the incision is completed, the catheter is removed, and forceps are inserted into the pelvic urethra.

After both sides of the skin incision have been sutured, the penis is cut off with scissors (Figure 31-16A) at the level of the caudal urethral incision. The cut end (Figure 31-16B) is sutured as shown in Figure 31-17. This helps to seal the cut end of the corpus cavernosum penis and eliminates much of the excessive postoperative hemorrhage often encountered with this surgical procedure. The final sutures are placed approximating the caudal skin edges (Figure 31-18). The wide end of the tomcat catheter is cut (approximately 2.5 cm), inserted into the new urethral opening, and sutured to the skin on each side (See Figure 31-18).

Postoperative Care

The pursestring suture in the anus is removed. An Elizabethan collar is placed on the cat to prevent licking of the incision. The same medical therapy as outlined previously is begun. The catheter is removed on the fifth postoperative day. The sutures and Elizabethan collar are removed on the tenth postoperative day.

The animal can be sent home during much of this postoperative period because urinary control is maintained even with the catheter, which is short and does not enter the bladder, in place. Owners must be instructed not to allow the cat to go outside while the sutures are still in place and to place shredded papers in the cat's litter box, so litter will not stick to, contaminate, and irritate the incision.

Complications

The major complications of perineal urethrostomy are postoperative hemorrhage, subcutaneous urine leakage, infections,

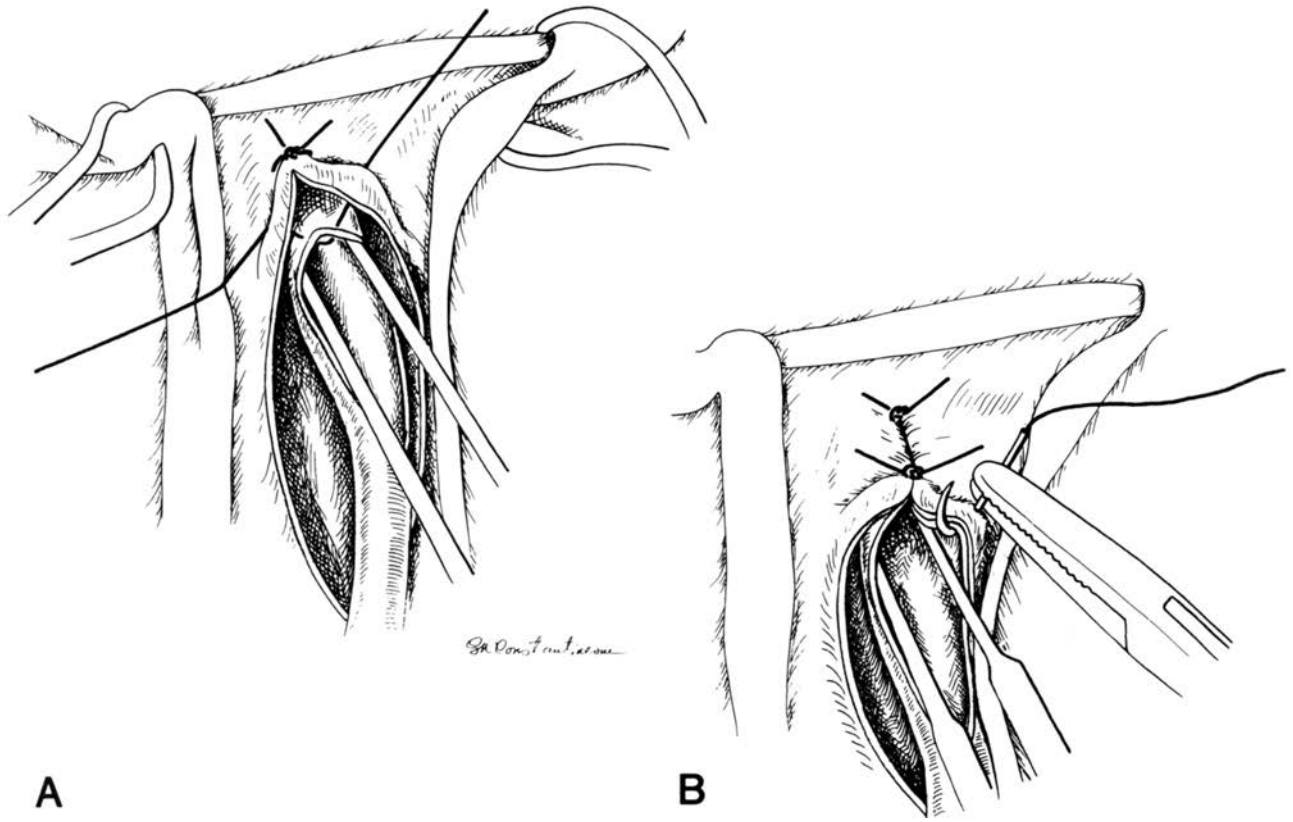


Figure 31-15. A. The first suture approximates the dorsal skin edges; then the first urethral suture is placed, engaging both skin edges and the pelvic urethral roof. **B.** Urethral suturing continues down the skin incision on each side.

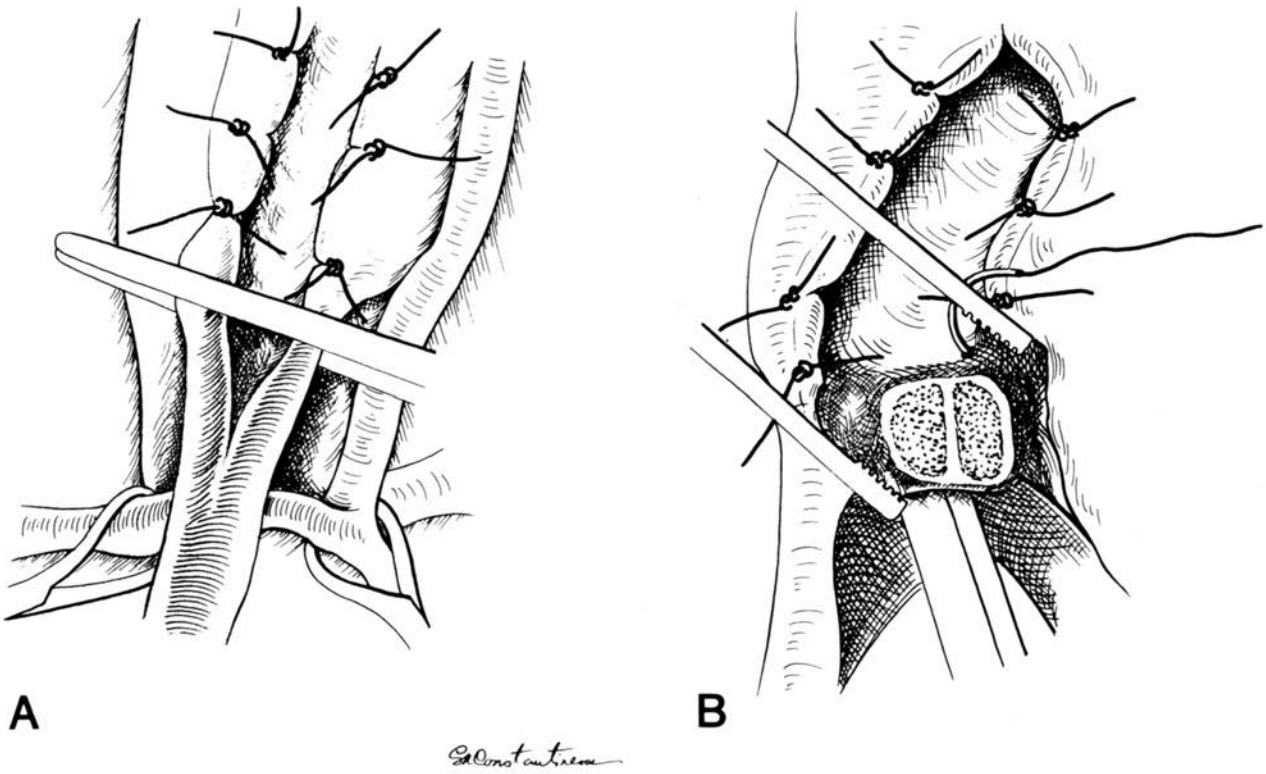


Figure 31-16. A. Excess penis is cut off with scissors at the level of the caudal incision. **B.** The cut end of the penis is shown, revealing the corpus cavernosum penis.

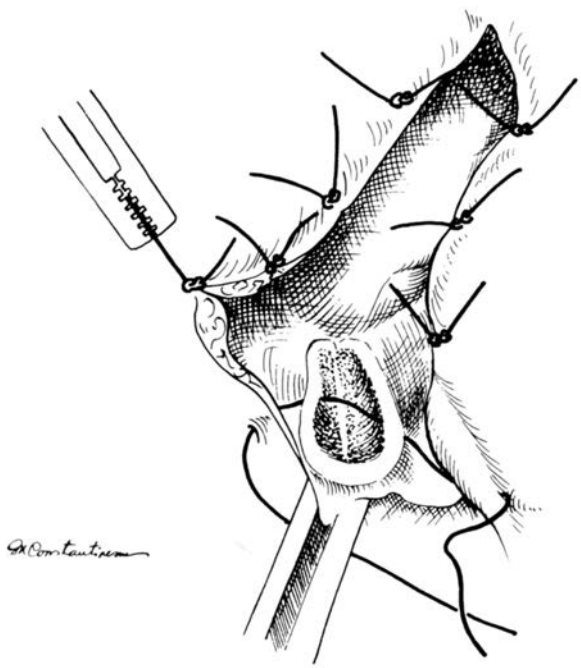


Figure 31-17. The exposed cut surface of the corpus cavernosum penis is sutured.

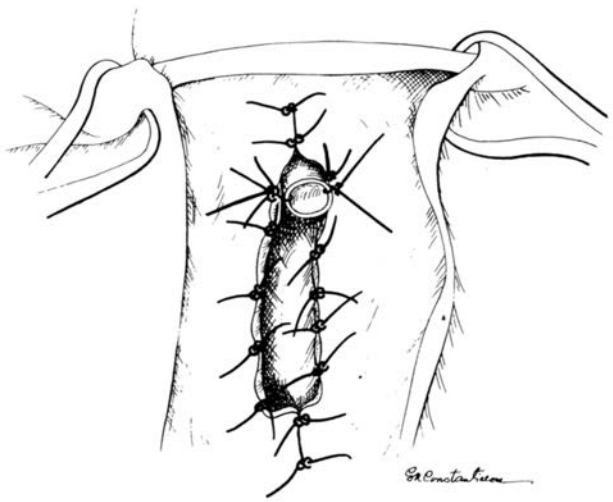


Figure 31-18. After suturing of the incision is completed, a 2.5-cm segment of catheter is sutured into the urethrostomy opening.

strictures, fecal and urinary incontinence, and rectal prolapse. Hemorrhage can be greatly reduced by taking care to include the cavernous tissue in the skin sutures. Infections can be decreased by eliminating postoperative contamination of the incision with litter and licking and by use of prophylactic antibiotics. Strictures can be prevented by adequate freeing of the urethra, to eliminate inpulling and suture line tension.

Urethroplasty for Stricture After Perineal Urethrostomy

Cats with urethrostomy stenosis present with stranguria producing only scanty urine and a palpably full bladder. If the stricture is due to improper dissection in the original surgical procedure (i.e., failure to transect ligaments and muscle attachments and free the urethra) or to failure to open the urethra properly, then the operation should be redone. If the original urethrostomy was done properly and a stricture subsequently occurred, a urethroplasty is performed.

The area around the stricture is clipped and prepared for surgery. The opening is located. The surgeon should use a 10X loupe to aid in visualization during surgery. A procedure similar to that for anal stricture (See Chapter 20) is used. Four cuts (dorsal, ventral, left lateral, and right lateral) are made with a No. 15 scalpel. Each cut incises the skin and underlying urethral mucosa. As each cut is made, the incisions open and form a diamond shape. The incisions are then sutured with 5-0 polydioxanone in the opposite direction in a manner similar to that shown in Figures 20-41 through 20-45. This technique alleviates the stricture.

Prepubic Urethrostomy in the Cat

Richard A. S. White

Surgical Anatomy

The unique anatomy of the cat's urinary bladder neck and proximal urethra allows the feline urethra to be sectioned and urethrostomy performed at the prepubic level whilst preserving urinary continence. In male cats, the bladder is situated considerably more rostrally to the pelvic brim than in other domestic species; the trigonal region gives rise to an elongated bladder neck, often erroneously regarded as the preprostatic urethra, that reaches the pubic level before differentiating into the urethra proper. The urethral sphincter mechanism is located immediately distal to the trigone and hence section of the urinary conducting system at the junction of bladder neck and urethra, can be expected to preserve normal urinary continence. The combination of this relatively long bladder neck and the absence of a prostate gland encircling the urethra facilitates the creation of a urethral stoma at the posterior abdomen / prepubic level in the cat.

Indications

Indications for prepubic urethrostomy (PPU) include conditions that result in persisting urethral obstruction distal to the pelvic level. In contrast with the more common but increasingly controversial indications for perineal urethrostomy (PU), the indications for PPU are more easily recognized despite being less frequently indicated. Conditions in which distal urethral function is lost include salvage of perineal urethrostomy (PU) complications, management of cats with perineal skin deficits that preclude PU, complex urethral ruptures and strictures, granulomatous urethritis and neoplastic disease. Paradoxically, PPU requires considerably less surgical expertise and experience than PU and is easier to perform and this occasionally leads to its inappropriate substitution for PU.

The potential risks and complications of PPU are probably less frequently encountered than those associated with PU, however, the procedure should only be performed when all medical strategies have been exhausted and where PU is not considered to be a feasible option.

Preoperative Preparation

The more common indications for this procedure may be associated with some risk of urinary tract infection or bacteruria and hence perioperative antibiotic therapy based on urine culture from a sample obained by cystocentesis is usually appropriate. An opioid analgesic that can be continued into the postoperative period (e.g. buprenorphine) should be administered, and if renal function is normal, non-steroidal anti-inflammatory therapy may be appropriate to provide additional analgesia. The patient should be positioned in dorsal recumbency and the ventral abdomen including the pubic region should be aseptically prepared for surgery. Urethral catheterization is helpful but often not possible due to the obstructing indication; the absence of a urethral catheter should not unduly hinder the procedure.

Surgical Technique

A short caudal ventral midline incision is created immediately rostral to the pubic brim and a small pair of Gelpi retractors inserted to improve abdominal exposure. The bladder neck/urethra is identified and gently freed from the surrounding periurethral adipose tissue as far distally as possible into the pelvic region (Figure 31-19). Care should be taken to avoid damage to the pelvic nerves located in the bladder neck area. The urethra is elevated using moistened umbilical tape or large hemostats (Figure 31-20) and then sectioned as far distally as possible; any bleeding from the distal urethra may be controlled by ligation or thermocautery. A catheter may be inserted into the proximal urethra at this stage to facilitate identification of the urethral lumen. The urethral stoma may be positioned in either a midline or a paramedian position. For the former option, the urethral opening is exteriorized through the laparotomy wound and the linea alba closed routinely proximal and distal to it, avoiding constriction of the urethra (Figure 31-21). Alternatively, the urethra can be drawn through a separate paramedian stab incision and the linea alba closed routinely. The subcutaneous dead space is closed with absorbable suture and the urethral stoma anchored to the skin with four simple interrupted (4/0 or 5/0) monofilament sutures (Figure 31-22). The urethral opening may be spatulated to increase the diameter of the opening and facilitate creation of the stoma if necessary.



Figure 31-19. Isolation of bladder neck/prepubic urethra via posterior laparotomy.

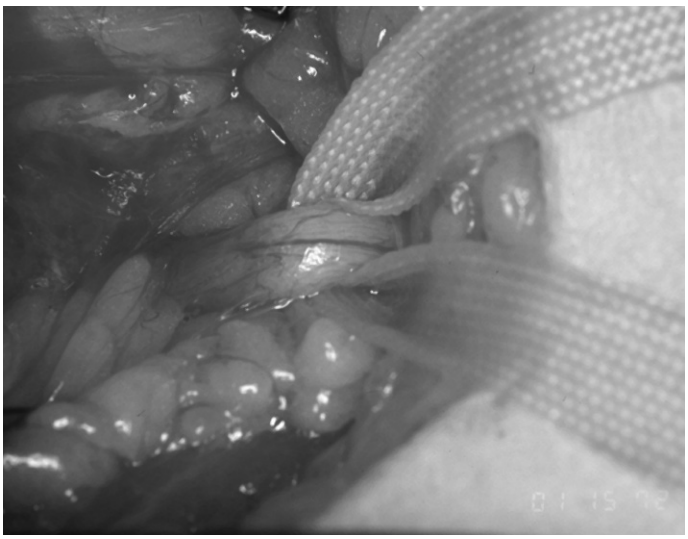


Figure 31-20. Elevation of bladder neck / prepubic urethra with umbilical tape.



Figure 31-21. Repair of linea alba allowing exteriorization of urethra.

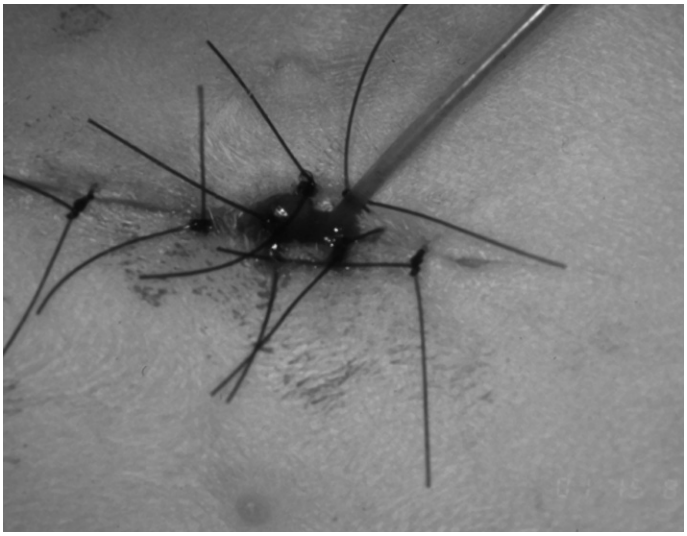


Figure 31-22. Urethral stoma created by suturing to surrounding skin.

Postoperative Care

Patients normally benefit from receiving opioid analgesia for 48 hours and should be prevented from self-trauma by means of an Elizabethan collar. Litter trays with shredded paper instead of litter are provided to minimize the potential for debris adhering to the stoma site. Depending on the original indication for the procedure, it may be necessary to initiate management of underlying pre-existing lower urinary tract disease. Patients will need to modify their squatting posture for urination somewhat and the interval until this is successfully accomplished will vary between individuals. In the intervening period, any urine-staining or scalding of the skin in the inguinal region should be carefully managed to prevent secondary pyoderma complicating the healing of the urethral stoma. Urinary retention due to discomfort and pre-existing lower urinary tract disease should be managed with analgesia, striated muscle relaxants (e.g. diazepam) or smooth muscle relaxants (e.g. phenoxybenzamine); repeated catheterization of the urethra is avoided if possible.

Complications

Healing of the stoma is usually uncomplicated but, as with any urethrostomy procedure site, leakage of urine into the subcutaneous tissues surrounding the stoma before an effective seal has formed may lead to peristomal skin irritation and in severe cases, incisional dehiscence postoperatively. More chronic urine leakage can promote low-grade periurethral cellulitis which can lead to stenosis and stricture of the stoma; revision of stenosis may be complex. Stricture of the stoma occasionally occurs but the overall incidence is low. Occasionally, peristomal cellulitis can spontaneously occur in long-term PPU patients although the etiology for this is uncertain. Temporary urinary diversion by urethral catheterization or in some cases by tube cystostomy allows the cellulitis to resolve and patients will resume normal continent urination. Cutaneous urine scalding can be a transient problem in cats that do not modify their urination stance. Cranial transplantation of the prepuce with the stoma located inside or subpubic urethrostomy have been recommended to avoid this complication. These are more complex procedures and not usually necessary. Transient urinary incontinence may

occur in some cats in the immediate postoperative period but usually resolves as the stoma heals. Some cats with pre-existing lower urinary tract disease may continue to be dysuric postoperatively which can be mistaken for incontinence; appropriate management of lower urinary tract disease should be initiated.

Conclusion

PPU is an acceptable surgical procedure for the management of cats where distal urethral function has been lost. The procedure is comparatively easy to perform and does not necessitate complex or prolonged postoperative care. Cats remain continent and most accommodate quickly to the change in posture necessary for urination without inguinal skin scalding. They will continue to lead a normal life. PPU should however be regarded as a salvage procedure and not substituted where medical management or PU would be a more appropriate operation.

Editor's Note: Urinary incontinence may occur postoperatively in cats that have had PPU.

Suggested Readings

McCully RM: Antepubic urethrostomy for the relief of recurrent urethral obstruction in the male cat. JAm Vet Med Assoc 126: 173-179, 1955.

Ford DC: Antepubic urethrostomy in the male cat. JAm Anim Hosp Assoc 4: 145-149, 1968.

Mendham JH: A description and evaluation of antepubic urethrostomy in the male cat. J small Anim Pract 11: 709-721, 1970.

Snow HN: Surgical transpositions of the feline urethra necessary to ameliorate urolithiasis. J small Anim Pract 13: 193-200, 1972.

Emms SG: Antepubic urethrostomy in a cat. Aust Vet J64: 384-385, 1987.McLaren IG: Prepubic urethrostomy involving transposition of the prepuce in the cat. Vet Rec 122: 363, 1988.

Bradley RL: Prepubic urethrostomy: An acceptable urinary diversion technique. Prob Vet Med 1: 122-127, 1989.

Menrath V: Repair of a mid-pelvic urethral rupture in the cat using antepubic urethrostomy. Feline Pract 121: 8 ó 11, 1993.

Mahler S, Guillo JY: Antepubic urethrostomy in three cats and a dog: Surgical technique and long-term results. Rev de Med Vet 150: 357-362, 1999.

Baines SJ, Rennie S and White, RAS: Prepubic Urethrostomy: A long-term study in 16 cats. Vet Surg 30: 107-113, 2001.

Ellison GW, Lewis DD and Boren FC: Subpubic urethrostomy to salvage a failed perineal urethrostomy in a cat. Comp Cont Ed 11: 946-951, 1989.

Management of Urethral Trauma

Jamie R. Bellah

Introduction

Blunt abdominal trauma and traumatic displacement of bone fragments, especially pubic fragments, can lacerate the membranous urethra.[1] Urethral injuries from other sources are less common but include gunshots, bite wounds, and iatrogenic trauma. The pelvic urethra may also be entrapped between pelvic fragments or mechanically compressed after elective pelvic surgery.[2,3] Absence of skeletal injury does not preclude urethral damage. Traumatic urethral injury usually occurs in male dogs because the postprostatic pelvic urethra is fixed at the greater ischiatic notch. The incidence of urethral injury after car accidents is reported to vary from less than 5% to 11%.[4]

Diagnosis

Urethral injury is suspected when dysuria or anuria is observed. Hemorrhage from the urethral opening or hematuria, usually at the first portion of the urine stream, may be noted soon after injury. Urethral trauma is not excluded on the basis of an animal's ability to void urine, however. Animals with urethral rupture may be depressed and anorexic, and penile urethral urine leakage may cause pyrexia and perineal or inguinal bruising and swelling. Uremia may or may not be present. A distended urinary bladder may be palpable. Proximal urethral lacerations or rupture may result in uroperitoneum, and clinical signs mimic those of a ruptured urinary bladder. Urine leakage may he detected from open wounds in the region of the pelvic cavity. If urine leakage is chronic a cutaneous urine fistula may result.[4] Suspicion of urethral injury should be evaluated initially by positive-contrast urethrography using a water-soluble organic iodide preparation. Injection of air is avoided because it is difficult to delineate the site of urethral injury after air dissects periurethrally, and also because the use of air as the distending gas can result in fatal air embolism.[5] Extravasation of contrast material occurs with both urethral laceration and urethral rupture, but in the latter instance, contrast material usually does not pass proximal to the complete tear. Cystoscopic examination may be used for evaluation of the lower urinary tract.[6] Animals with proximal urethral trauma should also be evaluated by intravenous pyelography because concomitant ureteral injury may be present.

Surgical Techniques

Management of urethral injuries depends on the type of injury sustained and on the overall health of the animal. Uroperitoneum and its systemic metabolic effects must be resolved before lengthy surgical intervention. If uroperitoneum is present, its effects are resolved by urine diversion and intravenous fluid therapy to alleviate dehydration, acidemia, and hyperkalemia. Gentle catheterization of the urethra may be accomplished, depending on the site of the urethral laceration, but often the catheter tip finds the urethral defect and cannot be passed successfully. Urine can be diverted by percutaneous placement of a prepubic drainage catheter (Stamey catheter) or by insertion of a cystostomy tube (Foley or Pezzar catheter). Both techniques require sedation and (narcoleptic) local anesthesia unless the animal is moribund. Abdominal drainage may be necessary if more proximal urinary tract injury does not allow urine diversion by the aforementioned techniques.

Definitive surgical treatment of urethral injuries requires careful preparation because often the site of injury is difficult to access (postprostatic rupture). Lacerations may be managed solely by urethral stenting if a catheter can be successfully manipulated into the urinary bladder, and it may need to remain in place for 7 to 10 days. Conservative treatment of urethral injury requires that longitudinal mucosal continuity across the region of urethral

trauma be present for successful urothelial repair. Despite the ability of urothelium to migrate, larger urethral defects require stenting for as long as three weeks for complete repair.[7] Surgical correction of urethral rupture often requires pubic osteotomy to expose the severed urethra adequately. Sufficient exposure so debridement and precise anatomic anastomosis are feasible cannot be overly stressed.[7] After debridement, simple interrupted sutures of absorbable material are used to perform the anastomosis over a urethral stent (catheter), with the knots outside the lumen of the urethra (Figure 31-23). The urethral mucosa must be anatomically apposed (without tension) or granulation tissue will be produced and contract the anastomosis, resulting in stricture despite the presence of a stent. Use of a catheter stent in addition to accurate suturing is believed to help prevent urethral stricture, however, overstretching the urethra may enhance fibrous tissue formation.[8] Monofilament absorbable suture material such as polydioxanone (PDS), polyglyconate (Maxon), and poliglecaprone (Monocryl) are appropriate for urethral anastomosis. Interrupted appositional sutures are recommended and continuous patterns are avoided as the latter tends to "purse-string" the urethral lumen. Fine nonabsorbable monofilament sutures such as nylon and polypropylene may be used for urethral apposition, but because the sutures remain long after tissue healing is complete, they are not desirable.[9] Urine diversion may be accomplished by placing a cystostomy tube (if necessary), and the urethral stent (catheter) remains to support the anastomosis and to divert urine away from the urethral wound to promote normal wound healing. The urethral stent should be large enough to maintain lumen size, but it should not be so large that it causes excessive pressure or tension on the anastomosis. If a large segment of pelvic urethra must be debrided, a permanent urine diversion procedure may be required. Antepubic urethrostomy or extrapelvic urethral anastomosis may be performed in those cases.

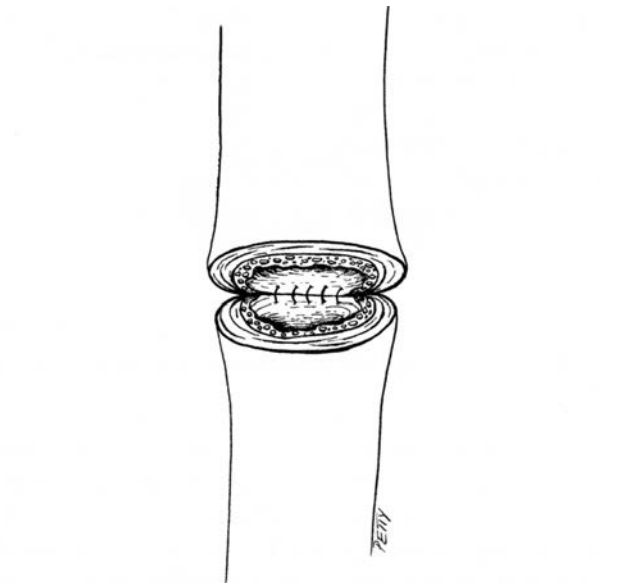


Figure 31-23. Anastomosis of the urethra requires accurate apposition of the urethral mucosa. Failure to do so results in stricture and dysuria.

Postoperative Care

Postoperative management of patients with urethral trauma and obstruction is intensive. Management of pain is often required for 12 to 24 hours. Animals must be restrained from prematurely removing urethral stents and cystostomy tubes. Restraint must be adequate, and may require Elizabethan collars, side braces, wire muzzles, and in some instances tranquilization. Prolonged catheterization (4 days or longer) often results in urinary tract infection, and periodic culture and susceptibility screening are important to avert a serious ascending infection. Proper use and care of closed urine drainage systems are mandatory. When urethral stents are removed, urine culture and susceptibility testing are done and antimicrobial therapy is based on those results.

Urethral stents (catheters) may be pulled when urothelium has bridged the urethral defect, as early as 5 days after repair. Careful injection of contrast material at low pressure is performed when contrast urethrograms are repeated, so the urethral wound is not disrupted. Difficult anastomoses, when repair is tenuous (or unsutured defects), may require urethral stenting for as long as 14 to 21 days.

The most common complication of urethral trauma repair is stricture. Stricture may occur early, resulting from dehiscence of the anastomosis, or a technically poor repair (tension or inadequate mucosal apposition), with a fibrous scar that may partially or completely occlude the urethral lumen. Stricture may also occur months after surgery or conservative management if contraction of periurethral scar tissue results in stenosis of the urethral lumen. Correction of urethral stricture may require resection and anastomosis or a urinary diversion procedure, however balloon dilatation of a urethral stricture in a dog has been reported. Strictures involving the more distal aspects of the urethra may be resolved by performing scrotal urethrostomy.

References

1. Bellah JR. Problems of the urethra. Probl Vet Med 1989:1;17.

2. Remedios AM, Fries CL: Implant complications in 20 triple pelvic osteotomies. Vet Comp Orthop Traumatol 6:202,1993.

3. Messmer M, Rytz U, Spreng D. Urethral entrapment following pelvic fracture fixation in a dog. J Small Anim Pract. 2001;42(7):341-4.

4. Bjorling DE. Urethral trauma. Slatter's Textbook of Small Animal Surgery, 3rd Edition. WB Saunders Co, Philadelphia. 2003:1647-1651.

5. Ackerman N, et al: Fatal air embolism associated with pneumourethrography and pneumocystograpy in a dog. J Am Vet Med Assoc 176:1616, 1972.

6. Messer JS, Chew DJ, McLoughlin MA. Cystocopy: Techniques and clinical applications. Clin Tech Small Anim Pract 2005;20:52-64.

7. Boothe HW. Managing traumatic urethral injuries. Clin Tech Small Anim Pract. 2000;15(1):35-39.

8. Layton CE, Gerguson HR, Cook JE, Guffy MM. Intrapelvic urethral anastomosis – a comparison of three techniques. Vet Surg 1987;16:175-182.

9. Jens B, Bjorling DE. Suture selection of lower urinary tract surgery in small animals. Comp Cont Educ Small/Exotics 2001;23:524-528.

Urethral Prolapse in Dogs

John A. Kirsch and J.G. Hauptman

Introduction

Urethral prolapse is an uncommon condition in the dog, and is most often seen in young male English Bulldogs.[1,2] It has not been reported in female dogs. Urethral prolapse typically appears as a red to purple mass protruding from the orifice of the urethra. Clinical signs of urethral prolapse in the dog include excessive licking of the prepuce, preputial bleeding, and stranguria. Suspected causes of urethral prolapse in the dog include excessive sexual excitement, masturbation, and genitourinary infections or calculi.[3,4] Its strong breed relation has also led to speculation that it occurs as a result of increased abdominal pressure secondary to chronic upper airway obstruction in brachycephalic breeds.[1] This theory is consistent with the condition in humans, where it is proposed that there is poor attachment between muscle layers of the urethra associated with episodic increases in abdominal pressure.[5] The strong breed association suggests a genetic predisposition. Differential diagnoses of urethral prolapse in the dog include trauma, urethritis, and neoplasia, particularly transmissible venereal tumor. Current described techniques for surgical treatment of urethral prolapse include manual reduction of prolapsed mucosa and placement of a temporary purse-string suture at the penile tip, which must be removed in five days,[3,4] urethropexy,[6] or resection of the prolapsed tissue and apposition of urethral and penile mucosa.[1-4] Common post-operative complications associated with surgery are swelling and hemorrhage at the surgical site. The incidence of recurrence based on technique is unknown, although we have observed recurrence after all described techniques; subjectively, the catheter reduction and purse-string technique is the least likely to result in permanent correction. Treatment decisions for urethral prolapse should be made based on the following factors: 1) viability of prolapsed tissue, 2) history of recurrence in the patient, and, 3) which procedure, if any, has been performed prior to presentation for the current episode. Non-viable or severely traumatized urethral tissue is an indication for resection of prolapsed tissue.

Preoperative Care

Every effort should be made to rule-out underlying genitourinary disease. Radiographs, with or without contrast, may be performed to evaluate for calculi. Catheterization is helpful to assess patency of the urethral lumen. A rectal exam should be performed to evaluate the prostate and pelvic urethra. Urinalysis and urine culture are performed to rule-out underlying disease and infection. Castration should be discussed with the owner prior to surgery, since the procedure can be performed at the time of prolapse correction, and due to the purported connection of urethral prolapse to sexual excitement.

Surgical Techniques

Clipping the prepuce may not be recommended, as it may contribute to postoperative irritation. Prior to surgery, the prepuce is flushed with a dilute povidone iodine solution. Elective castration should be performed prior to correction of urethral prolapse, as it is the more sterile of the two procedures. The penis is manually extended from the prepuce and maintained in this position either by an assistant or by a Penrose drain tourniquet placed around its base (Figure 31-24). Extreme care should be taken with all techniques to employ gentle tissue handling and accurate suture placement, which will maximize success and minimize postoperative morbidity.

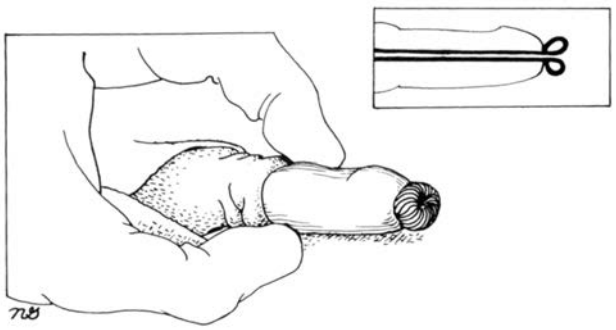


Figure 31-24. Extended penis with urethral prolapse.

Purse-string

A catheter or grooved director is used to reduce the urethral prolapse, and a purse-string suture is placed at the urethral orifice. The suture is tightened just enough the maintain mucosal reduction upon removal of the catheter. Care must be taken to ensure an adequate opening, as some localized swelling is expected following suture placement. If urethral patency is in question, one should elect a different corrective procedure.

Urethropexy

A lubricated grooved director is introduced into the urethral orifice, reducing the prolapsed urethral mucosa (Figure 31-25B). The director should be passed beyond the distal aspect of the os penis. If this fails to achieve reduction of all urethral mucosa, an assistant can grasp the penis at its tip and apply distal traction to invert the mucosa. Monofilament, 2-0 or 3-0, absorbable or nonabsorbable suture on the largest radius swaged-on tapered needle available is passed full thickness through the penis from the external surface, as far proximally as the needle curvature will allow, to the intraluminal surface directing the needle distally out the urethral orifice (Figure 31-25C). The grooved director is used as a receiving surface for the needle to prevent penetration of the opposite wall of the urethral lumen. The needle is then passed, in reverse fashion, from the urethral lumen to the external surface of the penis exiting just distal to the initial needle entry site (Figure 31-25D). The resulting full thickness suture is tied snugly with four throws, the initial throw being a surgeon's throw (Figure 31-25E). This technique is repeated until three equally spaced sutures are placed. The grooved director can be removed/rotated between sutures. Following suture placement, an 8-10 French red rubber catheter is passed to confirm patency of the urethra. Sutures are not removed.

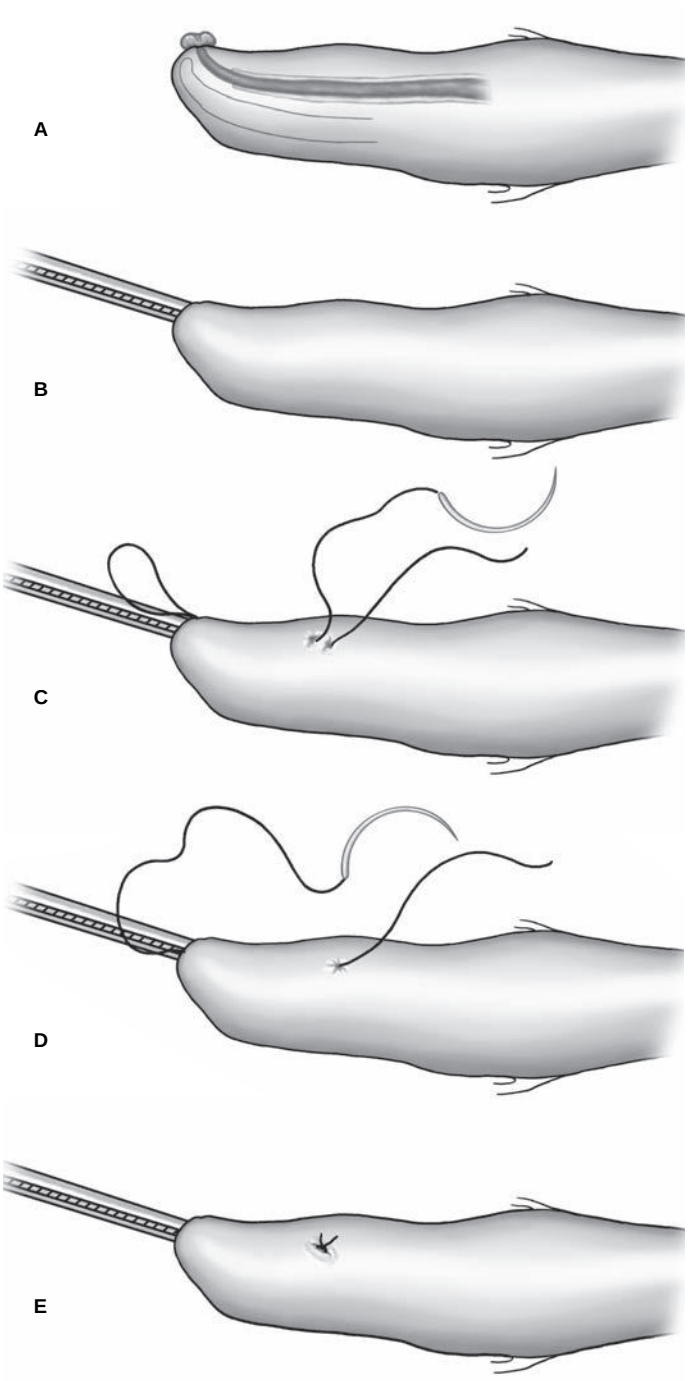


Figure 31-25. Urethropexy technique for treatment of urethral prolapse in the dog. **A.** Prolapsed mucosa visible at distal tip of penis, **B.** introduction of grooved director into urethral lumen to reduce prolapsed mucosa, **C.** first suture pass is external-to-internal, exiting urethral orifice, **D.** second suture pass from internal to external, exiting just distal to initial suture entry point, **E.** resulting full thickness suture is tied snugly. Process is repeated until reduction is maintained. All diagrams represent patient in dorsal recumbency.

Resection

A sterile catheter is placed in the urethra. An incision is made 90 to 180° at the base of the prolapsed tissue, resulting in a clean incision in healthy mucosa of urethra internally, and glans penis externally, using the catheter for support. The mucosal edges are apposed with 4-0 or 5-0 absorbable monofilament suture, preferably with a taper-point needle, in a simple interrupted pattern, spaced 1-2 mm apart. Absorbable braided suture (e.g.. Polyglactin 910) is also acceptable, but results in more tissue drag, and requires more throws for knot security, adding bulk to the repair. Care must be taken to achieve adequate bites of the urethral mucosa, and good mucosal apposition. This results in less second-intention healing and hemorrhage. Once apposed, the incision is completed around the orifice, and the process repeated. Proceeding as above, in stages, minimizes retraction of urethral mucosa, enabling better visualization and apposition.

Postoperative Care

The urinary catheter is removed following correction. Recovery should employ the use of sedatives and pain medication as judged necessary to ensure a quiet and smooth emergence from anesthesia. An Elizabethan collar should be worn at all times by the patient for a minimum of 10 days following the procedure, to prevent self-trauma. Exercise is limited to leash-controlled walks for 10 to 14 days. The prepuce should be monitored daily for irritation and swelling. It is normal for minor bleeding to be observed, intermittently and during urination, for 3 to 5 days post-operatively. Mild straining is also occasionally observed, but the urine stream should be consistent and adequate at all times following surgery. Underlying urinary tract disease or infection should be treated appropriately. Patients may be discharged with standard post-operative pain medication for elective soft-tissue procedures (NSAIDS). On an individual basis, short term (5 to 10 days) oral sedation with acepromazine is beneficial, and even advisable. Prognosis is good. We recommend the urethropexy technique as the easiest and most effective technique.[6]

References

1. Hobson HP, Heller RH: Surgical correction of prolapse in the male urethra. Vet Med/ Small Anim Clin 1971;66:1177.

2. Sinibaldi KR, Greene RW. Surgical correction of prolapse of the male urethra in three English Bulldogs. J Am Anim Hosp Assoc 1973;9:450.

3. Fossum TW, Hedlund CS. Surgery of the urinary bladder and urethra. In: Fossum TW, ed. Small Animal Surgery. St. Louis: Mosby-Year Book Inc., 1997:503-505.

4. Boothe HW. Penis, prepuce, and scrotum. In: Slatter D, ed. Textbook of Small Animal Surgery. Philadelphia: Saunders, 1993:1336-1348.

5. Lowe FC, Hill GS, Jeffs RD, Brendler CR. Urethral prolapse in children: Insights into etiology and management. J Urol 1986; 135:100.

6. Kirsch JA, Hauptman JG, Walshaw R. A urethropexy technique for surgical treatment of urethral prolapse in the male dog.. J Am Anim Hosp Assoc 2002; 38 (4): 381-4.

Chapter 32

Prostate

Surgery of the Prostate

Clarence A. Rawlings

Prostate disease includes hyperplasia, infection, cysts, abscesses, and cancer. Severe diseases of cysts, abscesses, and cancer are treated by excisional and partial prostatectomies. All prostatic disease, except cancer, can be prevented by castration during the first year of life. Castration, as a treatment of prostatic disease, reduces hyperplasia and the potential for persistent infections. Despite castration as a treatment for prostatic disease, prostatic abscesses can persist and present later as a clinical problem. When prostatic disease develops, castration is recommended in all patients except those with prostatic cancer. The terminal prognosis for prostatic cancer mandates an attempt to early diagnosis.

Prostatic abscesses and cysts are difficult to treat. Surgery is required, and treatment is frequently complicated by disease recurrence, incontinence, infection, sepsis, and even death. Treatments initially attempted for abscesses and cysts included extra-abdominal drainage by Penrose drains or marsupialization. Early complications of these drainage procedures included sepsis in one-third of patients and death in one-fifth. The remainder of these dogs had transient improvement, but abscessation recurred in nearly one-fifth and incontinence in one-fourth of the dogs. To reduce the postoperative complications associated with prostatic tissue as a septic focus and mediator of infection, excisional prostatectomy was performed to remove all prostatic tissue. Although excisional prostatectomy reduced the incidence of early postoperative sepsis and eliminated recurrence, over 90% of dogs with excised diseased prostates also developed incontinence.

I prefer to treat most patients with abscesses and cysts by castration and partial prostatectomy using an ultrasonic aspirator followed by omentalization. This technique eliminates nearly all the prostatic tissue while preserving the urethra and most nerves. Closed-suction drains have been successfully used to drain noninfected cysts, such as those with vascular and lymphatic drainage problems in perineal hernia. These dogs should be castrated. Many patients with abscesses and cysts appear to be adequately treated using peritoneal omentalization. All fluid-filled pockets must be explored and adequately drained. Before omentalization of paraprostatic cysts, the cysts should be excised as much as possible without damaging the urethra or the neurovascular supply.

Diagnosis

Diagnostic studies are designed to establish the anatomic distribution and histologic type of disease, to characterize the systemic response to the prostatic disease, to identify coexistent problems, to identify infections, and to characterize incontinence and outflow obstruction. The presenting complaints vary with the severity and type of disease. Tenesmus can be produced by any prostatic enlargement, that is, by hyperplasia, cyst, abscess, and neoplasia. Urethral obstruction is most typical of cancer, but it may occur in patients with cysts, abscesses, and hyperplasia. Incontinence is common in severe prostatic disease. Urethral discharge can be produced by nearly any prostatic disease with an opening into the prostatic urethra. Persistent urinary tract infections are frequently related to prostatic infections, particularly abscesses and infected cysts. Abdominal masses can be produced by cysts and abscesses. Many systemic responses develop in response to prostatic disease.

The size and character of the prostate should be determined by physical examination, including combined rectal and abdominal palpation, radiography, and ultrasonography. Contrast studies, especially retrograde urethrography, can be useful to identify the urethra, bladder, and prostate. Cystic structures as seen with an ultrasonogram have a more serious prognosis than hypertrophy, especially if a urinary tract infection is present. Cytologic and bacterial cultures can be obtained by sampling the urethral discharge, by semen ejaculation, by prostatic massage, by traumatic catheterization, or by direct sampling by needle aspiration or use of a larger biopsy needle. Placement of a needle into the prostate can be facilitated by ultrasonography or palpation. Care must be taken in placing a large-bore needle into a fluid-filled pocket of an infected prostate gland.

Most dogs with severe prostate disease do not urinate normally. Incontinence is common and frequently worsens after surgery. Even dogs that have undergone only a biopsy have dribbled urine after surgery, probably as a result of disease progression. Although obstruction in the absence of cancer is commonly thought to be infrequent, obstruction does occur and may be associated with calculi and strictures unrelated to cancer. Detrusor instability can develop in dogs with prostatic disease. A urethral pressure profile can identify decreased urethral pressures, which are common in dogs with prostatic disease, and a cys-tometrogram can identify an inability to develop a detrusor response or an irritable bladder. If incontinence persists after surgery, medical treatment can be attempted for each of these conditions.

Preoperative Care

Dogs with prostatic infections, especially those with abscesses, frequently become septic and develop toxic shock. Diagnosis is based on physical examination, urinalysis, complete blood and platelet counts, and serum chemistry profile, particularly liver enzymes, glucose, and albumin. Perioperative antibiotics must be given, preferably based on culture results. Although *Escherichia coli* is the most common organism isolated in bacterial prostatitis, some dogs have already been treated with long-term antibiotics and have developed resistant infections. Septic dogs, without culture results, are started on a combination of clindamycin and enrofloxacin. Measures to prevent and treat shock must be done and include fluid support, blockers of ischemia and reperfusion injury, and cardiotonic drugs (dopamine or dobutamine). Hypovolemia and hypotension must be treated by large volumes of intravenous fluids. If the albumin and total solids are low, plasma,

hetastarch, or dextrans should be considered. Blockers have been used and included dexamethasone (2 mg/kg intravenously), flunixin (1 mg/kg intravenously), and deferoxamine (20 to 40 mg/kg intramuscularly or slowly intravenously) but their efficacy remains controversial. Monitoring must include either indirect or direct arterial blood pressure. The anesthetic regimen should be based on the patient's disease status. Finally, surgery must be both expeditious and accurate to reduce the spread of sepsis.

Surgical Techniques

Excisional Prostatectomy

Excisional prostatectomy is used to treat cancer. This treatment is usually palliative, but it can be effective in extending the patient's normal life for several months because transitional and prostatic carcinomas usually grow slowly. Another treatment option for proximal urethral cancer is excision of the lower urinary tract and implantation of the ureters into the colon. This produces ascending renal infections. Dogs with neoplastic urethral obstruction can be successfully managed for months by a cystostomy tube. Neither medical therapy nor radiation treatment provides significant benefits in patients with prostatic cancer. Urethral stents can provide temporary relief of urethral obstruction. Prostatectomy also can successfully cure prostatic abscesses and cysts, but the high rate of incontinence makes this procedure less desirable than partial prostatectomy or peritoneal omentalization.

Incisional biopsies are done by cutting deeply into the prostatic gland and then placing deep mattress sutures into the capsule to produce hemostasis (Figure 32-1). The prostate is approached by a midline laparotomy (Figure 32-2A). The periprostatic fat is incised on the ventral midline and is reflected laterally (Figure 32-2B). An excisional prostatectomy requires dorsal dissection. Before prostatic surgery, a temporary tourniquet is placed about the distal aorta, just cranial to its bifurcation into the external iliac arteries. After placement of a urethral catheter, a retraction suture is placed around the urethra caudal to the prostate. Caudal dissection is facilitated by cranial incision of the ventral ligament of the penis. The prostate is rotated to ligate vessels close to the prostatic capsule and to ligate the vas deferens. The surgeon attempts to preserve the caudal vesical artery bilaterally and to preserve much of the urethra, both on the side of the neck and distally. Prostate tissue or fluid should be cultured. Multiple biopsy specimens are taken from the prostate and sublumbar lymph nodes. Neoplastic tissue must be excised, and this can require extensive urethral resection. Margins, especially of the urehra, are sampled in order to stage the cancer spread. Retraction sutures in the urethra caudal to the prostate can reduce traction problems. The urethra is transected cranial (Figure 32-2C) and caudal to the prostate (Figure 32-2D). The prostate is removed, and the urethral catheter is redirected into the bladder. The urethra is anastomosed with interrupted sutures using an absorbable monofilament synthetic suture material, usually of 4-0 or 5-0 size (Figure 32-2E). Some urethras are thick enough that a second layer of sutures can be placed in muscle tissue. A cystostomy catheter is placed in addition to the urethral catheter to ensure that urine is diverted and that little tension is placed on the anastomosis (Figure 32-2F). Both catheters

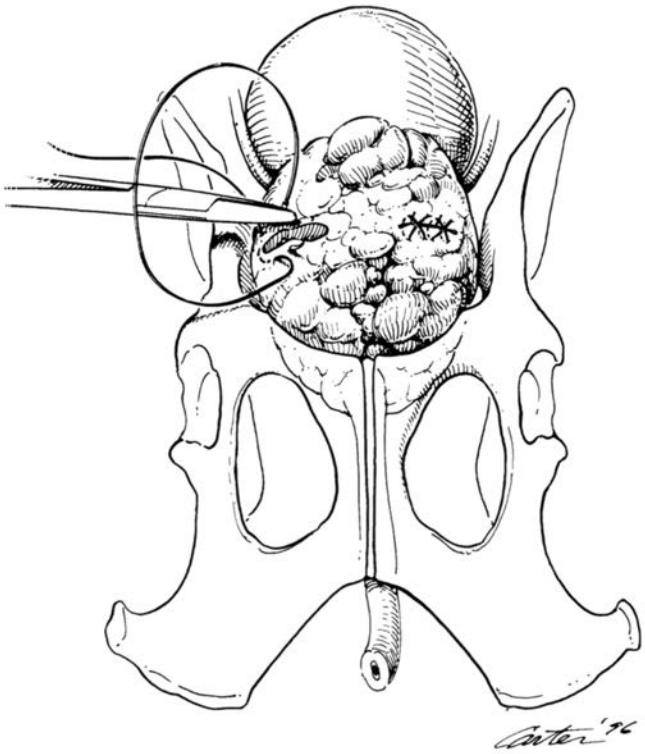


Figure 32-1. Incisional biopsies are performed through a ventral midline laparotomy. Multiple biopsy specimens should be obtained, with each sample at least I cm wide and 2 cm deep. After each biopsy specimen is taken, interrupted cruciate sutures are placed at least 5 mm from the biopsy margins. Hemostasis is achieved as the sutures are tightened.

are left in place for 1 week, and urine is collected by a closed system. The balloon of the cystostomy catheter is deflated, and the catheter is withdrawn 1 week after the surgical procedure. The urethral catheter is left in place for another day and then is withdrawn.

Partial Prostatectomy

Partial prostatectomy is my preferred procedure for treatment of patients with prostatic cysts and abscesses, but it is contraindicated for cancer. The use of the ultrasonic surgical aspirator permits removal of up to 85% of the prostatic glandular tissue in addition to all cysts and abscesses. Because the remaining prostatic tissue is dorsal and close to the urethra, most of the urethral innervation and muscles appear to be left intact. Incontinence is much less frequent and severe after partial prostatectomy of dogs with severe cavitary disease than before the surgical procedure or after ex-cisional prostatectomy. As with excisional prostatectomy, castration should be performed.

The prostate is approached in the same fashion as previously described, except dorsal and lateral dissections are avoided or at least limited. After obtaining biopsy specimens and after placing the aortic tourniquet and retraction suture about the urethra caudal to the prostate, the surgeon incises poles of the prostate ventrally with electrocautery (Figure 32-3A). The Cavi-tron Ultrasonic Surgical Aspirator (CUSA System 200 Macro-Dissector, Valleylab, Inc., Pfizer Hospital Products Group, Boulder, CO) is used to fragment, irrigate, emulsify, and

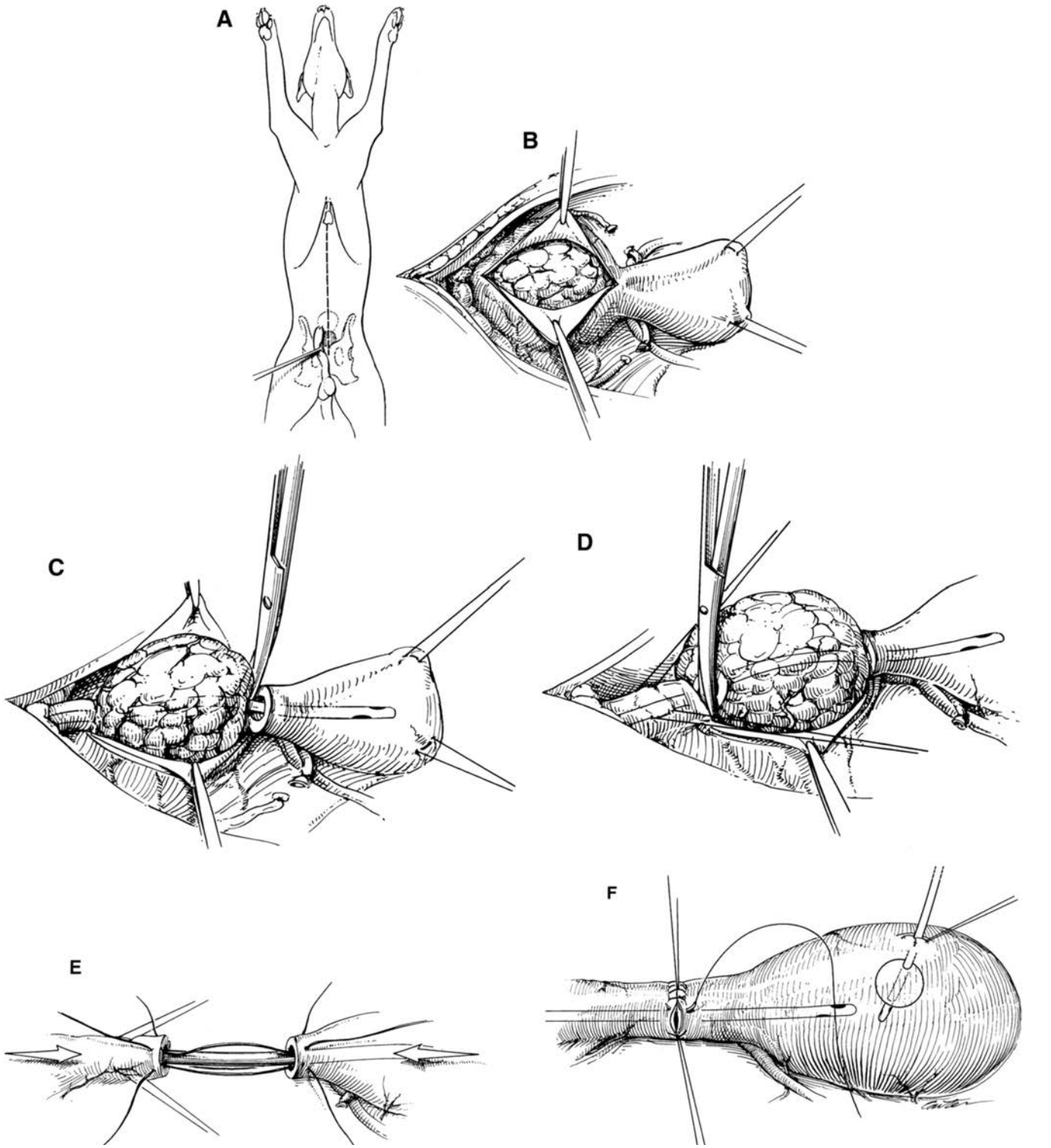


Figure 32-2. A. A ventral midline laparotomy is performed to approach the prostate for an excisional prostatectomy. Most prostate glands can be adequately exposed if the incision is extended caudally to the brim of the pubis. **B.** The periprostatic fat is incised on the midline and is reflected from the ventral and lateral surfaces. Hemostasis is improved if a tourniquet is placed about the aorta just cranial to its bifurcation. The vasa deferentia are ligated and divided, as are the prostatic vessels. Care must be taken to preserve the caudal vesical artery on both sides. Dissection should be close to the capsule, especially dorsal, cranial, and caudal to the prostate. A traction suture placed around the urethra, caudal to the prostate, and incision of the ventral ligament of the penis aid prostatic exposure. **C.** The urethra is transected cranial to the prostate. If excisional prostatectomy is done for cancer, the resection may need to be wider to ensure tumor-free margins. **D.** The urethra is transected caudal to the prostate. After the prostate is removed, the urethral catheter is replaced in the bladder. **E.** The urethral anastomosis is made with interrupted sutures of 4-0 or 5-0 absorbable synthetic monofilament material. The sutures are placed through all layers of the urethra, but additional sutures may be placed in a second pattern in some urethras. **F.** In addition to the urethral catheter, a cystostomy catheter is placed into the ventral region of the bladder. A double pursestring is used to secure the catheter.

aspirate approximately 85% of the glandular tissue (Figure 32-3B and C). A catheter is placed within the urethra to identify and avoid damaging it. Urethral fistulas are identified by inflating the urethra with fluid (Figure 32-3D). After glandular dissection and excision of the ventral hemisphere on the ventral midline of the capsule, omentum is placed over the urethra and the dorsal prostatic capsule is suture around the omentum and urethra on the ventral side to form a cuff around the prosatic urethra.

Postoperative Care and Complications

Early potential complications can include shock potentially leading to death, infection (sepsis), pain, and renal shutdown. Fluid support should be continued at greater than maintenance rates based on monitoring results of, initially, arterial blood pressure and, later, volume of diuresis. If shock develops, treatment must be aggressive. Urinary output is recorded, and the bladder is evaluated frequently to ensure that it remains decompressed. Urinary catheters are usually removed during the first

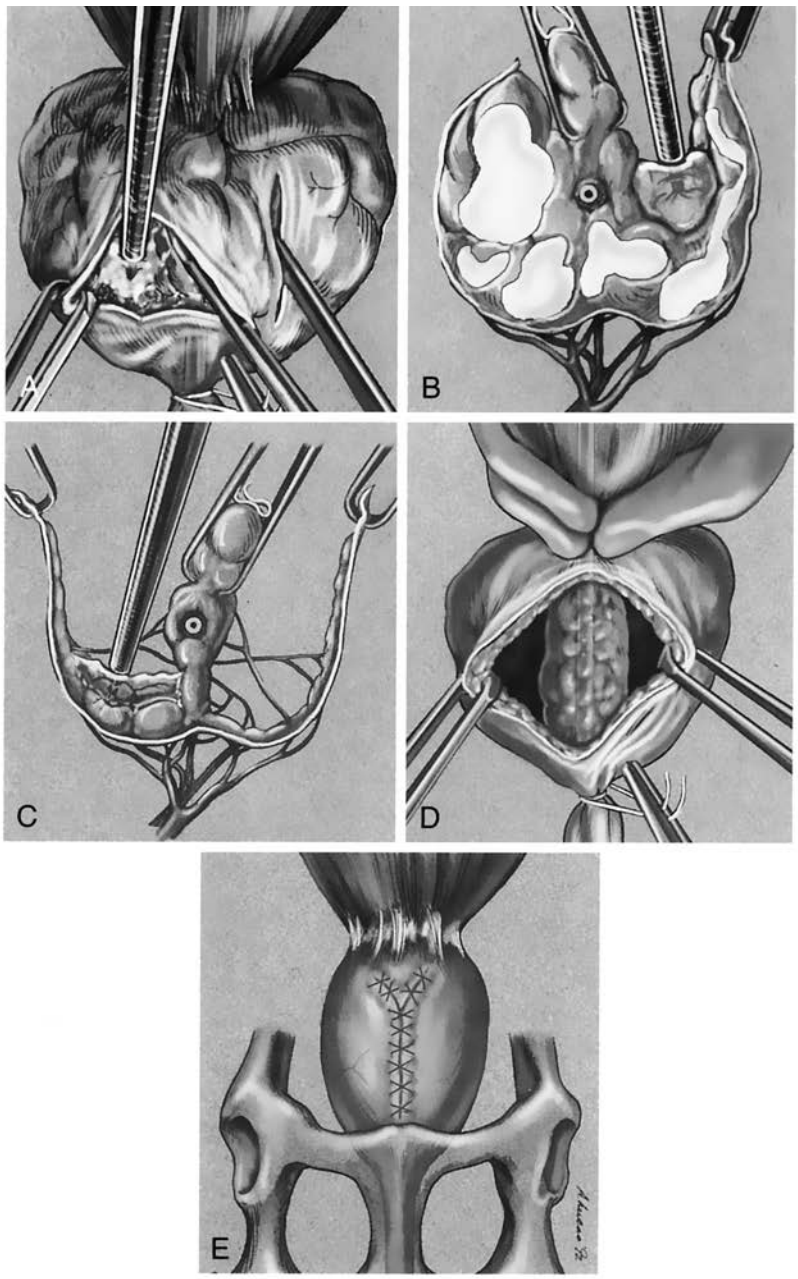


Figure 32-3. A. Ventral view of a partial prostatectomy. After lymph node biopsy and placement of an aortic tourniquet, a 14- to 18-French urethral catheter is placed through a cystotomy, and a traction suture is placed about the urethral caudal to the prostate. Two parallel incisions are made into the ventral prostatic capsule using electrocautery. **B.** Transverse view. The ultrasonic aspirator is used to resect glandular tissue. All identifiable cystic pockets are entered. **C.** Transverse view. The surgeon attempts to remove 85% of the glandular tissue, including all abscess pockets. During ultrasonic aspiration, the urethral catheter and the dorsal capsule are frequently palpated and are avoided. **D.** Ventral view. The urethral catheter tip is withdrawn into the prostatic urethra, and the urethra is inflated by injecting saline. Urethral openings are identified and closed by suturing. **E.** Ventral view. Prostatic tissue between the paramedian incisions and ventral to the urethra and the excessive capsule are excised. The capsule is closed with interrupted sutures. An indwelling urethral catheter is left to decompress the bladder during the early postoperative period. From Vet Surg 1994;23:182-186.

2 days after partial prostatectomy. For excisional prostatectomy, catheters are left for 1 week and require protection with side braces or Elizabethan collars. Antibiotics are continued. Pain medications are normally given at least during the initial 8 hours after surgery. Intensive care monitoring is critical for several hours postoperatively. In addition to monitoring of urine output, temperature, pulse, and respiration, and attitude, complete blood counts with platelet counts, blood urea nitrogen, albumin, glucose, and urinalysis should be performed. Liver enzymes are also useful to detect signs of sepsis and septic shock. In dogs with signs of sepsis, decreasing albumin concentrations indicate a need for plasma. Nutritional status should be documented by measuring food intake and body weight daily. No deaths have been reported in dogs treated by partial prostatectomy.

Long-term complications of surgical treament in dogs with severe prostatic disease include persistent infections and disease, as well as incontinence. Dogs usually urinate normally after partial prostatectomy, and fewer than 20% of dogs have even minor urinary control problems. After excisional prostatectomies, most dogs develop mild incontinence, and a few (approximately 10%) have continual dribbling of urine. Prostatectomy of normal dogs produces no decrease in urinary control function and only minor urodynamic changes, but the combination of prostatic disease and removal of the prostate increases incontinence. Some incontinent dogs with low urethral pressures have been successfully treated with phenylpropanolamine (1.5 mg/kg orally three times daily), and those with detrusor instability have been treated with oxybutynin (2.5 mg orally three times daily). Recurrent prostatic infections and disease should not occur when the prostate has been excised. Dogs with partial prostatectomy have not had recurrence during the first year after discharge from the hospital. Complications have been seen during hospitalization when a urethral to cyst fistula either persisted or recanalized. This fistula can been repaired during an additional surgery. Since a small amount of prostatic tissue is present and can be infected, at least two dogs have developed recurrent disease more than 1 year after surgery. The potential for urinary tract infection is high in any dog following surgery for major prostatic disease. These dogs must have regular urinalysis and cultures combined with aggressive antibiotic therapy. Intense surveillance and treatment should reduce problems with recurrent infections.

Acknowledgment

The illustrations by Dan Biesel and Kip Carter are appreciated.

Suggested Readings

Basinger RR, Rawlings CA. Surgical management of prostatic diseases. Compend Contin Educ Small Anim Pract 1987,9:993-1000.

Basinger RR, Rawlings CA, Barsanti JA, et al. Urodynamic alterations after prostatectomy in dogs without clinical disease. Vet Surg 1987;6:405-410.

Basinger RR, Rawlings CA, Barsanti JA, et al. Urodynamic alterations associated with clinical prostatic diseases and prostatic surgery in 23 dogs. J Am Anim Hosp Assoc 1989;25:385-392.

Cowan LA, Barsanti JA, Crowell W, et al. Effects of castration on chronic bacterial prostatitis in dogs. J Am Vet Med Assoc 1991,199:346-350.

Hardie EM, Barsanti JA, Rawlings CA. Complications of prostatic surgery. J Am Anim Hosp Assoc 1982;20:50-56.

Mullen HS, Mathieson DT, Scavelli TD. Results of surgery and postoperative complications in 92 dogs treated for prostatic abscessation by a multiple Penrose drain technique. J Am Anim Hosp Assoc 1990;26:369-379.

Rawlings CA, Crowell WA, Barsanti JA, et al. Intracapsular subtotal prostatectomy in normal dogs: use of an ultrasonic surgical aspirator. Vet Surg 1994;23:182-189.

Stone EA, Barsanti JA, eds. Urologic surgery of the dog and cat. Philadelphia: Lea & Febiger, 1992.

White RAS, Williams JM. Intracapsular prostatic omentalization: a new technique for managment of prostatic abscesses in dogs. Vet Surg 1995;24:390-395.

Use of Omentum in Prostatic Drainage

Richard A. S. White

Causes of Prostatic Abscesses and Cysts

Abscessation of the prostate gland in dogs is considered to result from an ascending bacterial infection that overcomes the normal urethral defense mechanisms and thereafter colonizes the prostatic parenchyma. A suppurative infection resulting in parenchymal microabscesses is thought to develop subsequently, but the precise mechanism by which these microabscesses coalesce into larger, loculated abscesses rather than remaining as diffuse prostatitis is unclear. The most commonly recovered organism is *Escherichia coli*, with *Staphylococcus* spp. and *Proteus* spp. occasionally encountered.

Discrete cysts involving the prostate gland are a well-defined but uncommon manifestation of prostatic disease. Two distinct categories of cyst have been previously described namely, *paraprostatic* and *prostatic retention cysts*. It now seems clear that both types of cysts in fact share a common etiology and are thought to develop as the result of obstruction of ducts within the parenchyma of the gland promoting the accumulatic of prostatic secretions. Concurrent prostatic disease is always present, and this may include benign prostatic hyperplasia, squamous metaplasia, abscessation, or neoplasia. Discrete cysts are capable of attaining considerable size and should be distinguished from the diffuse cystic changes that often occur in combination with benign prostatic hyperplasia.

Clinical Signs and Diagnosis

Dogs with *prostatic abscesses* are pyrexic and have signs of caudal abdominal pain on rectal and transabdominal palpation of the prostate gland. The prostate gland is invariably enlarged and may have a doughy feel when palpated. Many dogs have neutrophilia (white blood count higher than 17 x 10^9/L), but this is not a consistent feature of the disease. Alkaline phosphatase concentrations may be elevated in some patients. Radiography enables one to confirm the prostatic enlargement, but ultrasound imaging is necessary to demonstrate the characteristic loculation within the parenchyma that contains the slightly echodense purulent fluid. Fine-needle aspiration may be used to recover purulent material, but it should be performed with care to avoid the risk of peritonitis after this procedure.

Prostatic retention cysts are encountered mostly in large breed dogs, especially boxers. Signs of urinary dysfunction, including stranguria, dysuria, hematuria, and incontinence, are invariably seen. Palpation identifies a caudal abdominal mass. A presumptive diagnosis of prostatic cyst can be made by evaluation of survey abdominal radiographs and ultrasound examination of the prostate in all dogs. Mineralization of the cyst wall is evident in some dogs. Biopsy may be indicated because some retention cysts accompany prostatic neoplasia, but fine-needle aspiration should again be performed with care.

Conventional Drainage Strategies

Chronic parenchymal lesions of the prostate gland, most notably abscesses and discrete cysts, are difficult clinical entities to resolve consistently by means of medical or surgical therapy. Various surgical techniques have been described for the management of prostatic abscesses and cysts.

Abscesses

The use of antibiotic therapy, even in conjunction with castration, is notoriously ineffective in resolving prostatic abscessation because of its failure to achieve adequate therapeutic concentrations throughout the prostate. Previously described techniques for drainage or removal of abscesses include marsupialization of the abscess, local resection, subtotal prostatectomy, and excisional prostatectomy. For many years, the most widely practiced technique was ventral drainage by means of dependent Penrose drains. All the foregoing techniques necessitate prolonged postoperative management, and long-term complications associated with these procedures include recurrent abscessation, chronic drainage after marsupialization, urinary incontinence, urinary tract infection, and the development of urethrocutaneous fistula.

Prostatic Retention Cysts

Marsupialization of prostatic cysts is a comparatively simple technique, but persistent discharge from the stoma, chronic urinary tract infection, and abscessation are recognized complications. Drainage and surgical resection of the cyst comprise a successful technique and should be regarded as the technique of choice for the management of paraprostatic cysts, for which the dissection is often uncomplicated. Many prostatic retention cysts, however, have extensive adhesions to the ureters, bladder neck, and prostate, and complete resection may increase the risk of postoperative incontinence or urinary retention resulting from neural or vascular compromise. Partial cyst resection may therefore be a preferable strategy to minimize the risk of incontinence, although this procedure may permit continued fluid secretion, redevelopment of the cyst, or formation of adhesions between the cyst remnant and other abdominal organs.

Omentum for Prostatic Drainage

The value of the omentum as an alternate source of vascularization and lymphatic supply in veterinary surgery is well established. Recognized applications include reconstruction of body wall deficits, filling of dead space, support for grafted tissue, reinforcement of gastrointestinal or urogenital repairs, and resolution of chronic wounds. The omentum is able to resolve bacterial contamination from perforated viscera and even can function in the presence of infection. The omentum can be used as a "physiologic drain" to resolve lesions of the prostatic parenchyma such as abscesses or to provide continued drainage of ongoing secretions from residual cystic tissue without merely walling them off from the abdominal cavity. Additionally, the omentum creates adhesions at the operative site, thereby minimizing the risk of visceral adhesion.

Intracapsular Prostatic Omentalization for Prostatic Abscesses

A caudal celiotomy extending from the umbilicus to the pubic brim is performed to permit adequate elevation of the prostate gland, which is then packed off from the remainder of the abdomen with moist laparotomy sponges. Stab incisions are made bilaterally in the lateral aspects of the prostate gland, and pus is removed by suction to minimize abdominal contamination. All abscess loculations within the parenchyma (Figure 32-4) are explored and are broken down by digital exploration. The prostatic urethra is carefully preserved and can be identified by palpation of a previously placed urethral catheter. A Penrose drain may be temporarily placed around the prostatic urethra within the parenchyma to help elevate the gland and to facilitate irrigation of the abscess cavities with warm saline. The stab incisions are then enlarged by resection of the lateral capsular tissue. Artery or tissue forceps are introduced into one capsulectomy wound and are used to draw a leaf of omentum into the contralateral wound and through the dorsal abscess cavity (Figure 32-5). The omentum is passed back through the ventral cavity, resulting in complete periurethral packing, to exit the prostate, and is then anchored to itself with absorbable mattress sutures outside the prostate gland (Figure 32-6). The celiotomy wounds are closed routinely, and castration is performed. Dogs should receive broad-spectrum antibiotic therapy periopera-tively, but this therapy does not need to be extended postoperatively unless complications occur, such as major contamination of the abdominal cavity before or during the surgical procedure.

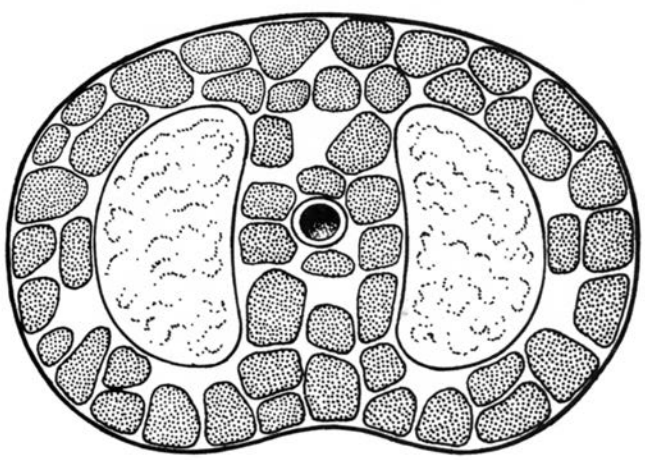


Figure 32-4. Schematic representation of an abscessed prostate gland demonstrating abscess cavities before disruption and drainage. (The patient is in dorsal recumbency). From Vet Surg 1995;24:390-395.

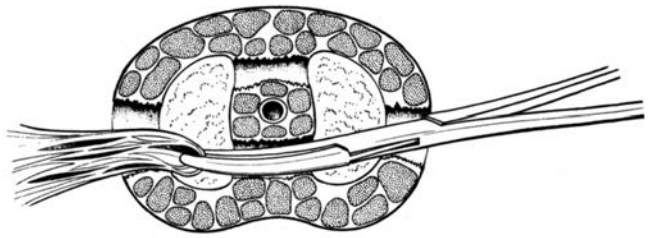


Figure 32-5. Bilateral stab incisions are made into the abscess to permit drainage and digital disruption of the loculations within the cavities. The stab incisions are then enlarged by resection of the capsular tissue to permit the introduction of a leaf of omentum into the dorsal abscess cavity by means of forceps positioned through the contralateral capsulectomy wound. From Vet Surg 1995;24:390-395.

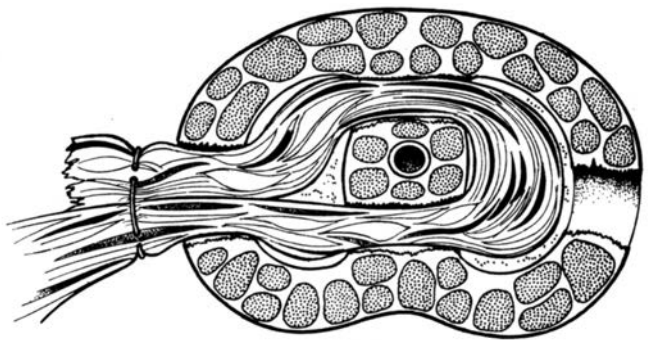


Figure 32-6. The leaf of omentum is then returned through the ventral cavity of the abscess to complete the periurethral packing. The omentum is anchored to itself by means of horizontal mattress sutures using absorbable material. From Vet Surg 1995; 24:390-395.

Partial Resection and Omentalization for Prostatic Retention Cysts

A caudal celiotomy extending from the umbilicus to the pubic brim is performed. The cyst is identified (Figure 32-7), and a single stab incision is made through the cyst wall. Complete drainage using suction to avoid con tamination of the abdominal cavity is performed (Figure 32-8), and the majority of the cyst wall is resected (Figure 32-9). Extensive dissection of the cyst in the region of the bladder neck and prostate should be avoided, to minimize the risk of damaging nerves that control continence. Omentum is packed into the cyst remnant and is secured in place (Figure 32-10) with mattress sutures of 2-0 absorbable suture material. The prostate gland should be carefully examined and palpated during the surgical procedure, and if neoplastic infiltration is suspected, an incisional biopsy should be performed. The celiotomy wounds are closed routinely, and castration is performed. Dogs should receive perioperative broad-spectrum antibiotics, which may need to be extended postoperatively if purulent debris is apparent in the cyst during the surgical procedure.

Postoperative Care and Complications

A significant advantage of omentalization drainage techniques for prostatic disease is that patients can normally be discharged from the hospital within 24 hours of the surgical procedure. As already indicated, prolonged antibiotic therapy is only necessary if complications are encountered.

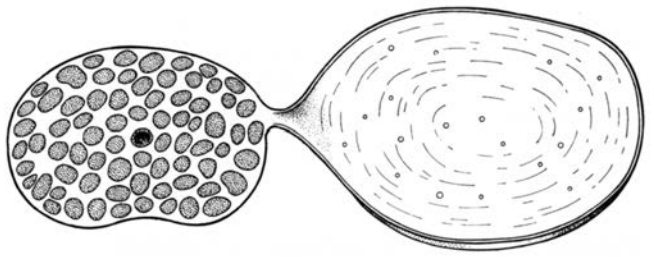


Figure 32-7. Schematic illustration of a prostatic retention cyst in transverse section. The cyst wall develops as a dilatation of the prostatic parenchyma caused by the accumulation of secretions within the gland. From Vet Surg 1997;26:202-207.

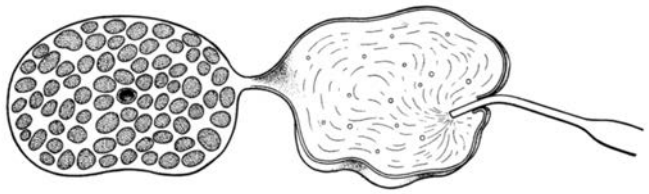


Figure 32-8. The cyst is drained by a single stab incision into the lumen. Suction is used to minimize spillage of cyst contents into the abdominal cavity. From Vet Surg 1997;26:202-207.

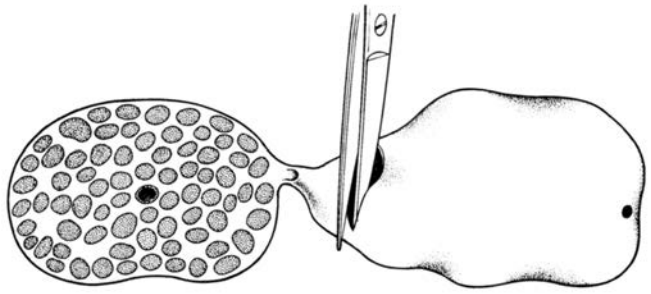


Figure 32-9. After drainage, the cyst wall is partially resected. Extensive dissection about the bladder neck and prostate is avoided.

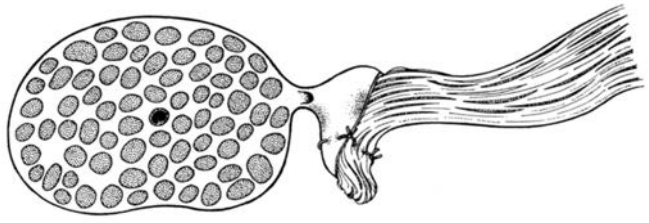


Figure 32-10. After partial resection of the cyst wall, an omental pedicle is created to fill the residual prostatic cavity. The omentum is anchored in place with stay sutures. From Vet Surg 1997;26:202-207.

Abscesses may recur if insufficient omentum is packed into the abscess cavity. The surgeon should ensure that adequate lateral capsulectomy resections—normally sufficient to accommodate the easy entry of the forefinger into the abscess cavity—are performed to avoid this complication.

Urinary incontinence is a frequent presenting sign in patients with prostatic retention cysts, and this problem may persist even after successful omentalized drainage of the cyst. Therapy with phenylpropanolamine (1 mg/kg every 24 hours orally) to increase urethral sphincter tone may be appropriate in some of these patients. Urinary retention is less common, and the patient's urinary function should be monitored carefully during the first 24 hours after the surgical procedure.

Prognosis

Omentalized drainage has proved successful for the management of both prostatic abscesses and retention cysts. Compared with other drainage techniques, the level of surgical expertise required for successful omentalization is modest, hospitalization stays are brief, and postoperative complication rates are low.

Suggested Readings

Basinger RR, Rawlings CA, Barsanti JA, et al. Urodynamic alterations associated with clinical prostatic diseases and prostatic surgery in 23 dogs. J Am Anim Hosp Assoc 1989;25:385-392.

Gourley LG, Osborne CA. Marsupialization: a treatment for prostatic abscess in the dog. J Am Anim Hosp Assoc 1966;2:100-105.

Hardie EM, Barsanti JA, Rawlings CA. Complications of prostatic surgery. J Am Anim Hosp Assoc 1984;20:50-56.

Hardie EM, Stone EA, Spaudling KA, et al. Subtotal canine prostatectomy with neodymium yttrium-aluminium-garnet laser. Vet Surg 1990,19:348-355.

Hosgood G. The omentum—the forgotten organ: physiology and potential surgical applications in dogs and cats. Compend Contin Educ Pract Vet 1990,12:45-51.

Mullen HS, Matthiesen DT, Scavelli TD. Results of surgery and postoperative complications in 92 dogs treated for prostatic abscessa-tion by a multiple Penrose drain technique. J Am Anim Hosp Assoc 1990;26:369-379.

Rawlings CA, Crowell WA, Barsanti JA, et al. Intracapsular subtotal prostatectomy in normal dogs: use of an ultrasonic surgical aspirator. Vet Surg 1994;23:182-189.

White RAS, Williams JM. Intra-capsular prostatic omentalization: a new technique for management of prostatic abscessation. Vet Surg 1995;24:390-395.

White RAS, Herrtage ME, Dennis R. The diagnosis and management of paraprostatic and prostatic retention cysts in the dog. J Small Anim Pract 1987;28:551-574.

Chapter 33

Uterus

Prepubertal Ovariohysterectomy

Lisa M. Howe

Introduction

Prepubertal gonadectomy is not a new procedure. Veterinarians in the U.S. have often recommended that female dogs and cats be neutered prior to the first estrus (i.e., prepubertal) to eliminate unwanted pregnancies and reduce the risk of mammary neoplasia. Traditionally, female dogs and cats not intended for breeding purposes have undergone ovariohysterectomy at approximately six months of age. However, in an attempt to help alleviate the pet overpopulation problem, veterinarians began to investigate whether it was also safe to alter puppies and kittens at a younger age.[1] Currently, the literature suggests that prepubertal gonadectomy in female cats is safe as young as 6 to 8 weeks of age, particularly in the shelter environment. In female puppies, however, it is best to delay ovariohysterectomy until at least 3 to 4 months of age to prevent an increased risk of estrogen responsive urinary incontinence.[2] However, for shelters with an over supply of puppies, the advantages of ovariohysterectomy of puppies before adoption may outweigh the risk of urinary incontinence.

Surgical Anatomy

The surgical anatomy of the pediatric puppy or kitten is identical to that of the adult dog or cat; however, pediatric reproductive tract tissues are extremely small, friable, and susceptible to tearing if not handled with finesse. Additionally, there is minimal fat associated with the broad ligament or ovarian bursa in pediatric puppies and kittens.

Surgical Procedures and Techniques

When performing surgery in the pediatric patient, it is important to remember certain anesthetic and surgical considerations that may differ from the adult animal. Anesthetic and surgical considerations for the pediatric patient include the increased potential for hypoglycemia, hypothermia, a relatively small blood volume, and the delicate nature of pediatric tissues. Since hepatic glycogen stores are minimal in neonates, prolonged fasting may result in hypoglycemia. Food should be withheld no longer than 8 hours, with 3-4 hours recommended for the youngest patients (6-8 weeks).[3,4] Hypothermia can be lessened by using warm water or warm circulating air blankets and by the use of warm intravenous fluids (if used). Minimizing the period under general anesthesia and operative time will also help lessen the severity of hypothermia. Excessive wetting of the pediatric patient during preparation of the surgical site should be avoided, and the use of warmed scrub solution (chlorhexidine) and avoidance of alcohol will be beneficial in helping preserve body heat.[3,4] Pediatric tissues are very friable and should be handled carefully. The

relatively small blood volume of pediatric patients makes meticulous hemostasis very important. Fortunately, the small size of blood vessels and the presence of minimal abdominal and ovarian bursal fat allow for excellent visualization of the vasculature, and makes precise hemostasis simple to achieve.

Pediatric ovariohysterectomy may be performed similarly to adult ovariohysterectomy with some slight modifications.[3,5,6] Incisions in puppies are started more caudal to the umbilicus than in adult dogs. Generally, the uterus is more easily exposed in puppies if the incision is started at least 2 to 3 cm caudal to the umbilicus. This results in the incision positioned at, or near, the middle third of the distance from the umbilicus to the cranial brim of the pelvis, similar to an incision made for the adult cat. In kittens, the incision is placed in a similar location as in the adult cat. Upon entrance into the abdomen, it is common to encounter substantial amounts of serous fluid in both puppies and kittens. It may be necessary to remove some of the fluid using gauze sponges to improve visualization. In contrast to adult dogs and cats, it is recommended that the use of a Snook ovariohysterectomy hook be avoided in pediatric patients due to the delicate nature of the uterine tissues. Because of incision location in both puppies and kittens, the uterus is easy to locate by retracting the bladder laterally and looking between the urinary bladder and colon. If necessary, and if incision length will allow, the urinary bladder may be elevated from the abdomen and reflected caudally to permit easier visualization of the uterus. If this technique is used, once the uterus has been identified and secured, the bladder should be returned to the abdomen so as to preserve body heat. Uterine tissues are extremely small and friable in young puppies and kittens, therefore care must be taken to avoid excess traction and tearing of tissues. After the uterus has been located, the suspensory ligament may be carefully broken down to improve exposure and visualization of the ovary. A window is made through the broad ligament adjacent to the ovarian vasculature. A hemostatic clamp is then placed just proximal (medial) to the ovary across the ovarian vessels using a mosquito hemostat on kittens and small puppies and a Kelly, Crile, or Carmalt forceps on larger puppies. Although the triple clamp method may be used in pediatric OHE, it is often cumbersome and difficult to place multiple clamps proximal to the ovary without tearing tissues. The ovarian vessels are doubly ligated using 3-0 to 4-0 absorbable suture material or stainless-steel hemostatic clips. A single ligature may be sufficient to prevent hemorrhaging in very small pedicles, and transfixation ligatures are usually avoided. After ligation and transection of the ovarian vessels on both sides, the remaining broad ligament should be broken down (if it has not already torn) and the uterine pedicle ligated at the junction of the uterine body and cervix with two fully encompassing uterine body ligatures or hemostatic clips. After the reproductive tract has been removed, it should be examined to ensure complete removal (of ovaries and uterine body), and the abdomen should be examined for evidence of hemorrhage. As abdominal wall closure is performed, it is important to carefully identify the ventral fascia (external rectus sheath) and differentiate it from the overlying subcutaneous tissues since they can occasionally be difficult to tell apart (particularly in puppies). The ventral fascia can be closed using either a simple continuous or simple interrupted suture pattern using 3-0 (or possibly 2-0 on large puppies) absorbable (polydioxanone, polyglyconate, or polyglactin 910) suture. The subcuticular layer may be closed with an absorbable suture material (3-0 to 4-0, poliglecaprone 25 preferred) in a continuous intradermal pattern to avoid the use of skin sutures. Alternatively, skin sutures may be loosely placed following closure of the subcutaneous tissues. Although some veterinarians avoid using skin sutures in pediatric patients to prevent premature removal by the patient, we routinely use *loosely* placed skin sutures without complication or premature removal.

To prevent unnecessary abdominal exploratory surgery in the future, all animals undergoing early age ovariohysterectomy should be tattooed to identify their neutered status. The recommended tattoo site is the prepubic area in females. The female gender symbol along with an encircled "X" is used to denote the neutered status. Tattooing may be performed after the surgical site has been clipped but prior to the surgical prep of the area.

Postoperative Care

Postoperatively, pediatric patients should be monitored for hypoglycemia, hypothermia, pain, or dysphoria. Supplemental heat, glucose containing agents, or additional analgesics or sedatives may be used to ensure smooth recovery from anesthesia. These patients may be fed a small meal one to two hours after recovery since they tend to recover much more quickly from anesthesia and surgery than adults. Unlike traditional age patients undergoing ovariohysterectomy, pediatric puppies and kittens are typically hungry at this time and are often ready to eat and resume normal activity.

Postoperative Complications

Although the anesthetic and surgical procedures for early-age gonadectomy have generally been reported as safe, veterinarians have been concerned about long-term health risks. Veterinarians have questioned whether the immune system of puppies and kittens would be adversely affected by the stress of anesthesia and surgery at early ages and during a time when animals are being immunized against potentially fatal infectious diseases. Veterinarians have also been concerned about the risk of urinary incontinence and neoplasia in female dogs, abnormal long bone growth patterns, and obesity in dogs and cats neutered at an early age. Since the 1990's, several studies have been published that critically evaluate these concerns among dogs and cats altered at different ages prior to, and following, puberty. These studies, as well as more recent studies, have begun to clarify the long term health risks and benefits of early age ovariohysterectomy as compared to traditional age gonadectomy.

Infectious Diseases and Long-Term Immune Suppression

In some short-term studies conducted at animal shelters, puppies and kittens neutered at early ages had no higher risk of infectious diseases than older animals. One study involved dogs and cats from two animal shelters undergoing gonadectomy surgeries in association with the fourth-year student surgical

teaching program of a university teaching hospital.[5] Twelve of 1988 (0.6%) animals died or were euthanized because of severe infections of the respiratory tract or as the result of parvovirus infection during the 7-day postoperative period, and the deaths (or euthanasias) included similar numbers of animals from all age groups.

In long term studies of 263 cats[7] (36 month median follow up) and 269 dogs[8] (48 month median follow up), prepubertal gonadectomy did not result in an increased incidence of infectious diseases after adoption in cats, compared with traditional age gonadectomy. In dogs, however, gonadectomy before 5.5 months of age was associated with increased incidence of parvoviral enteritis. In more recent studies of 1660 cats9 (47 month median follow up) and 1842 dogs[2] (54 month median follow up), those gonadectomized before 5.5 months of age were no more likely than those gonadectomized after 5.5 months of age to have any conditions that might be presumably associated with long term immune suppression. Further, in cats, the study showed that early age gonadectomized cats had a lower incidence of gingivitis, a condition that may be associated with immune suppression. On a short-term basis, however, dogs from the study that were gonadectomized at an early age had an increased incidence of parvoviral enteritis that often occurred soon after adoption. In both of the long-term dog studies[8,2] (269 dogs and 1842 dogs), the increased incidence of parvoviral enteritis on a short-term basis probably represented an increased susceptibility of the younger puppies during the periadoption period, rather than long-term immune suppression.

Body and Long Bone Growth

At one time veterinarians believed that puppies and kittens neutered at an early age might be "stunted" in growth. Several research studies have now defined and dismissed these concerns. In a 15-month study, the effects of prepubertal gonadectomy on skeletal growth, weight gain, food intake, body fat, and secondary sex characteristics were investigated in 32 mixed-breed dogs neutered at seven weeks or seven months or left intact.[10] Growth rates were unaffected by gonadectomy, but the growth period and final radial/ulnar length was extended in bitches neutered at seven weeks of age. Thus, animals were not stunted in growth, but were actually slightly (as determined by radiographs) taller. In a similar study,[11] thirty-one cats were neutered at seven weeks or seven months or left intact. Distal radial physeal closure was delayed in gonadectomized cats when compared to intact cats. However, no differences were detected between cats neutered at seven weeks or seven months for mature radius length or time of distal radial physeal closure. Similar findings in cats were reported in another study.[12] In males and females, distal radial physeal closure was delayed in both groups of gonadectomized cats (neutered at seven weeks or seven months of age) compared to intact animals. In female cats, proximal radial physeal closure was also significantly delayed in cats neutered at 7 weeks of age.

The clinical significance of delayed closure of growth plates is not clear, but it does not appear to render the growth plates more susceptible to injury. In the long term studies of 263 cats[7] and 269 dogs[8] examining outcome of gonadectomy performed at an early age or traditional age, no differences in the incidence of musculoskeletal problems were seen between groups. Further, in the long term studies of 1660 cats[9] and 1842 dogs,[2] age at gonadectomy was not associated with the frequency of long bone fractures. In all these studies, long bone fractures were rare overall, suggesting that physeal fractures are not a common problem in gonadectomized dogs and cats in general.

Long-term studies have examined the incidence of hip dysplasia in dogs and the association with age at gonadectomy. Although one study of 269 dogs[8] found no association between age at gonadectomy and hip dysplasia, another study of 1842 dogs[2] found that early age gonadectomy was associated with a significant increased incidence of hip dysplasia. Puppies that underwent gonadectomy before 5.5 months of age had a 6.7% incidence of hip dysplasia, while those that underwent gonadectomy at the more traditional age had an incidence of 4.7%. However, those that were gonadectomized at the traditional age were three times more likely to be euthanized for the condition as compared to the early age group, suggesting that early age gonadectomy may be associated with a less severe form of hip dysplasia. A recent study showed that in the Golden Retriever breed, cranial cruciate ligament rupture was seen more frequently in dogs neutered before 1 year of age (early neutered) than those neutered after a year of age or remaining intact.[17] Although the incidence of hip dysplasia was higher in males of the early neutered group as compared to the intact group, this was not the case in the female dogs.

Obesity

Although obesity can occur in both neutered and intact animals, and is influenced by a number of factors such as diet and activity level, there are data to suggest that neutered cats may gain significantly more than those remaining intact. Clinically, spayed females seem likely to gain weight however objective data concerning whether dogs are more likely to experience weight gain following ovariohysterectomy is less clear. When comparing gonadectomized cats to sexually intact cats, intact cats were found to weigh less than cats altered at seven months, but there was no difference between intact cats and those neutered at seven weeks.[11] Another study,[12] 13 of 34 cats assessed obesity by body mass index at 24 months of age. Body condition scores and body mass index values were higher in animals gonadectomized at seven weeks or seven months than in intact animals, indicating that animals gonadectomized at either age were more likely to be obese than intact cats. Heat coefficient, a measure of resting metabolic rate, was higher in intact cats than in gonadectomized cats. Based on these data, the author suggested that neutered female cats require an intake of 33% fewer calories than intact female cats.[13] Another study[14] confirmed these findings, and demonstrated that the maintenance energy requirement is substantially lower for spayed female cats than for sexually intact cats. It was noted that sexually intact cats appeared to self regulate food intake, whereas spayed cats tended to eat all food available.

Information on body condition was gathered on over 8000 dogs

from 11 veterinary practices in the United Kingdom during a six month survey.[15] In this retrospective study, spayed dogs were about twice as likely to be obese as intact female dogs. However, another study[10] found no differences in food intake, weight gains, or back-fat depth among neutered (seven weeks or seven months) and intact animals during a 15-month prospective study. Interestingly, a long-term study of 1842 dogs[2] actually found that the proportion of overweight dogs was *lowest* in the early age gonadectomized dogs, as compared to the traditional age dogs.

Estrogen Responsive Urinary Incontinence

The incidence of estrogen-responsive urinary incontinence is increased among neutered female dogs and there is concern that gonadectomizing puppies at an earlier age might further increase the risk for spayed bitches. Urinary incontinence in dogs neutered at traditional ages can develop within days of the surgery or not until several years later. Estrogen-responsive urinary incontinence was reported in 34 of 791 (4%) bitches neutered at traditional ages, and seven of 2,434 (0.3%) sexually intact bitches.[16] A long term study that evaluated 269 dogs[8] adopted from shelters and neutered before 5.5 months of age, or $\geq$ 5.5 months of age, found only three cases where owners reported urinary incontinence. One dog was neutered at an early age and two dogs were neutered at the traditional age. In contrast, however, the long term study of 1842 dogs[2] demonstrated that decreasing age at the time of ovariohysterectomy was associated with increasing incidence of urinary incontinence that required medical treatment. Puppies that underwent ovariohysterectomy before three months of age appeared to be at the greatest risk. Based upon this study, female puppies should not undergo ovariohysterectomy until at least three to four months of age. The authors note, however, that in certain shelter environments, the need for gonadectomy prior to adoption may outweigh the risk of urinary incontinence.

Perivulvar Dermatitis

The vulvas of puppies neutered prior to puberty appear smaller when compared to intact bitches. Vulvar size may also appear small in intact bitches during anestrus or in some bitches spayed later in life. Perivulvar dermatitis can result in bitches with recessed or small vulvas, especially if the bitch has excessive skin and adipose tissue that cause skin folds that partially cover the vulva. Although perivulvar dermatitis has been associated with weight gains and recessed vulvas following ovariohysterectomy, there is no data to suggest that the occurrence is higher in bitches spayed at early ages over those neutered at conventional ages.

Neoplasia

Compared to intact dogs, gonadectomized dogs have been reported to have a higher risk of osteosarcoma, despite the fact that the neutered dogs actually lived longer than the intact dogs.[18,19]

Additionally, it has been suggested that ovariectomized females may be at an increased risk of hemangiosarcoma when compared to intact females,[20,21] although this was not confirmed in a later study.[17] Although rare, transitional cell carcinoma of the bladder may be seen more frequently in neutered dogs than in intact dogs.[22]

References

1. Lieberman, LL: A case for neutering pups and kittens at two months of age. *J Am Vet Med Assoc* 191:518, 1987.

2. Spain, CV, Scarlett JM, Houpt KA: Long-term risks and benefits of early-age gonadectomy in dogs. *J Am Vet Med Assoc* 224:380, 2004.

3. Faggella AM, Aronsohn MG: Evaluation of anesthetic protocols for neutering 6- to 14-week-old pups. *J Am Vet Med Assoc* 205:308, 1994.

4. Faggella AM, Aronsohn MG: Anesthetic techniques for neutering 6- to 14-week-old kittens. *J Am Vet Med Assoc* 202:56, 1993.

5. Howe LM: Short-term results and complications of prepubertal gonadectomy in cats and dogs. *J Am Vet Med Assoc* 211(1):57, 1997.

6. Aronsohn MG, Faggella AM: Surgical techniques for neutering 6- to 14-week-old kittens. *J Am Vet Med Assoc* 202:53, 1993.

7. Howe LM, Slater MR, Boothe HW, *et al.*: Long-term outcome of gonadectomy performed at an early age or traditional age in cats. *J Am Vet Med Assoc* 217:1661, 2000.

8. Howe LM, Slater MR, Boothe HW, *et al.*: Long-term outcome of gonadectomy performed at an early age or traditional age in dogs. *J Am Vet Med Assoc* 218:217, 2001.

9. Spain CV, Scarlett JM, Houpt KA: Long-term risks and benefits of early-age gonadectomy in cats. *J Am Vet Med Assoc* 224:372, 2004.

10. Salmeri KR, Bloomberg MS, Scruggs SL, *et al.*: Gonadectomy in immature dogs: Effects on skeletal, physical, and behavioral development. *J Am Vet Med Assoc* 198:1193, 1991.

11. Stubbs WP, Bloomberg MS, Scruggs SL, *et al.*: Prepubertal gonadectomy in the domestic feline: Effects on physical and behavioral development. *J Am Vet Med Assoc* 209: 1864, 1996.

12. Root MV: The effect of prepubertal and postpuberal gonadectomy on the general health and development of obesity in the male and female domestic cat. *PhD Thesis, University of Minnesota*, Saint Paul, MN, 1995.

13. Root MV: Early spay-neuter in the cat: effect on development of obesity and metabolic rate, *Veterinary Clinical Nutrition* 2:132, 1995.

14. Flynn MF, Hardie EM, Armstrong J: Effects of ovariohysterectomy on maintenance energy requirements in cats. *J Am Vet Med Assoc* 209:1572, 1996.

15. Edney ATB and Smith PM: Study of obesity in dogs visiting veterinary practices in the United Kingdom. *Vet Rec* 118:391, 1986.

16. Thrusfield MV: Association between urinary incontinence and spaying in bitches. *Vet Rec* 116:695, 1985.

17. De la Riva GT, Hart BL, Farver TB, et al.: Neutering dogs: effects on joint disorders and cancers in Golden Retrievers. PLOS One 8(2):e55937, 2013.

18. Cooley DM, Beranek BC, Schlittler DL, et al.: Endogenous gonadal hormone exposure and bone sarcoma risk. Cancer Epidemiol Biomarkers Prev 11(11):1434-1440, 2002.

19. Ru G, Terracini B, Glickman LT: Host related risk factors for canine osteosarcoma. Vet J 156(1):31-39, 1998.

20. Ware WA, Hopper DL: Cardiac tumors in dogs: 1982-1995. J Vet Intern Med 13(2):95-103, 1999.

21. Prymak C, McKee LJ, Goldschmidt MH, et al.: Epidemiologic, clinical, pathologic, and prognostic characteristics of splenic hemangiosarcoma and splenic hematoma in dogs: 217 cases (1985). J Am Vet Med Assoc 193(6):706-712, 1988.

22. Norris AM, Laing EJ, Valli VE, et al.: Canine bladder and urethral tumors: a retrospective of 115 cases (1980-1985). J Vet Intern Med 6(3):145-153, 1992.

Ovariohysterectomy

Roger B. Fingland and Don R. Waldron

Indications

The most common indication for ovariohysterectomy (OVH) is elective sterilization. Ovariohysterectomy is the treatment of choice for most uterine diseases including pyometra, uterine torsion, localized or diffuse cystic endometrial hyperplasia, uterine rupture, and uterine neoplasia.[1] In a study of 1712 ovariohysterectomies in dogs, 82% were performed for elective sterilization, 18% for reproductive tract disease, and 7% as adjunctive therapy for mammary neoplasia.[2] Ovariohysterectomy is indicated for diabetic and epileptic animals to prevent hormonal changes that alter the effectiveness of medications.

Endogenous estrogen production plays a role in the etiology of spontaneous mammary tumors.[3] Ovariohysterectomy before the first estrus provides a definitive protective factor, reducing the incidence of mammary neoplasia to 0.5%.[1,3] The risk factor is 8% when ovariohysterectomy is delayed until after one estrus, and after two or more estrus cycles, the risk rises to 26%.[1,3]

Ovariohysterectomy may be a justifiable adjuvant therapy for mammary neoplasia. Controversy exists, however OVH may inhibit the recurrence of benign or malignant tumors that have estrogen receptors. Proponents of OVH also note that remaining mammary tissue atrophies permitting easier surgery on any mammary tumors that subsequently develop.

Surgical Anatomy

The ovaries, oviducts, and uterus are attached to the dorsolateral walls of the abdominal cavity and the lateral wall of the pelvic cavity by paired double folds of peritoneum called the right and left broad ligaments. Cranially, the broad ligament is attached by means of the suspensory ligament of the ovary (Figure 33-1). The broad ligament is divided into three regions: the mesovarium, the mesosalpinx, and the mesometrium. The suspensory ligament runs from the ventral aspect of the ovary and mesosalpinx cranially and dorsally to the middle and ventral thirds of the last two ribs.[3] The proper ligament is the caudal continuation of the suspensory ligament. The proper ligament attaches to the cranial end of the uterine horn. The round ligament of the uterus attaches to the cranial tip of the uterine horn and is a caudal continuation of the proper ligament. The round ligament extends caudally and ventrally in the broad ligament, and, in most bitches, it passes through the inguinal canal and terminates subcutaneously near the vulva.[4]

The ovarian arteriovenous (AV) complex lies on the medial side of the broad ligament and extends from the aorta to the ovary. The distal two-thirds of the ovarian AV complex is convoluted, similar to the pampiniform plexus in males.[2] The ovarian artery is less convoluted in cats.[5] The ovarian artery supplies the ovary and the cranial portion of the uterine tube in the dog and cat. The arterial supply to the uterus in the nonpregnant dog and cat is relatively independent of the supply to the ovary. Small anastomoses in the broad ligament are present between branches of the ovarian artery and branches of the uterine artery.[5]

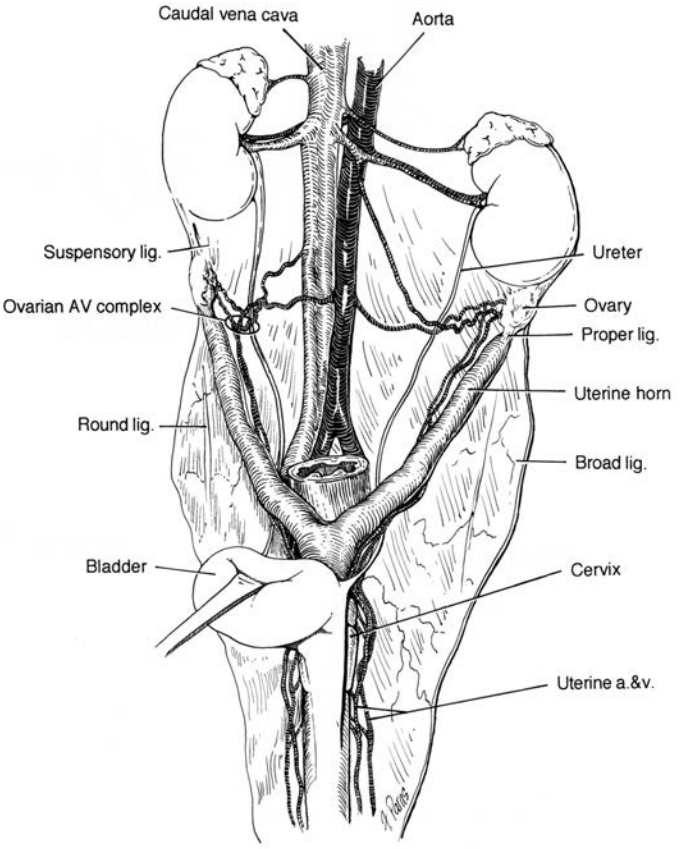


Figure 33-1. The female canine reproductive tract.

The left ovarian vein drains into the left renal vein, and the right ovarian vein drains into the caudal vena cava. The uterine veins run in close association with the uterine arteries and terminate caudally into the internal iliac veins.

Surgical Technique

The urinary bladder should be manually expressed before ovariohysterectomy. A midline abdominal incision is made extending from the umbilicus to a point halfway between the umbilicus and the brim of the pubis in the dog. The incision begins approximately 1cm caudal to the umbilicus in the cat and extends approximately 3 to 5 cm caudally. The abdominal incision must be carried further caudally in the cat to provide adequate exposure of the uterine body. A longer abdominal incision is recommended if the uterus is enlarged. The left or right uterine horn is located by using either an ovariohysterectomy (Snook) hook or the surgeon's index finger. A small hemostat may be placed on the proper ligament to aid in retraction of the ovary. The suspensory ligament is stretched or broken using the index finger (Figure 33-2A). Tension must be directed caudally along the dorsal body wall rather than perpendicular to the incision to avoid tearing the ovarian AV complex. Separate ligation of the suspensory ligament is seldom necessary. The ovarian AV complex is located, and a "window" is made in the mesovarium immediately caudal to the complex (Figure 33-2B). The ovarian AV complex is double clamped using Rochester-Carmalt hemostatic forceps in the canine or mosquito hemostats in the feline (Figure 33-3). The surgeon should maintain constant digital contact with the ovary when applying the first clamp to ensure that the entire ovary is removed. A third clamp is

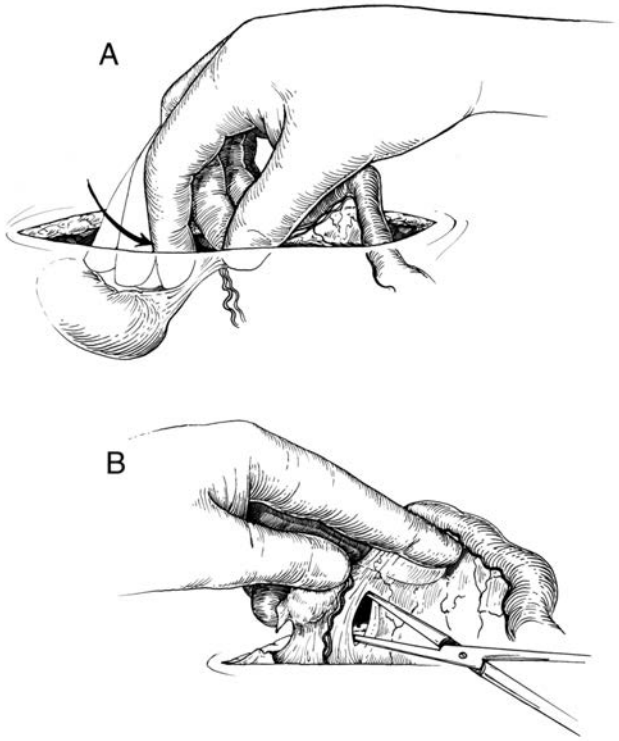


Figure 33-2. Isolation of the left ovary. **A.** The ovary is grasped between the thumb and middle finger, and the suspensory ligament is stretched or broken with the index finger. Tension must be directed caudally along the dorsal body wall. **B.** A window is made in the mesovarium caudal to the ovarian arteriovenous complex.

placed over the proper ligament between the ovary and uterine horn (Figure 33-4). The pedicle is severed between the middle clamp and the ovary (Figure 33-4). When this technique is used, the pedicle is severed between the middle clamp and the clamp closest to the ovary (See Figure 33-4, inset). Clamps should be placed on the ovarian pedicle as close to the ovary as possible to prevent accidental inclusion of the ureter.

Absorbable suture (e.g., chromic catgut, polydioxanone, or polyglyconate) is preferred for all ligatures. A circumferential

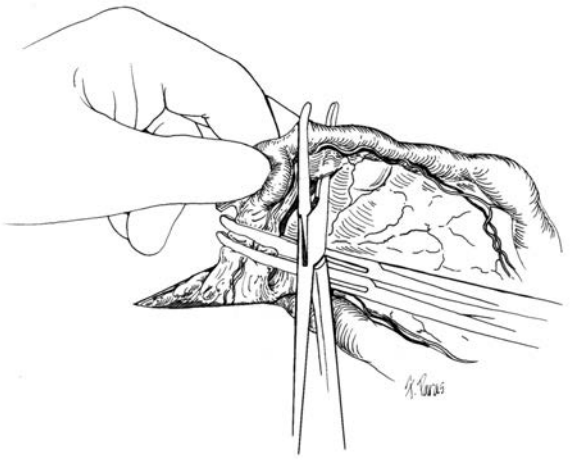


Figure 33-3. Two clamps are placed on the ovarian arteriovenous complex proximal to the ovary, and a third clamp is placed over the proper ligament.

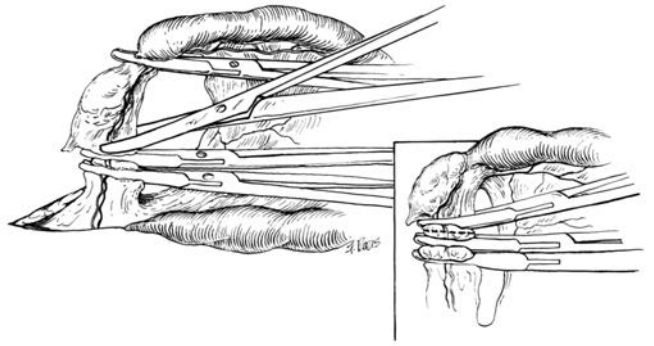


Figure 33-4. The ovarian arteriovenous complex is transected between the ovary and the middle clamp. When all three clamps are placed proximal to the ovary (inset), the ovarian arteriovenous complex is transected between the middle clamp and the clamp closest to the ovary.

suture is loosely placed around the proximal clamp (Figure 33-5). The clamp is removed while the circumferential suture is tightened so the circumferential suture lies in the groove of crushed tissue created by the clamp (Figure 33-5, inset). As the suture is tightened the second hemostatic clamp is "flashed" or temporarily opened which allows the tissue pedicle to return to its circumferential configuration and allows complete tightening of the first ligature. The benefits of clamp "flashing" are more noticeable in larger tissue pedicles. A second circumferential or transfixation suture is placed between the first circumferential suture and the cut end of the pedicle (Figure 33-6). The pedicle is grasped (without grasping the ligature) with thumb forceps, the final clamp is released, and the pedicle is inspected for bleeding. If no bleeding occurs, the pedicle is replaced into the abdomen.

The ipsilateral uterine horn is isolated by following the first side uterine horn distally to the bifurcation. The ligation procedure is repeated on the right ovarian pedicle. A window is made in the broad ligament adjacent to the uterine artery and vein (Figure 33-7A). The broad ligament is grasped and torn (Figure 33-7B and C). Mass ligation of the broad and round ligament is seldom necessary; however, large vessels in the broad ligament should be ligated especially in larger mature dogs.

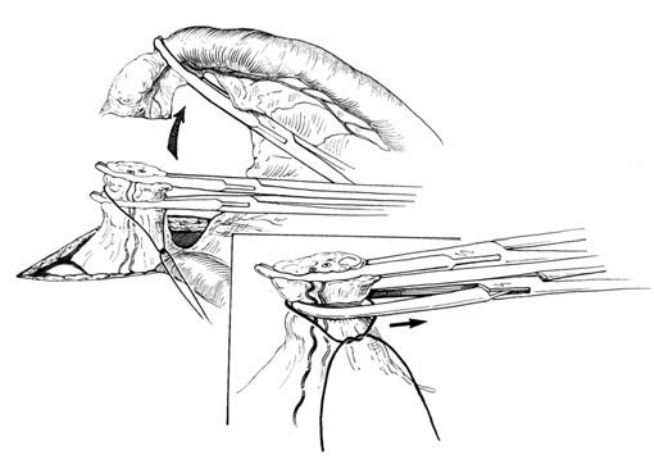


Figure 33-5. A circumferential ligature is loosely placed around the most proximal clamp. The clamp is removed, and the ligature is tightened in the groove of crushed tissue created by the clamp (inset).

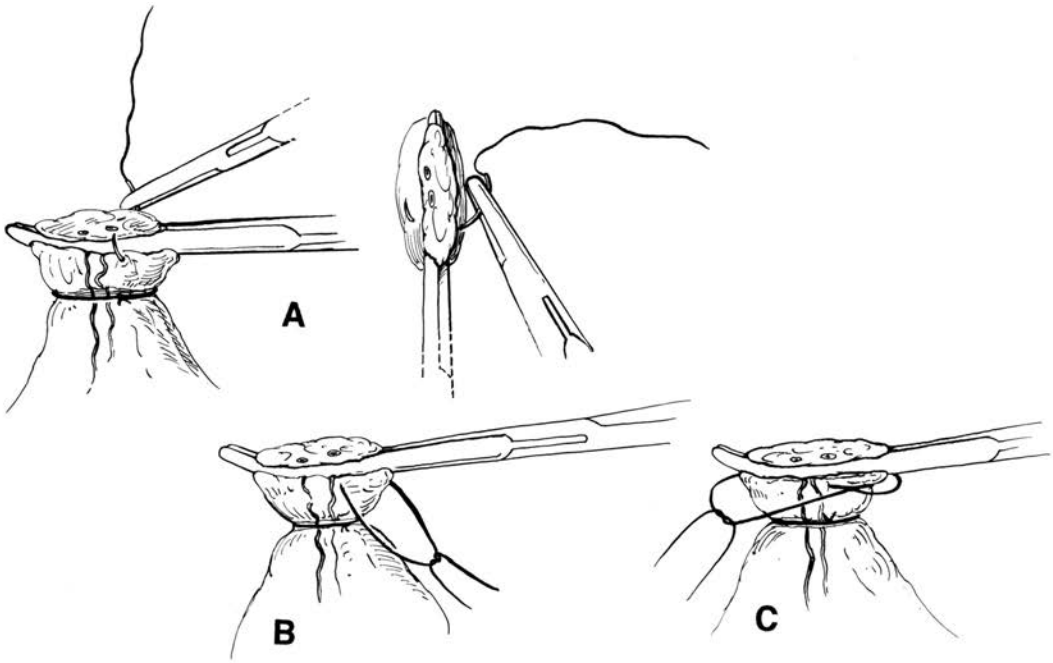


Figure 33-6. A transfixation suture is placed between the circumferential suture and the cut edge of the ovarian arteriovenous complex. **A.** Approximately one-third of the width of the ovarian arteriovenous complex is included in the initial suture. **B.** The initial suture is tied. **C.** The ends of the suture are directed around the ovarian arteriovenous complex and are tied.

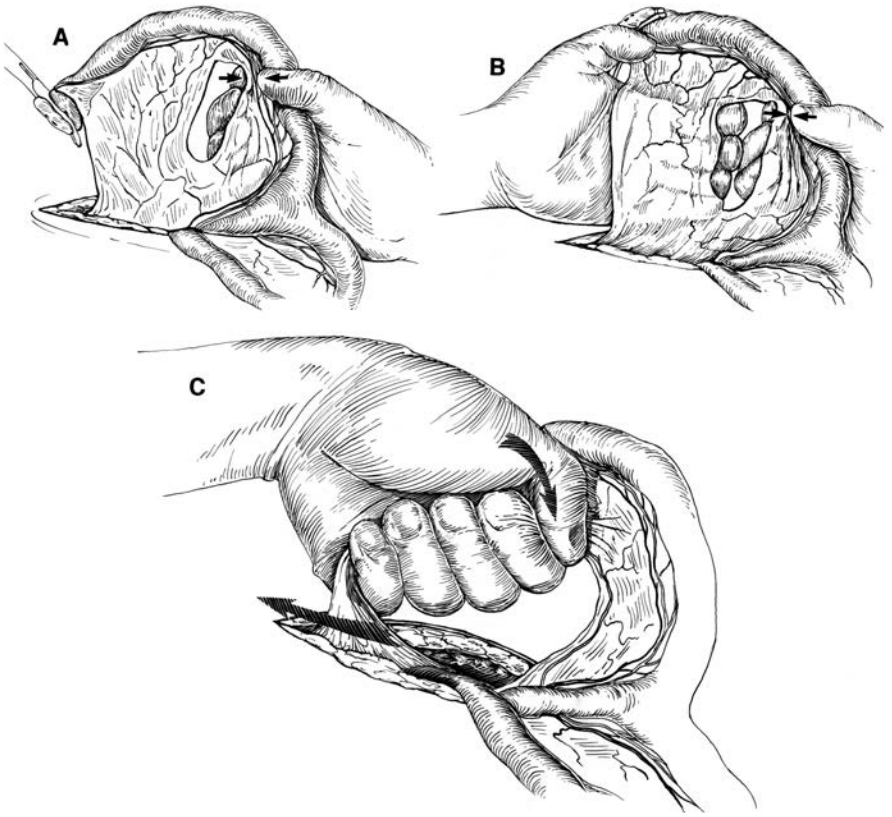


Figure 33-7. Separation of the broad ligament. **A.** The uterine artery and vein are protected with the thumb and index finger, and a window is made in the broad ligament. **B.** The broad ligament is grasped. **C.** The broad ligament is torn. Large vessels should be individually ligated.

The uterine body is exteriorized, and the cervix is located. Various techniques may be used to ligate and divide the uterine body, depending on the size of the uterus and the surgeon's preference. The triple-clamp technique may be used when the uterine body is small, such as in cats and small dogs. Three clamps are placed immediately proximal to the cervix. Care must be taken when applying clamps to the uterine body particularly in the cat because the clamps may cut rather than crush the tissue. Some surgeons prefer to not use crushing clamps on the feline uterine body. The uterine body is severed between the middle clamp and the proximal clamp. The uterine arteries and veins are individually ligated between the distal clamp and the cervix. A circumferential suture is loosely placed around the distal clamp, the clamp is removed, and the suture is tightened in the groove of crushed tissue. A transfixation suture is placed between the circumferential suture and the remaining clamp. The remaining clamp is removed, and the uterine stump is evaluated for bleeding and replaced into the abdomen.

A second technique for ligation of the uterine body involves placement of bilateral individual ligatures on each uterine artery. The uterine body is exteriorized and retroflexed. Sutures that initially incorporate the uterine artery and vein and a small bite of uterine serosa are placed on either side of the uterine body (Figure 33-8A and B). A clamp may be loosely placed proximal to the sutures to prevent backflow of blood after transection. The uterine body is severed between the clamp and the proximal sutures (Figure 33-8C). The uterine stump is evaluated for bleeding and is replaced into the abdomen. This technique is advantageous because clamps are not placed on the section of the uterine body that is ligated; therefore, the potential for cutting the tissue with the clamp is eliminated. Depending on the size of the uterine body and vessels, either mass ligatures, transfixation, or individual ligatures may be used to safely ligate the uterine vasculature.

A Parker-Kerr suture pattern has been used for ligation when the uterine body is greatly enlarged (i.e.-pyometra) but is seldom if ever indicated. A Parker-Kerr pattern has the potential for creating a closed cavity of tissue thus preventing drainage of infected material. The uterine arteries and veins should be ligated separately distal to the Parker-Kerr suture pattern.

The ovarian pedicles and uterine stump should be evaluated for bleeding before abdominal closure. The left ovarian pedicle is located by retracting the descending colon medially to expose the left paralumbar fossa. Retraction of the descending duodenum medially exposes the right paralumbar fossa and the right ovarian pedicle. The ovarian pedicles lie immediately caudal to the caudal pole of the kidneys. The uterine stump lies between the bladder and colon and is located by retroflexing the bladder. Sutures should not be grasped when evaluating the ovarian pedicles and uterine stump because excessive traction on the suture may cause it to loosen.

The abdominal incision is closed with either a simple interrupted or simple continuous suture pattern using appropriately sized polydioxanone suture. Sutures should be placed in the external rectus sheath.[6] It is not necessary to suture the internal rectus sheath or the peritoneum.[6] The subcutaneous tissue and skin are closed routinely.

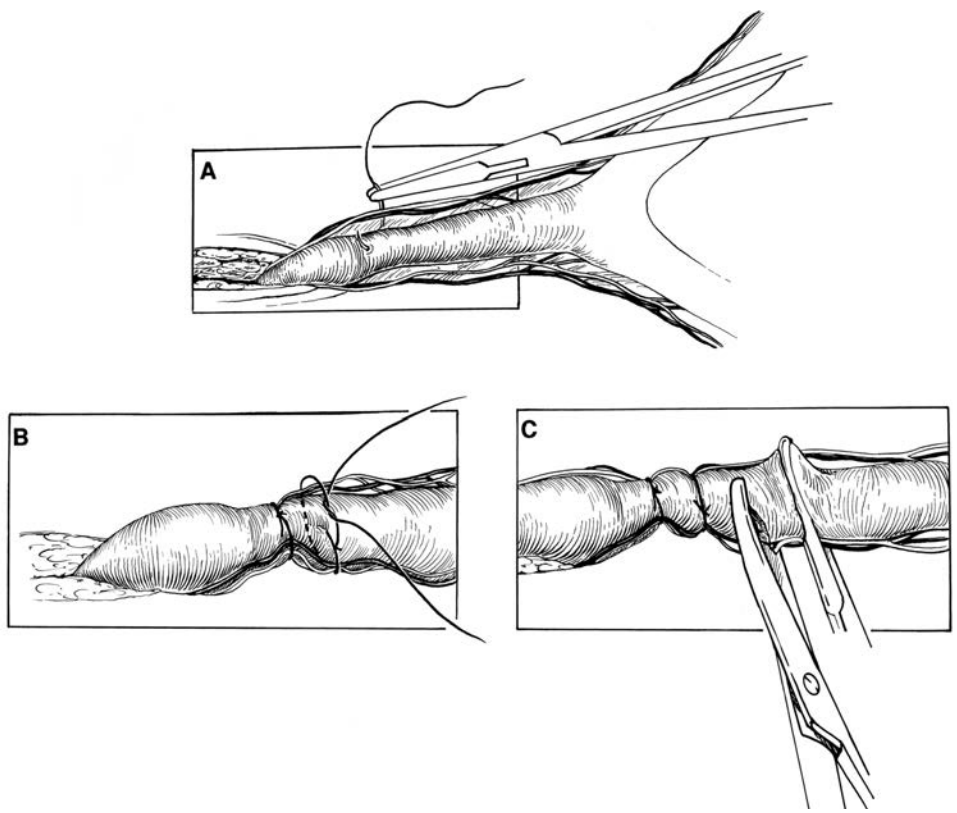


Figure 33-8. Ligation of the uterine body. **A.** A transfixion suture is placed to include the left uterine artery and vein. **B.** A similar transfixion suture is placed to include the right uterine artery and vein. **C.** A clamp is placed across the uterine body proximal to the transfixion sutures, and the uterine body is transected.

A flank approach for feline ovariohysterectomy is used widely in Europe, but it is not recommended. Recovery of a dropped ovarian pedicle is problematic, and it may be difficult to expose the opposite ovary and the uterine bifurcation through this approach.[7]

Complications and Sequelae

Hemorrhage

Intra-operative hemorrhage has been reported as the most common complication of ovariohysterectomy in dogs over 25 kg.[8] Hemorrhage during ovariohysterectomy may result from tearing of the ovarian AV complex while strumming the suspensory ligament. This complication may be avoided by carefully strumming the ligament as previously described. Intra-operative hemorrhage also may result from tearing of large vessels in the broad ligament, tearing of the uterine vessels by excessive traction on the uterine body, or accidental releasing of a clamp before placement of ligatures. Large vessels in the broad ligament should be individually ligated, and excessive traction on the uterine body should be avoided by lengthening the abdominal incision.[1] Improperly placed sutures may result in intra-operative or post-operative hemorrhage. The ovarian pedicles and uterine stump should be double ligated and evaluated for bleeding before abdominal closure. Other potential sources of hemorrhage that may be noted intra-operatively include the abdominal musculature, (rectus abdominis muscle), subcutaneous tissue and skin.

Uterine Stump Pyometra

Uterine stump pyometra can occur if the animal has elevated blood progesaterone levels. The source of progesterone may be endogenous, from residual ovarian tissue (incomplete removal), or exogenous, from progestational compounds used to treat dermatitis.[1,9] Uterine stump pyometra can be prevented by ensuring complete removal of the ovaries during OVH.

Recurrent Estrus (Ovarian Remnant Syndrome)

Recurrent estrus usually results from functional residual ovarian tissue after incomplete ovariohysterectomy. Clinical signs associated with estrus and ovarian hormonal activity may be present.[10] The hormonal effects may be delayed, depending on whether or not vascularity to the ovarian remnant has been maintained. Collateral circulation to the ovarian tissue may develop even though the ovarian AV complex has been ligated and transected.[11] Treatment of recurrent estrus after ovariohysterectomy is surgical exploration and excision of residual ovarian tissue. Surgical exploration during estrus is preferable. Identification of an ovarian remnant on one side should not preclude inspection of the other ovarian site.[10] Functional residual ovarian tissue is more commonly found on the right side.[12] Residual ovarian tissue occasionally cannot be identified or palpated, and its presence is often made manifest by increased vascularity of the ovarian pedicle. All excised tissue should be submitted for histopathologic examination. A disproportionate number of cats that develop the ovarian remnant syndrome have been operated through a flank incision.[10] Incomplete ovariectomy may be prevented by maintaining constant digital contact with the ovary during application of hemostatic clamps to the ovarian AV complex.

Ligation of Ureter

Accidental ligation of a ureter may occur during ligation of the uterine body or an ovarian AV complex.[12] Ligation of a ureter results in hydronephrosis and may predispose to pyelonephritis. The ureter may be accidentally crushed or ligated if the ovarian AV complex is dropped and indiscriminate clamping of tissue occurs in the lumber gutter. A ureter is more likely to be included in a uterine body ligature if the bladder is full because the trigone and vesicoureteral junction are cranially displaced, resulting in more slack on the ureters. Accidental ligation or crushing of a ureter may be prevented by ligating the ovarian AV complex as close to the ovary as possible, by evacuating the patient's urinary bladder preoperatively, and by isolating and ligating the uterine vessels carefully.

Urinary Incontinence

Urinary incontinence after ovariohysterectomy can be caused by a low systemic estrogen level, by adhesions or granulomas of the uterine stump that interfere with urinary bladder sphincter function, or by vaginoureteral fistulation from common ligation of the vagina and ureter.[13] Estrogen-responsive urinary incontinence may occur in any spayed bitch and is a poorly understood sequela of ovariohysterectomy.[14] The onset of estrogen responsive incontinence postoperatively is variable and may take several years.[14] The mean reported age of onset is 8.3 years and bitches spayed before 12 weeks of age appear to be at increased risk for developing incontinence.[14] The recommended therapy for estrogen-responsive urinary incontinence is oral administration of phenylpropanolamine (1.5-2.0 mg/kg PO, bid to tid) or diethylstilbestrol at 0.1 to 1.0 mg per day for 3 to 5 days, followed by a maintenance does of 1.0 mg per week.[14]

Fistulous Tracts and Granulomas

The most common cause of sublumbar fistulous tracts in spayed bitches is adverse tissue reaction to implanted nonabsorbable multifilament suture material (e.g., polymerized caprolactam, Braunamid, B. Braun Melsurgen AG, Germany) used for ovarian or uterine ligature.[12,15-17] The high bacterial adherence and capillarity of multifilament suture may contribute to persistent and progressive infection when the suture is contaminated with bacterial organisms and is buried in tissue.[18] No ovarian or uterine stump granulomas or fistulous tracts were reported in 377 bitches that had ovariohysterectomies using 2-0 chromic catgut suture.[8]

The interval between ovariohysterectomy and appearance of fistulous tracts is often several months and may be several years.[12] Fistulous tracts can occur anywhere on the trunk, although they most commonly occur in the flank when associated with ovarian pedicle ligatures and in the inguinal or thigh region when associated with a uterine ligature.[18] Ovarian pedicle granulomas caused by adverse tissue reaction to suture material may involve the kidney or proximal ureter, resulting in hydronephrosis and pyelonephritis. Uterine stump granulomas may involve the urinary bladder, distal ureters, or colon, leading to cystitis, pollakiuria, urinary incontinence, or bowel obstruction.[18] Exploratory celiotomy with excision of the offending ligature and of associated granulation tissue is the treatment of choice. All ovarian and uterine ligatures should be removed even though

some appear uninvolved because they may subsequently provoke an adverse tissue response.[12] Local exploration of fistulous tracts is seldom successful and is indicated only if exploratory celiotomy fails to identify the offending tissue.[1] The use of absorbable suture material for ovarian and uterine ligatures during ovariohysterectomy reduces or removes the incidence of this complication.[18]

Body Weight Gain

Body weight gain was the most common long-term sequela reported in one study, occurring in 26.2% of bitches undergoing elective ovariohysterectomy.[19]

The cause of excessive weight gain after ovariohysterectomy is poorly understood. One theory suggests that the fat deposits of the body possess receptors for specific steroid hormones so deposition is blocked or facilitated in a regional manner in response to testosterone, estradiol, progesterone, and cortisol. Estradiol inhibits lipoprotein lipase in adipocytes of fat deposits, so circulating fatty acides cannot be esterified and deposited.[20] A low systemic estradiol level after ovariohysterectomy may lead to excessive fat deposition and weight gain.

Eunuchoid Syndromes

The eunuchoid syndrome is occasionally observed in working dogs after ovariohysterectomy. Affected dogs have decreases in aggression, interest in work, and stamina.[20] Autotransplantation of an ovary to the subserosa of the stomach wall, which is drained exclusively by the portal vein, may prevent this complication.[20] The graft produces estradiol and progesterone, which are partially metabolized by the liver. Circulating estradiol levels are inadequate to initiate estrus, but they are sufficient to prevent the eunuchoid syndrome.[20]

Complications of Celiotomy

Accidental incision of the spleen or urinary bladder, failure to remove all gauze sponges from the abdominal cavity before closure, dehiscence, seroma formation, and self-mutilation may occur with any abdominal procedure. Self-inflicted trauma of the abdominal wound is the most commonly reported complication of ovariohysterectomy of dogs less than 25 kg.[8] Most of these complications can be prevented by gentle tissue handling, close attention to surgical detail and by adhering to the basic principles of aseptic surgical technique.

Early Prepubertal Gonadectomy

Minimal scientific evidence exists to support the widely accepted practice of delaying elective sterilization until an animal is 5 to 8 months old. Veterinarians are comfortable with this practice because untoward effects occur infrequently. Early prepubertal gonadectomy (i.e., at 8 to 12 weeks of age) has been investigated because the efficacy of sterilization programs could be enhanced if all animals were neutered before adoption. Much has been learned about the effects of early prepubertal gonadectomy on skeletal growth, obesity, behavior, secondary sex characteristics, anesthetic risk, and immunology.[21] The current body of knowledge supports the notion that early prepubertal gonadectomy is not deleterious[21] (See Chapter 35).

References

1. Stone EA. Ovariohysterectomy. In: Slatter DC, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1985:1667-1672.

2. Wilson GP, Hayes HM. Ovariohysterectomy in the dog and cat. In: Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983:334-338.

3. Farton JW, Withrow SJ. Canine mammary neoplasia: an overview. Calif Vet 1981;7;12.

4. Evans HE, Christensen GC. Miller's anatomy of the dog. 2nd ed. Philadelphia: WB Saunders, 1981.

5. DelCampo CH, Ginther OJ. Arteries and veins of uterus and ovaries in dogs and cats. Am J Vet Es 1974;35:409.

6. Rosin E. Single layer, simple continuous suture pattern for closure of abdominal incisions. J Am Anim Hosp Assoc 1985;21:751.

7. Krzaczynski J. The flank approach to feline ovariohysterectomy. Vet Med Small Anim Clin 1974;May :572.

8. Berzon JL. Complications of elective ovariohysterectomies in the dog and cat at a teaching institution: a clinical review of 853 cases. Vet Surg 1978;8:89.

9. Teale ML. Pyometritis in spayed cats (letter). Vet Rec 1972;90:129.

10. Stein BS. The genital system. In: Catcott EJ, ed. Feline medicine and surgery. 2nd ed. Santa Barbara, CA: American Veterinary, 1975.

11. Shenwell RE, Weed IC. Ovarian remnant syndrome. Obstet Gynecol 1970;36:299.

12. Pearson H. The complications of ovariohysterectomy in the bitch. J Small Anim Pract 1973;14:257.

13. Pearson H. Gibbs G. Urinary incontinence in the dog due to accidental vaginoureteral fistulation during hysterectomy. J Small Anim Pract 1980;21:287.

14. Rosin AH, Ross L. Diagnosis and pharmacological management of disorders of urinary continence in the dog. Compend Contin Educ Pract Vet 1981;3:601.

15. Osborne CA, Polzin DJ. Canine estrogen responsive incontinence: an enigma. DVM .

16. Pearson H. Ovariohysterectomy in the bitch. Vet Rec 1970; 87:257.

17. Borthwick R. Unilateral hydronephrosis in a spayede bitch. Vet Rec 1972;90:244.

18. Spackmann CJ, Caywood DD, Johnston GB, et al. Granulomas of the uterine and ovarian stumps: a case report. J Am Anim Hosp Assoc 1948;20:449.

19. Dorn AS, Swist RA. Complications of canine ovariohysterectomy. J Am Anim Hosp Assoc 1977;13:720.

20. LeRoux PH, Van Der Walt LA. Ovarian autograft as an alternative to ovariectomy in bitches. J S Afr Vet Med Assoc 1977; 48:117.

21. Salmeri KR, Olson PN, Bloomberg MS. Elective gonadectomy in dogs: a review. J Am Vet Med Assoc 1991;198:1183.

Harmonic Scalpel Assisted Laparoscopic Ovariohysterectomy (HALO)

Robert Hancock

Introduction

Ovariohysterectomy (OVH) is the most common elective surgical procedure performed for small animal sterilization in the United States.[1] Ovariohysterectomy provides canine and feline population control and decreases the incidence of life threatening diseases such as pyometra and mammary cancer. It is well documented that traditional OVH procedures performed by celiotomy inflict pain and morbidity in veterinary patients as a result of tissue trauma, organ manipulation, and inflammation.[2,3] With an increasing concern for postoperative morbidity from owners and increased public awareness of minimally invasive techniques, the frequency of minimally invasive veterinary procedures has increased recently.

Preoperative Considerations

Advantages and Disadvantages

Laparoscopic ovariohysterectomy and hysterectomy procedures in human and veterinary patients have been shown to have numerous advantages over traditional celiotomy techniques including decreased postoperative stress and pain, faster recovery periods, decreased hospital stays, improved cosmesis, and improved visualization of abdominal organs.[4] Two recent veterinary studies documented decreased postoperative pain and less incisional erythema in laparoscopic ovariohysterectomy patients.[5,6] Disadvantages of laparoscopic ovariohysterectomy include the inherent limitations of minimally invasive surgery, cost of equipment, procedural learning curve, and increased time of the operative procedure compared to traditional surgical techniques.

Anesthesia

The anesthetist should be prepared for changes in the cardiovascular and pulmonary systems during surgery. After induction of general anesthesia and aseptic preparation of the abdomen for surgery the animal is placed in a modified Trendelenburg position which requires a 20 to 30° tilt in the surgical table, placing the pelvic limbs above the level of the head.[7] This positioning provides the surgeon with better visualization of the caudal abdominal organs. However, this patient position can lead to increased pressure on the diaphragm from viscera leading to cardiopulmonary dysfunction. In addition, laparoscopic surgery requires insufflation of the abdomen with gas which increases abdominal pressure. Intra-abdominal pressures above 15 mm Hg can lead to decreased venous return and cardiac output, vasovagal reflexes, decreased compliance of the diaphragm, and ventilation-perfusion mismatch.[4,8,9] Finally, although the risk of gas embolus is low, due to carbon dioxide's high blood solubility, fluctuation in cardiopulmonary system function should be monitored carefully.

Harmonic Scalpel

The harmonic scalpel consists of an electrical generator, handpiece, an active and inactive blade system, and a foot pedal. Electrical energy is produced through an external generator and converted to ultrasonic energy by means of a piezoelectric, ceramic transducer located within the handpiece. The piezoelectric crystal vibrates at approximately 55,000 hertz, causing longitudinal movement against the inactive part of the blade. Mechanical energy from the oscillating blades results in energy transfer to tissue proteins, leading to protein denaturization and the formation of a sticky protein coagulum. This protein coagulum is capable of sealing vessels as large as 5 mm in size.[11,12]

The harmonic scalpel has been used for safe hemostasis in hysterectomy and other abdominal procedures for humans and ovariohysterectomy procedures in horses and dogs. The harmonic scalpel was designed to be used through laparoscopic and thorascopic instrument portals. This scalpel is able to cut, coagulate, and seal vessels simultaneously at much lower temperatures (50 to 100°C) than electrosurgery or laser surgical devices (150 to 400°C).[5,10] The ability to seal vessels at low temperatures with a protein coagulum is referred to as coaptive coagulation. Because of the lower temperatures, less collateral tissue damage occurs with the harmonic scalpel when compared to monopolar and bipolar cautery. In addition, the risk of stray electricity and electrical burn is eliminated with the harmonic scalpel. Lasers and cautery units vaporize cells via rapid heating and cellular explosion, resulting in eschar and smoke formation. Smoke from these devices can accumulate and decrease visualization in a hollow cavity and slow operative time. The harmonic scalpel produces no smoke, thus allowing rapid coagulation with excellent visualization of the surgical field.

Surgical Procedure

The ventral abdomen is prepared for surgery by wide clipping from the xiphoid to the pubis. Following routine preparation of the abdomen for surgery four quarter drapes are placed approximately 2 cm lateral to each row of mammary teats, at the level of the xiphoid cranially, and at the level of the pubis caudally. The dog is then placed in a Trendelenburg position to facilitate craniad displacement of the visceral contents. A 1 cm skin incision is made at the level of the umbilicus to expose the linea alba.

The abdomen is entered through the linea alba with a surgical trocar (Endopath® 355S Surgical Trocar Ethicon Endo-Surgery, Cincinnati OH) using the Hasson technique. Pneumoperitoneum is established with an insufflator (Electronic Insufflator Model 26012, Karl Storz,) to a pressure of 10mmHg using carbon dioxide gas. A 30° forward-oblique, 5 mm telescope (Hopkins II, Karl Storz, Charleston, MA) is placed through the umbilical port and used to identify the epigastric blood vessels in the abdominal wall to facilitate placement of the paramedian instrument ports under direct camera supervision (5X Hunt Trocar / 5 mm Pyramidal Tip, Apple Medical Corp, Bolton, MA). Each port is introduced 1cm lateral to the 4th mammary teat in the caudal abdomen, using care to avoid the caudal superficial epigastric artery and vein. (Figure 33-9) Babcock forceps (Endopath—5 mm Babcock Forceps, Ethicon Endo-Surgery Inc, Cincinnati, OH) are then placed

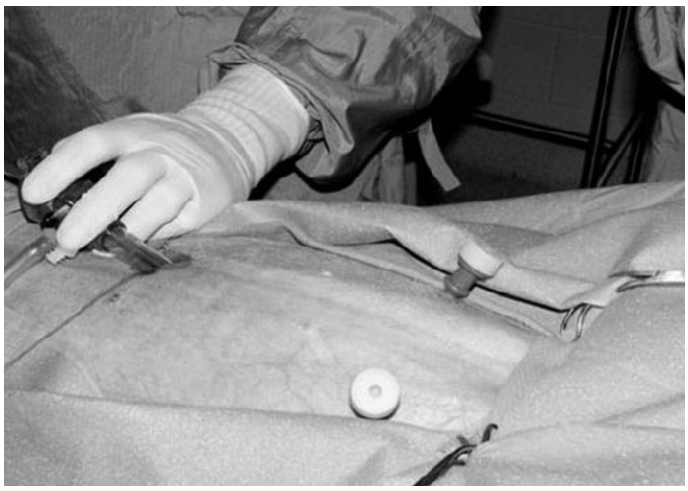


Figure 33-9. Ports are introduced 1 cm lateral to the 4th mammary teat in the caudal abdomen. Babcock forceps are then placed through the right paramedian portal and clamped to the proper ligament of the right ovary.

through the right paramedian portal and clamped to the proper ligament of the right ovary. Caudo-ventral tension is maintained on the ovarian vascular pedicle and suspensory ligament using the Babcock forceps. The harmonic scalpel (Ultracision LCSC5, Ethicon Endo-Surgery Inc, Cincinnati, OH) should then be placed through the left paramedian port and the suspensory ligament, ovarian vascular pedicle, and broad ligament of the uterus are transected and coagulated from cranial to caudal to the level of the uterine body. The uterine artery and vein are transected just proximal to the cervix, followed by the body of the uterus. The procedure is then repeated in reverse order on the left side transecting the broad ligament of the uterus first, followed by the left suspensory ligament, and finally the ovarian pedicle.

All of the transected areas are inspected for hemorrhage after completion of the procedure. The camera is then removed from the umbilical port and placed into the instrument port. Babcock forceps are then introduced through the umbilical port, clamped to the uterine body, and the entire reproductive tract is withdrawn through the umbilical port under direct camera visualization.

Pressure is applied to each side of the abdominal wall to facilitate the escape of carbon dioxide gas from the abdominal cavity prior to closure. The umbilical port can be closed with one, simple interrupted, absorbable suture. The subcutaneous tissue of the umbilical port is apposed with one, simple interrupted, absorbable, cruciate suture, followed by a single simple interrupted cruciate, nonabsorbable, skin suture. The paramedian ports are apposed similarly.

Alternative to Use of the Harmonic Scalpel

If a harmonic scalpel is not available or not used; other extracorporeal or intracorporeal knot tying techniques including Endoloop and Endoknot sutures can be placed on the ovarian and uterine pedicles for hemostasis. The Endoloop sutures consist of a pretied Westin Knot. These loops are placed through the ipsilateral cannula to the level of the intended tissue to be ligated and the loop is slowly closed with a knot pusher. The major disadvantage of using intracoporeal and extracorporeal sutures are the increased operative time and learning curve associated with their use, as well as, the risk of continued hemorrhage at the ovarian and uterine pedicles.[6,13]

Bipolar and monopolar laparoscopic cautery units can also be used for coagulation of ovarian and uterine pedicles. However, visualization during laparoscopy can be impaired by smoke when using bipolar cautery units within the abdomen. These affects are more profound in smaller sized animals. Also, when using any cautery unit there is a risk of collateral thermal damage, due to much higher coagulation temperatures and stray electricity to surrounding organs. One study evaluated laparoscopic ovariectomy using monopolar and bipolar cautery techniques. There was mesovarial arterial bleeding in 8% of dogs treated with bipolar cautery and 13% of dogs where monopolar cautery was used. Additional Endoloop ligatures were required to prevent recurrent hemorrhage in 20 of 103 of the reported cases.[14] The harmonic scalpel produces no smoke and minimal vapor. No additional hemostasis was required in any dog in one study where the harmonic scalpel was used.[5]

The use of the harmonic scalpel technique could be used for ovariectomy, as well as ovariohysterectomy procedures. Surgical times for ovariohysterectomy procedures with HALO are consistently less than 1 hour in duration and have been shown to decrease postoperative pain when compared to traditional OVH celiotomy techniques. With experience and proper training the HALO procedure provides a safe, efficient, minimally invasive technique for a commonly performed elective surgery. Laparoscopic OVH will likely become more common as owners and veterinarians seek less invasive surgical procedures for animals.

Editor's Note: The use of the harmonic scalpel and energy vessel sealing devices are well established in minimally invasive surgery (MIS). Several techniques of performing MIS ovariectomy or ovariohysterectomy are successfully used in the bitch.

References

1. Stone EA, Cantrell CG, Sharp NJ: Ovary and Uterus, in Slatter D (ed): Textbook of Small Animal Surgery (ed 2). Philadelphia, W.B. Saunders, 1993, pp 1293-1308.

2. Hardie EM, Hansen BD, Carrol GS: Behavior after ovariohysterectomy in the dog: what's normal. *Applied Animal Behvior Science* 51:111-128, 1997.

3. Slingsby LS, Lane EC, Mears ER, et al: Postoperative pain after ovariohysterectomy in the cat: a comparison of two anesthetic regimens. *Vet Rec* 143:589-590, 1998.

4. Remedios AM, Fergusen J: Minimally Invasive Surgery: Laparoscopy and thoracoscopy in small animals. *Compendium of Continuing Education* 18:51-57, 1996.

5. Hancock R, Lanz OI, Waldron DR, et al: Comparison of Postoperative Pain after Ovariohysterectomy By Harmonic Scalpel-Assisted Laparoscopy Compared With Median Celiotomy and Ligation In Dogs. *Vet Surg* 34:1-10, 2005.

6. Davidson EB, Moll DH, Payton ME: Comparison of Laparoscopic Ovariohysterectomy and Ovariohysterectomy in Dogs. *Vet Surg* 33:62-69, 2004.

7. Bernstein AM, Koo HP, Bloom DA: Beyond the Trendelenburg position: Friedrich Trendelenburg's life and surgical contributions. *Surgery* 126:78-82, 1999.

8. Richter KP: Laparoscopy in dogs and cats. *Vet Clin North Am Small Anim Pract* 31:707-727, ix, 2001.

9. Rothuizen J: Laparoscopy in small animal medicine. *Vet Q* 7:225-228, 1985.

10. Austin B, Lanz OI, Hamilton SM, et al: Laparoscopic ovariohysterectomy in nine dogs. *J Am Anim Hosp Assoc* 39:391-396, 2003.

11. Dusterdieck KF, Pleasant RS, Lanz OI, et al: Evaluation of the harmonic scalpel for laparoscopic bilateral ovariectomy in standing horses. *Vet Surg* 32:242-250, 2003.

12. McCarus SD: Physiologic mechanism of the ultrasonically activated scalpel. *J Am Assoc Gynecol Laparosc* 3:601-608, 1996.

13. Bailey JE, Freeman LJ, Hardie RJ: Endosurgery, in Bojarab WJ (ed): Current Techniques In Small Animal Surgery. St. Louis, Williams and Wilkins Company, 1998, pp 729-741.

14. Van Goethem BE, Rosenveldt KW, Kirpenstein J: Monopolar Versus Bipolar Electrocoagulation In Canine Laparoscopic Ovariectomy: A Nonrandomized, Prospective, Clinical Trial. Vet Surg 32:464-470, 2003.

Cesarean Section: Traditional Technique

Curtis W. Probst and Trevor N. Bebchuk

Introduction

Cesarean section in the dog and cat usually is an emergency procedure because prolonged dystocia risks the life of the mother and neonate. Cesarean section can be planned and performed before the onset of active parturition when dystocia is predicted owing to preexisting injuries or abnormalities that compromise the birth canal. Cesarean section is indicated when dystocia results from primary uterine inertia, when secondary uterine inertia has occurred in protracted dystocia of over 24 hours' duration, when obstructive dystocia (e.g., grossly oversized fetus or abnormally small pelvic canal) is present, or when removal of the obstructive fetus is not likely to alter the ultimate outcome of the dystocia.

Surgical Anatomy

The gravid uterus lies on the abdominal floor during the last half of pregnancy. The heavily gravid uterine horns are parallel and in contact with each other, unlike the divergent uterine horns in the non-pregnant animal. As the horns enlarge, they also flex and bend the uterus cranially and ventrally on itself. When making the abdominal incision during cesarean section, the surgeon must be aware that the uterus is close to the thin, distended abdominal wall.

The uterus is composed of three layers: tunica serosa (perimetrium), tunica muscularis (myometrium), and mucosa (endometrium). The tunica serosa is a layer of peritoneum that covers the entire uterus and is continuous with the mesometrium (broad ligaments). The muscular layer consists of a thin longitudinal outer layer and thick inner layer. The deeper myometrium contains blood vessels, nerves, and circular and oblique muscle fibers. The tunica muscularis is the layer of greatest tensile strength. The tunica mucosa is the thickest of the three layers.

The uterus is well supplied with arterial blood from the ovarian and uterine arteries (See Figure 33-1). The uterine vessels greatly enlarge during gestation and potentially complicate an ovariohysterectomy performed in conjunction with a cesarean section. Lymphatic drainage of the uterus is through the internal iliac and lumbar lymph nodes. Autonomic nervous innervation is through the hypogastric and pelvic plexuses.

Preoperative Preparations

Animals considered for cesarean section are often in poor physiologic condition at the time of presentation and should be carefully examined. Abdominal radiographs are useful in documenting the presence and number of fetuses, thus helping the surgeon to avoid inadvertently leaving a fetus in the uterus or pelvic canal. Laboratory tests are often limited to measurement of the animal's hematocrit, total plasma protein, serum urea nitrogen, or urine specific gravity. These tests assist in evaluating the need for corrective fluid therapy or cross matching of potential blood donors. Most pregnant animals are mildly anemic because of an increase in plasma volume during gestation without a concomitant increase in red blood cells. The surgeon should consider this physiologic anemia when deciding whether the dam requires a whole-blood transfusion.

An intravenous fluid infusion should be established before any anesthesia is given. The preferred fluid is a balanced electrolyte solution such as lactated Ringer's solution. A solution of 2.5% dextrose and half-strength lactated Ringer's may be more appropriate if the animal has not eaten for some time and hypoglycemia is suspected. A baseline administration rate of 10 mL/kg/hr may be increased as indicated by physiologic parameters. All volume deficits should be corrected before the surgical procedure is begun, if possible. If the fetuses are known to be dead and decomposing or if uterine infection is established, intravenous antibiotic therapy (cephalothin sodium, 40 mg/kg IV, or cefazolin sodium 22 mg/kg IV) should be instituted at this time.

The surgeon and the client should discuss, before surgery, the nature of the surgical procedure, its potential complications, and the issue of simultaneous ovariohysterectomy. The length of the surgical procedure may be important, depending on the condition of the dam. The advisability of an additional operation for ovariohysterectomy should be carefully considered. Ovariohysterectomy may be better postponed until the litter is weaned and the uterine vasculature has returned to normal size.

Surgical Technique

The dam is clipped from the xiphoid to the pubis, and the ventral abdomen is initially prepared by surgical scrubbing before induction of anesthesia to reduce total anesthesia time. Anesthesia induction and intubation are performed on the operating table. Usually, the dam has not been fasted before anesthesia; therefore, the patient should be intubated rapidly to minimize the risk of aspiration should vomiting occur during induction of anesthesia.

Operative speed is important in cesarean sections because prolonged "incision-to-delivery" time is associated with

increased fetal asphyxia and depression. A 10 to 20° left or right lateral tilt from dorsal recumbency is frequently used in women to prevent supine hypotension syndrome, which is thought to result from compression of the gravid uterus on the posterior vena cava, thus reducing venous return. Supine hypotension syndrome does not occur in the full-term pregnant bitch due to the bicornuate uterus and its position during pregnancy. Maternal posture has no effect on systemic blood pressure, therefore dorsal recumbency is an acceptable position for cesarean sections in dogs and cats.

After induction of anesthesia, the patient's limbs are tied down, and the final surgical preparation of the ventral abdomen is rapidly completed. The ventral abdomen is four-quadrant toweled and is draped from the xiphoid to the pelvic brim, to allow room for extension of the abdominal incision if necessary.

A ventral midline incision is made commencing at the umbilicus. The length of the incision is determined by the estimated size of the uterus. The mammary glands often are hypertrophied, and the surgeon should not invade mammary tissue when making the skin incision. The surgeon should also remember that the uterus is enlarged and should not be lacerated when the abdominal cavity is entered. I prefer using thumb forceps and a scalpel to open the abdominal cavity; however, Mayo scissors also are acceptable.

After the abdominal incision is completed, the wound edges are protected with laparotomy pads moistened with sterile saline. The first uterine horn and then the second are exteriorized by careful lifting through the incision. The surrounding and underlying viscera are packed off with additional moistened laparotomy pads to prevent abdominal contamination with fetal fluids. A small incision with a scalpel is then made in a relatively avascular area on the dorsal or ventral aspect of the uterine body; one must be careful not to lacerate a fetus inadvertently with the scalpel. The uterine incision is then extended with scissors to a length sufficient for easy removal of the fetuses (Figure 33-10).

In dystocia, the fetus present in the uterine body should be removed first. Each fetus is brought to the incision by gently "milking it down" the uterine horn. This is done by squeezing the uterine horn proximal to the enlargement. Once the fetus is near the incision, it may be grasped, and gentle traction may be applied to facilitate rapid removal from the uterus (Figure 33-11).

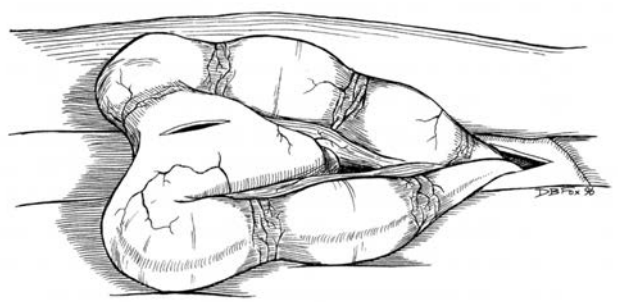


Figure 33-10. The gravid uterus has been exteriorized and surrounded with moistened laparotomy pads. An incision has been made in the dorsal aspect of the uterine body.

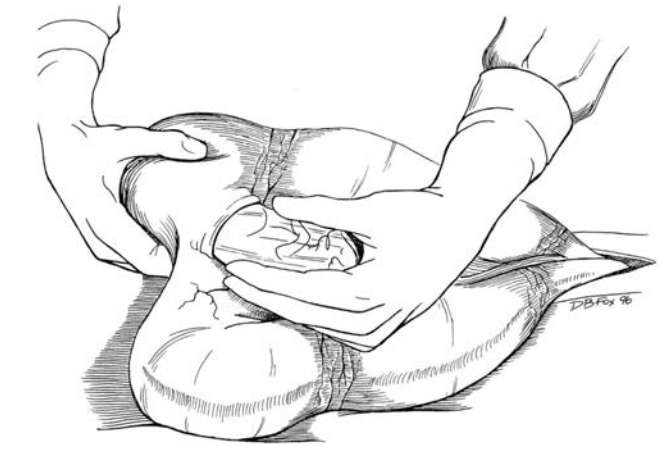


Figure 33-11. Each fetus is brought to the incision by squeezing the uterine horn proximal to the enlargement; it may be grasped and gentle traction applied to remove it from the uterus.

As each fetus is removed, the amniotic sac is broken to allow breathing to begin (Figure 33-12). Fetal fluids should be removed from the operative field by suction to minimize contamination. The umbilical vessels are then clamped and are severed approximately 2 to 3 cm from the fetal abdominal wall (Figure 33-13). The neonate is placed on a sterile towel and is passed to an attendant. The associated placenta is then slowly removed from the endometrium by gentle traction to minimize hemorrhage. This procedure is repeated until all fetuses and placentas have been removed. If considerable difficulty is encountered in mobilizing the fetuses down the uterine horns, additional incisions can be made in the horns. Before closure, the uterus is palpated from the pelvic canal to each ovary to be certain that all fetuses and placentas have been removed.

Another method of delivery is to remove the neonate and placenta with the umbilical cord and fetal membranes still intact. The amniotic sac is broken, and the cord is clamped when the neonate has been handed to an attendant. More maternal hemorrhage may be noted with this method.

Once all fetuses have been removed, the uterus rapidly begins to contract; this contraction is important in arresting hemorrhage. If the uterus has not begun to contract at the time of closure, oxytocin (5 to 20 units intramuscularly) can be administered.

I prefer absorbable suture material such as polydioxanone or polyglyconate with swaged-on noncutting needles for uterine closure. The edges of the uterine incision are carefully apposed with an inverting, continuous Cushing pattern followed by a continuous Lembert oversew (Figure 33-14). Before the uterus is returned to the abdomen, the closure should be inspected and the uterus should be cleansed with warmed sterile saline solution. If abdominal contamination has occurred during the surgical manipulations, the abdomen should be liberally lavaged with warmed sterile saline solution. The omentum is replaced over the uterus and other abdominal viscera before abdominal closure; the linea alba is closed with simple interrupted sutures of appropriate-sized absorbable suture material. Nonabsorbable suture material, such as polypropylene, nylon, or stainless steel

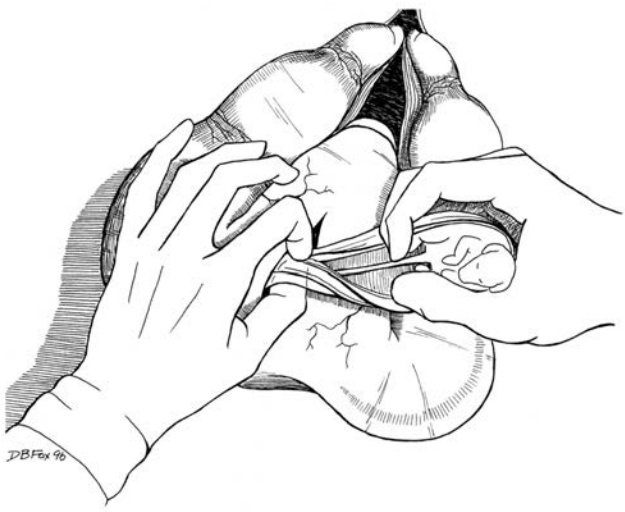


Figure 33-12. As the fetus is removed from the uterus, the amniotic sac is broken to allow breathing to begin.



Figure 33-13. The umbilical vessels are clamped and severed approximately 2 to 3 cm from the fetal abdominal wall.

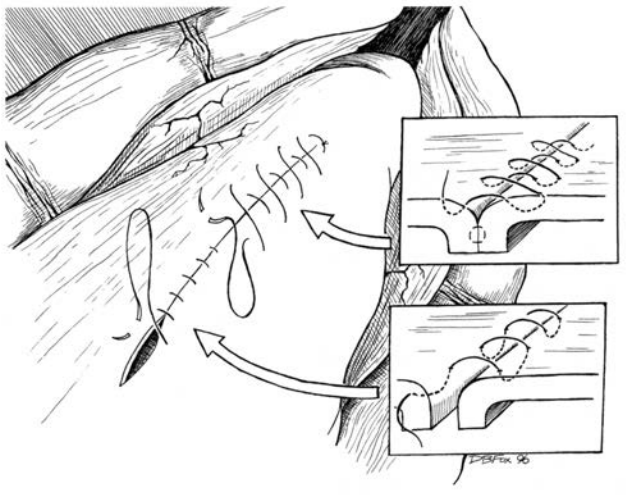


Figure 33-14. Double-layer closure of the uterus. *A.* A continuous Cushing pattern is used for the first layer. *B.* The first-layer closure is oversewn with a continuous Lembert pattern.

wire, may also be used to close the linea alba. The subcutaneous tissue is closed with 3-0 or 2-0 absorbable suture, and the skin is closed with nonabsorbable suture.

Before the conclusion of the surgical procedure, all inhalation anesthetic agents are discontinued, and the dam is weaned from assisted ventilation by progressively decreasing the respiratory rate. The dam should then be given several maximal inspirations to reopen any atelectatic areas of lung before a return to breathing room air.

Extubation should not be too hasty because patients that undergo cesarean section may have full stomachs and may vomit during induction or recovery. Vomiting during recovery is a major problem in parturient women, but it is less important in the dog and cat.

Resuscitation of the Neonates

After the neonate has been handed to the assistant, its umbilical cord should be temporarily clamped, the fetal membranes should be removed (if this has not yet been done), and its viability should be ascertained. If a heartbeat can be palpated, the nasopharynx should be cleared of fluid and mucus by gentle suction or cotton swabs. If a suction apparatus is not available, a bulb syringe can be used for suction. A gentle, controlled, downward swing of the neonate may help to clear fluid from the upper airways by centrifugal force. The neonate is then vigorously dried because skin stimulation stimulates respiratory drive in a reflex manner.

The neonate should be breathing and crying by this stage. Other encouraging signs are pink mucous membranes and a strong pulse. More active resuscitative measures include narcotic antagonists such as naloxone (0.01 mg/kg IM or IV) and the respiratory stimulant doxapram (1 to 2 drops sublingual or 0.1 ml IV in the umbilical vein). In the event of cardiorespiratory collapse, an emergency endotracheal intubation may be attempted with a plastic intravenous catheter (18 to 20 gauge).

Postoperative Care of the Dam and Neonates

When the puppies or kittens have been resuscitated and dried, they should be kept in a warm environment to avoid chilling. The clamp is removed from the umbilical cord, which is checked for hemorrhage. If hemorrhage occurs, the cord should be ligated with 3-0 chromic gut.

While the mother is recovering from anesthesia, her mammary glands should be cleaned with warm water to remove any residual surgical preparation solutions, blood, or fetal fluids. The dam should be returned to her litter as soon as she has recovered. The dam should continue to be carefully watched by the veterinarian or the owner in the first hours after the operation because sudden lapses into shock can occur if uterine bleeding recommences.

Colostrum is important to the neonates. Although some transplacental acquisition of passive immunity occurs before birth, most antibodies are transferred through the colostrum after birth. Nursing also stimulates the release of oxytocin to mediate

uterine contraction. Although drugs can be transferred to the neonate in the milk, this is not important unless drugs are administered to the mother on a continuing basis. Drugs that are weak bases and become ionized at a low pH usually accumulate in the milk at a higher concentration than in the dam's blood.

Before the litter is discharged, puppies or kittens should be inspected for obvious congenital abnormalities, such as deformed limbs, cleft palate, and imperforate anus. This check, together with advice to the owners on neonatal care, ensures good veterinarian-client relations. The dam and her litter can be discharged as soon as she is able to stand and appropriate behavior patterns toward the litter are confirmed. Owners should be instructed to monitor the dam carefully for the next 24 to 48 hours. They should look for evidence of continued uterine hemorrhage, anorexia, or signs of infection or dehiscence of the abdominal incision. The dam should be returned in 7 to 10 days for suture removal.

Postoperative Complications

Certain complications are associated with both emergency and elective cesarean section. Perioperative maternal mortality rates of over 4% have been reported, perhaps owing to the emergency nature of the operation and the patient's stressed condition at the time of surgery. Hypovolemia and hypotension are the most common complications and are treated with vigorous fluid therapy or blood replacement. Hemorrhage of uterine origin should be controlled with oxytocin (5 to 20 units IM or IV). In severe hemorrhage, the dosage may be repeated after 2 to 4 hours, and whole blood transfusion may be started. Persistent hemorrhage may require an emergency ovariohysterectomy. If an infected uterus is encountered during the surgical procedure, ovariohysterectomy or packing of the uterus with antibiotic boluses and systemic antibiotics should be considered.

Postoperative peritonitis should not be a problem unless a break in surgical technique or abdominal contamination with septic uterine contents has occurred. Infection can be controlled with careful surgical technique, intraoperative abdominal lavage, and antibiotic therapy in most cases. Agalactia may occur in the queen or bitch after cesarean section, but normal milk flow usually occurs within 24 hours. Oxytocin (0.5 units/kg intramuscularly) may be administered to stimulate milk production if necessary. Excessive depression of either the mother or the offspring after anesthesia indicates that one should critically review the anesthetic protocol for reduction in doses of analgesics or barbiturate depressants.

Suggested Readings

Abitbol MM: Inferior vena cava compression in the pregnant dog. *Am J Obstet Gynecol* 130:194, 1978.

Gilroy BA, DeYoung DJ: Cesarean section. *Vet Clin North Am* 16:483, 1986.

Macintire DK: Emergencies of the female reproductive tract. *Vet Clin North Am* 24:1173, 1994.

Moon PE, Erb HN, Ludders JW, et al: Perioperative management and mortality rates of dogs undergoing cesarean section in the United States and Canada. *J Am Vet Med Assoc* 213:365, 1998.

Probst CW, Webb AI: Postural influence on systemic blood pressure gas exchange, and acid/base status in the term-pregnant bitch during general anesthesia. *Am J Vet Res* 44:1963, 1983.

Probst CW, Broadstone RV, Evans AT: Postural influence on systemic blood pressure in large full-term pregnant bitches during general anesthesia. *Vet Surg* 16:471, 1987.

Cesarean Section by Ovariohysterectomy

Holly S. Mullen

Indications

Traditional cesarean section (hysterotomy) has been the treatment of choice for canine and feline dystocia that is not responsive to medical management. Hysterotomy is a well described and widely accepted technique. Most references advise against ovariohysterectomy at the time of hysterotomy, citing additional stress to the female, increased blood loss, longer anesthetic time, and problems with neonatal survival.[1,3] Sometimes, no reason is specified.[4] Many practicing veterinarians have performed ovariohysterectomy for dystocia in the dog and cat with excellent results. The technique of "en bloc" cesarean section (ovariohysterectomy) followed by rapid removal of neonates from the gravid uterus) has been shown to be safe and effective for both cats and dogs.[5] Future reproduction is impossible after this technique, a fact that pleases most owners. The technique described is easier, quicker, and has less chance for intra-operative contamination than traditional cesarean section.

Surgical Technique

Preoperative considerations and anesthetic techniques are identical to those for routine cesarean section. A caudal ventral midline incision is made through the skin, subcutaneous tissue, and linea alba of the abdomen. Care is taken as the linea is incised to not lacerate the large gravid uterus which may be in contact with the ventral abdomainl wall. The incision is packed off with sterile, saline moistened laparotomy sponges. The gravid uterus is exteriorized, and the uterine horns are laid out laterally to the incision (Figure 33-15). Next, the suspensory ligaments are cut or broken to allow mobilization of the ovaries by their vascular pedicles. No clamps are applied at this time. The broad ligament is broken down manually or incised on both sides of the uterus from the ovarian pedicle to the cervix. This leaves the blood supply to the uterus and fetuses intact while freeing up all attachments except the ovarian pedicles and the uterine body (Figure 33-16).

Ovariohysterectomy can now be performed rapidly and safely, with a maximum of no more than 45 to 60 seconds elapsed between clamping of the ovarian pedicles and uterine body and delivery of the neonates by assistants. The surgeon palpates the patient's cervix and vagina to check for a fetus. If one is present, it is manipulated gently back into the uterine body. Two hemostatic clamps are placed across each ovarian pedicle, and three clamps are placed across the uterine body just distal to the

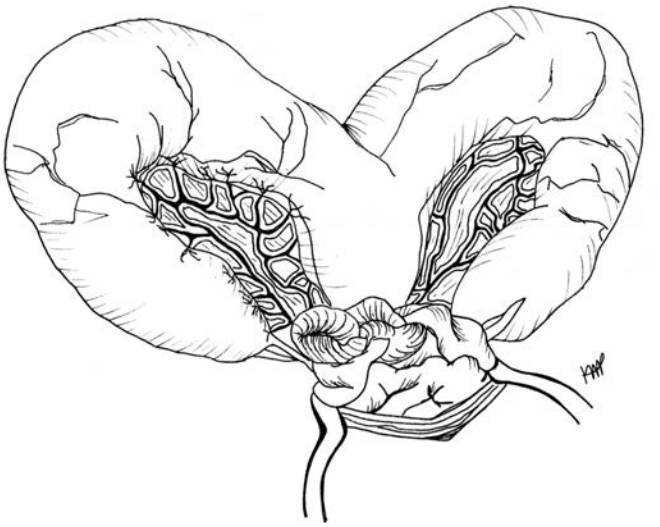


Figure 33-15. The gravid uterus is exteriorized, and both horns are laid out laterally to the abdominal incision.



Figure 33-16. The suspensory ligaments are broken down to exteriorize the ovaries, and the broad ligament is torn on both sides of the uterine horns. The ovarian pedicles and the uterine body provide blood supply to the uterus and are the only structures remaining that need to be transected and ligated to remove the gravid uterus.

cervix. A moistened laparotomy pad is placed to minimize any abdominal contamination from the uterine incision. The gravid uterus and ovaries are removed by dividing between the clamps (Figure 33-17). The surgeon hands the gravid uterus to a team of assistants, who immediately open the uterus and resuscitate the neonates. The ovarian pedicles and uterine stump are ligated with chromic gut or other absorbable suture sized according to the surgeon's preference. The abdomen is closed routinely. Subcuticular sutures are preferred over skin sutures to prevent irritation of the suture line by the nursing pups. Appropriate postoperative pain relievers, such as oxymorphonc (0.03 to 0.1 mg/kg) intravenously, intramuscularly, or subcutaneously, morphine sulfate (.1 to .5 mg/kg) subcutaneously or intramuscularly, or buprenorphine (5 to 10 ug/kg intravenously, intramuscularly, or subcutaneously), are given after the uterus has been removed.

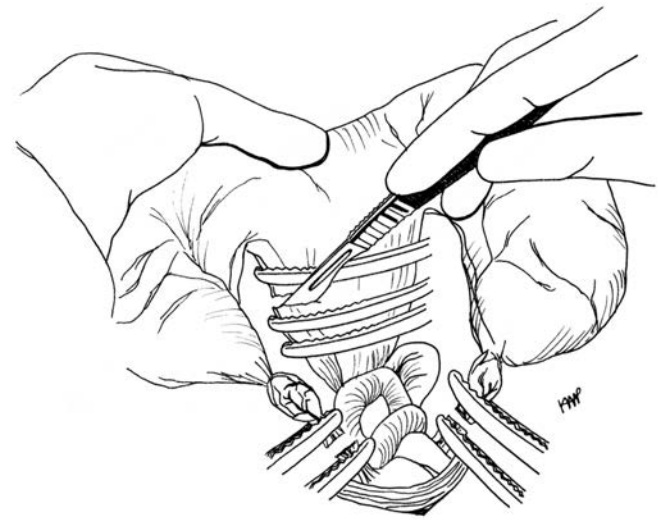


Figure 33-17. The gravid uterus can be removed in 45 to 60 seconds by first placing two hemostats on each ovarian pedicle and then three clamps on the uterine body and transecting between them as shown.

Resuscitation of the Neonates

The gravid uterus is handed to an assistant after removal, who takes it from the sterile operating room to a location previously prepared for neonatal resuscitation. The uterus is opened with scissors or a scalpel blade (Figure 33-18), taking care not to cut a fetus. The neonates are rapidly removed and resuscitated by the assistants. Ideally, one assistant should be available to treat each neonate, although one person can care for two or three neonates at a time if they are healthy. Hypoxia is thought to be one of the primary reason for neonatal mortality.[6] The mortality rate of puppies and kittens delivered by ovariohysterectomy is reportedly lower than the mortality rates by either traditional cesarean section or natural parturition.[5] This finding suggests that ovariohysterectomy for the treatment of dystocia has no adverse effect on neonatal survival.

Contraindications for Ovariohysterectomy

No important complications or contraindications for this technique have been described.[5] Some limitations include the

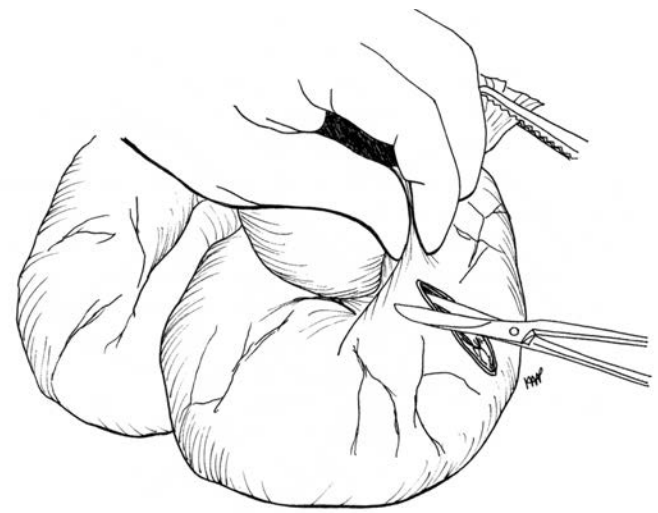


Figure 33-18. An assistant opens the uterus with scissors or a scalpel blade and removes and resuscitates the neonates.

need for multiple assistants for simultaneous neonatal resuscitation of a large litter and the loss of future reproductive capability (although this is usually considered an asset). Anemia is not a complication with this technique, because no significant decrease in packed cell volume was reported in either dogs or cats undergoing cesarean section by ovariohysterectomy.[5] In a small, significantly anemic female with a markedly engorged uterus, however, hysterotomy followed by rapid involution of the uterus will allow return of some of the uterine blood to the peripheral circulation before removal of the nongravid uterus.

Advantages of Ovariohysterectomy

Ovariohysterectomy for dystocia is rapid and safe for both the bitch and the neonate. Use of this technique minimizes anesthetic time and reduces intraoperative peritoneal contamination by uterine contents, which may occur during hysterotomy. Both dogs and cats continue to lactate normally as long as the babies continue to nurse. There is scant to no pos-toperative lochial discharge, as is common for several days after birth because the uterus has been removed. Ovariohysterectomy also provides an opportunity for future population control in pets that are unable to reproduce naturally or whose owners may not be able to afford a second operation for sterilization of the animal in the future. The health of the mother and of the neonates is not compromised when cesarean section by ovariohysterectomy is used as the surgical treatment for dystocia.

References

1. Herron MR. Herron MA. Surgery of the uterus. Vet Clin North Am 1975;5:471 476.

2. Probst CW, Webb M. Cesarean section in the dog and cat: anes¬thetic and surgical techniques. In: Bojrab AU, ed. Current tech¬niques in small animal surgery. 2nd ed. Philadelphia: Lea & Fee¬iger, 1983:346 351.

3. Gaudet DA, Kitchell BE. Canine dystocia. Compend Contin Educ Pract Vet 1985;7:406 418.

4. Probst CW. Uterus: cesarean section. In: Bojrab AU, ed. Current techniques in small animal surgery. 3rd ed. Philadelphia: Lea & Febiger, 1990:404 408.

5. Robbins MA, Mullen, HS. En bloc ovariohysterectomy as a treatment of dystocia in dogs and cats. Vet Surg 1994; 23: 48 52.

6. Fox MW. Neonatal mortality in the dog. J Am Vet Med Assoc 1963;143:1219 1223.

Chapter 34

Vagina and Vulva

Surgical Treatment of Vaginal and Vulvar Masses

Ghery D. Pettit

In the bitch, physiologic enlargement of the vulvar labia during proestrus and estrus is a normal estrogenic response. It may be mimicked or exaggerated by masses within the vestibule of the vulva or the vagina that cause the labia to protrude. Such masses include hyperplasia of the vaginal floor, vaginal prolapse, vestibular or vaginal tumors, and clitoral enlargement. Subtle perineal bulges may be detected, but the masses usually become apparent to an animal's owner when they protrude through the vulva, cause irritation and licking, or interfere with mating. They may cause dysuria. Prolonged estrogenic stimulation from follicular cysts or granulosa cell tumors can cause persistent hyperplasia of the labial and vaginal mucosa, making the labia larger, firm, pigmented, and hairless.

Inspection, digital vaginal or rectal palpation, and vaginoscopy provide preliminary identification of most vaginal lesions. In at least one instance, an intraluminal vaginal tumor was diagnosed by pneumovaginography. Surgical treatment of these lesions is facilitated by episiotomy. Excised neoplasms should be identified histologically.

Hyperplasia of the Vaginal Floor

During proestrus and estrus, the vestibular and vaginal mucosae normally become swollen, thickened, and turgid. Exaggeration of this estrogenic response occasionally leads to the development of a transverse mucosal fold on the floor of the vagina just cranial to the external urethral orifice. Although "hyperplasia" is the accepted term for this condition, histologically the swelling is mostly edema with some fibroplasia. If the redundant fold becomes large enough, it protrudes between the labia of the vulva as a red, fleshy mass (Figure 34-1A). The disorder occurs most often during a bitch's first, second, or third estrus. Spontaneous regression occurs during metestrus, but recurrence is common at the next estrus. The condition has been reported in more than 20 breeds of dogs, with frequent mention of brachycephalic breeds, such as boxers and English bulldogs.

Because the protrusion is vulnerable to trauma, inflammation, and ulceration, tends to recur, and is aesthetically objectionable, amputation is frequently the treatment of choice. Recurrence after surgical excision is uncommon, and natural mating is possible at subsequent estrous periods. With or without surgical excision, ovariectomy provides permanent relief.

Alternatively, one can manage the condition conservatively until it regresses spontaneously by lubricating the mass with an antibiotic ointment and applying an Elizabethan collar to prevent

self-abuse. If breeding during the same estrus is important, artificial insemination can be performed. Simultaneous excision of the mass and artificial insemination are technically possible but seldom indicated.

A third option is to try to shorten the duration of estrogenic stimulation of the vaginal tissue by inducing ovulation at the onset of clinical signs. A single dose of gonadotropin-releasing hormone or human chorionic gonadotropin has been used for this purpose. Regression of the prolapse occurs about 1 week after induction of ovulation.

Surgical Treatment

The animal is positioned in ventral recumbency with the hindquarters elevated, and the perineum is prepared aseptically. The vestibule and vagina are cleansed with a mild antiseptic solution (1:10 povidone-iodine [Betadine] or 1:5000 benzalkonium chloride [Zephiran chloride] solution). A median episiotomy incision is begun with a scalpel or an electrosurgery unit and is completed with scissors. Doyen intestinal forceps can be positioned on each side of the incision to serve as a guide and to reduce bleeding. Hemorrhage is controlled with hemostatic forceps, ligation, or electrocoagulation. Retracting the margins of the episiotomy incision exposes the vaginal lumen. The mass must be elevated for catheterization of the urethra, to identify and protect that structure (Figure 34-1B and C). The superfluous tissue is amputated by making connecting, curved, transverse incisions through its base. One incision is made on the dorsal surface of the mass (the cranial aspect of its base), and the other is made on its ventral surface (the caudal surface of the base of the mass). The incisions should be no deeper than necessary to excise the mass. The mucosal opening is closed with absorbable suture material in a transverse, simple continuous pattern (Figure 34-1D). The catheter is removed, and the episiotomy incision is closed (Figure 34-1E). The mucosa is apposed with simple interrupted absorbable sutures. In obese or heavily muscled animals, the musculature should be sutured separately with absorbable sutures. The skin incision is closed with simple interrupted nonabsorbable sutures. If bleeding persists, a vaginal tampon may be left in place for 12 hours.

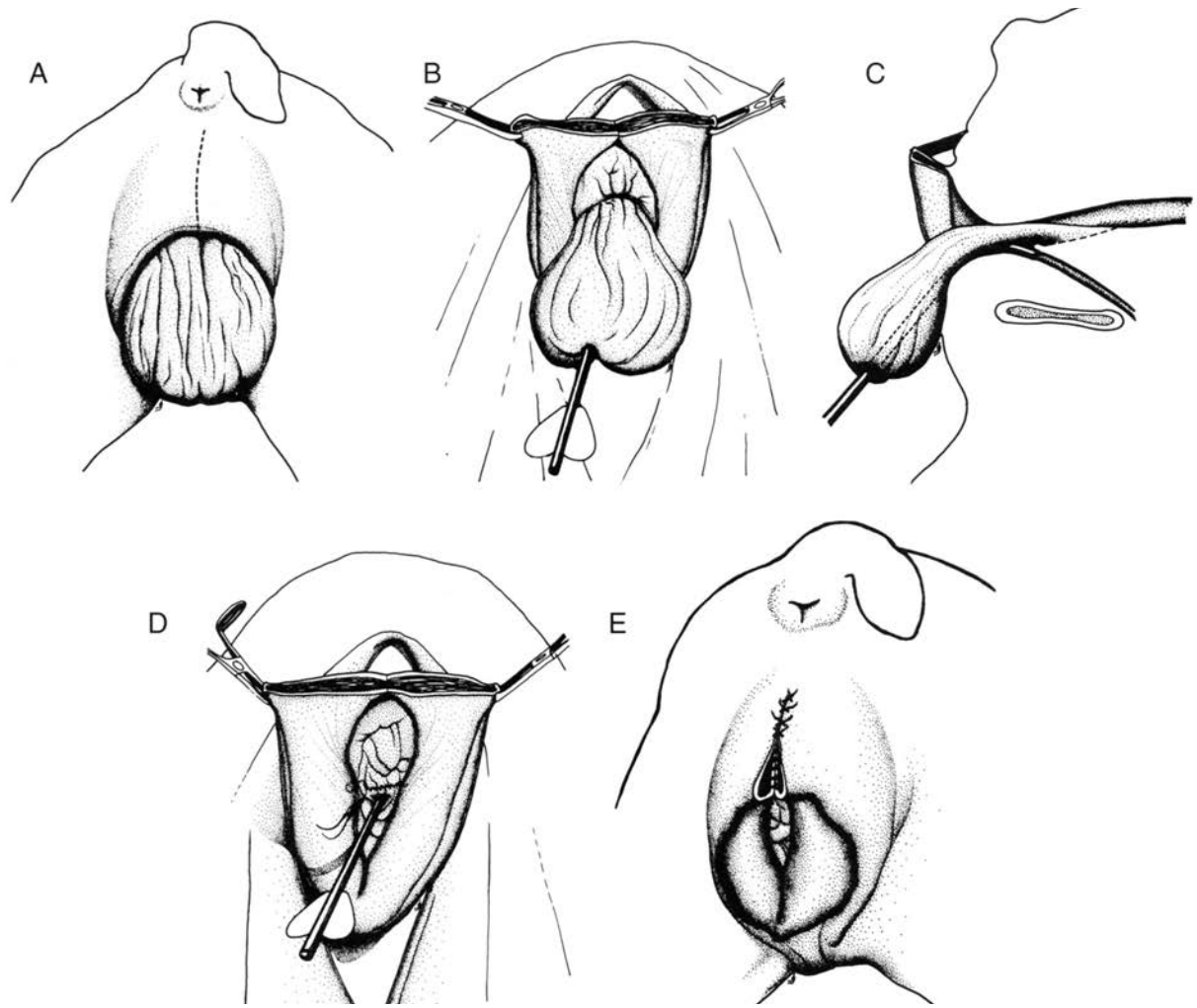


Figure 34-1. Hyperplasia of the vaginal floor. **A.** The broken line indicates the site of the episiotomy incision. **B.** The vestibule has been opened by performing an episiotomy, and a urethral catheter has been inserted. **C.** Lateral view. Episiotomy and urethral catheterization have been performed. The broken line on the floor of the vagina indicates the incision site for amputation of the redundant mucosal mass. **D.** The mass has been amputated, and the mucosal incision is closed with a simple continuous suture. **E.** Postoperative view. The catheter has been removed, and the episiotomy incision is being closed.

Vaginal Prolapse

Cylindric prolapse of the vaginal wall is much rarer than hyperplasia of the vaginal floor. In this condition, which also occurs during estrus, a donut-shaped eversion of the entire vaginal circumference protrudes from the vulva (Figure 34-2). Vaginal prolapse has been reported after forcible separation of the male and female during the genital tie. As in hyperplasia of the vaginal floor, the external urethral orifice is ventral to the entire mass, but access to the vaginal canal is through the center of the protrusion, rather than dorsal to it.

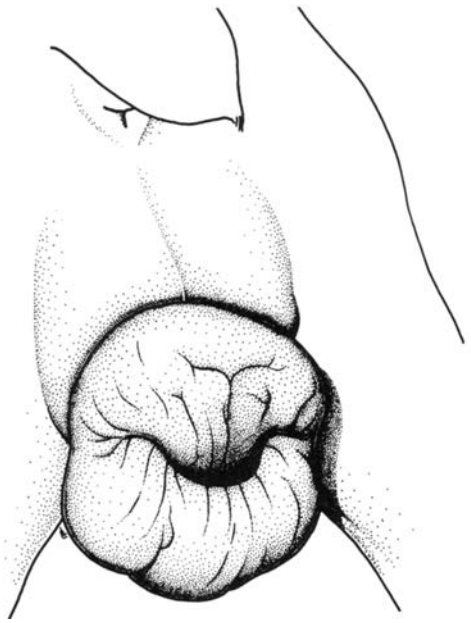


Figure 34-2. Vaginal prolapse. The entire circumference of the vaginal wall has everted.

Complete vaginal prolapse also occurs during parturition or advanced pregnancy, as a prelude to prolapse of the cervix, uterine body, and one or both uterine horns. It results from excessive straining while the supportive tissues are relaxed. The everted organs are usually discolored from venous congestion, soiled, and traumatized.

Some authors prefer to classify hyperplasia of the vaginal floor as a type of vaginal prolapse. According to that interpretation, hyperplasia of the vaginal floor that does not protrude through the vulva is called type I prolapse, and hyperplasia that protrudes completely is called type II. A true cylindric prolapse is called type III.

A recent "type III" vaginal prolapse can be reduced, but recurrence is likely. Recurrence, hemorrhage, infection, and necrosis make amputation necessary. Shock and dehydration are common complications that must be treated appropriately.

Surgical Treatment

With the animal under general anesthesia, the protruding structures are washed gently with warm saline solution or a mild detergent. Additional trauma is avoided. The mass is compressed manually to reduce edema before reduction is attempted. Sprinkling the mucosal surface with table sugar may further reduce the swelling, and episiotomy makes reduction easier. Once accomplished, reduction is maintained by placing heavy nonabsorbable sutures across the vulvar labia.

Reduction of a vaginal prolapse can be facilitated by traction on the uterus through a ventral abdominal incision. When this technique is used, suturing the uterine body or horns to the abdominal wall (hysteropexy) provides protection against recurrence.

If reduction is impossible or inadvisable, the protruding tissue must be amputated. Paying careful attention to the distorted anatomy minimizes errors. With a catheter in place to identify and protect the urethra, a circumferential incision is made in stages through the vaginal wall. The outer, everted mucosa is incised first. The incision is deepened to penetrate all layers of prolapsed vaginal tissue until the inner, noneverted mucosa is reached. Hemostasis is maintained by ligation or electrocoagulation, and the proximal mucosal margins are united with horizontal mattress sutures. The incision is extended for another short distance, the exposed segment is sutured, and the process is repeated until the amputation is complete.

Tumors of the Vulva and Vagina

Vulvar and vaginal neoplasms, which usually occur in older bitches, account for no more than 3% of all canine tumors; 70 to 80% of them are benign. The most common tumors of the vulva and vagina are leiomyoma, fibroma, and lipoma. Leiomyosarcoma is the most common malignant vaginal tumor. Mast cell tumors, sebaceous adenomas, and epidermoid carcinomas have been reported.

Leiomyomas and fibromas are often grossly indistinguishable. They form smooth, firm, spheric masses that are often pedunculated and protrude into the vestibular or vaginal lumen. They may protrude from the vulva and resemble an early hyperplasia of the vaginal floor. Lipomas occur as a gradually enlarging mass under the intact mucosa; they may protrude into the lumen, or they may become apparent under the perineal skin adjacent to the vulva. Surgical excision of benign vulvar and vaginal tumors combined with ovariohysterectomy is effective in preventing recurrence, but malignant tumors have been reported in spayed females.

The transmissible venereal tumor is an allogeneic cellular transplant that is transmitted by implantation of exfoliated cells into traumatized vaginal or penile epithelium. The condition is most prevalent and perhaps most severe when dogs are crowded and stressed. In females, the transmissible venereal tumor appears in the vagina as single or multiple projecting masses with roughened or reddened, ulcerated surfaces. Metastasis is rare. Spontaneous regression occurs after 2 to 6 months in about 60% of experimentally transplanted tumors, but reports of spontaneous regression in naturally occurring cases are inconsistent. Surgical excision is an appropriate initial treatment. If surgery is impossible or if recurrence or metastasis is noted, radiation therapy and chemotherapy are effective. Immunotherapy may be as effective as chemotherapy, but additional clinical trials are needed.

Surgical Treatment

Episiotomy is performed for better exposure. Pedunculated intraluminal tumors can be amputated, but encapsulated extraluminal tumors are removed by submucosal resection (Figure 34-3). An incision is made through the mucosa, and the tumor is bluntly peeled away. The mucosal incision is closed with absorbable sutures. Submucosal resection is especially useful for large or multiple tumors.

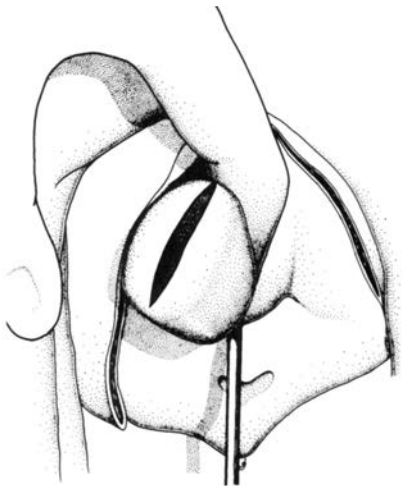


Figure 34-3. Vestibular leiomyoma. Episiotomy has been performed, and a mucosal incision has been made to facilitate submucosal resection of the tumor.

Clitoral Enlargement

Enlargement of the clitoris, sometimes with an os clitoridis, is an androgenic response. The condition has been caused by administration of exogenous androgens or anabolic steroids, and it has been reported in bitches with hyperadrenocorticism. Clitoral enlargement has occurred in puppies whose dams were treated with androgens during pregnancy. Friction between the protruding clitoris and the vulva may cause inflammation. Treatment includes topical antibiotic ointments, removal of the androgen source, or excision of the enlarged clitoris. If an os clitoridis is not present, the clitoris regresses to normal size when exogenous androgen is withdrawn.

Suggested Readings

Adams WM, Biery DN, Millar HC. Pneumovaginography in the dog: a case report. J Am Vet Radiol Soc 1978; 19:80.

Alexander JE, Lennox WJ. Vaginal prolapse in a bitch. Can Vet J 1961;2:428.

Brodey RS, Roszel JF. Neoplasms of the canine uterus, vagina, and vulva: a clinicopathologic survey of 90 cases. J Am Vet Med Assoc 1967;151:1294.

Johnston SD. Vaginal prolapse. In: Kirk RW, ed. Current veterinary therapy X. Small animal practice. Philadelphia: WB Saunders, 1989:1302.

Krongthong M, Johnston SD. Clinical approach to vaginal/vestibular masses in the bitch. Vet Clin North Am Small Anim Pract 1991;21:509.

Madewell BR, Theilen GH. Tumors of the urinary tract. In: Theilen GH, Madewell BR, eds. Veterinary cancer medicine. 2nd ed. Philadelphia: Lea & Febiger, 1987:591.

Purswell BJ. Vaginal disorders. In: Ettinger SJ, Feldman EC, eds. Textbook of veterinary internal medicine. 4th ed. Philadelphia: WB Saunders, 1995:1642.

Richardson RC. Canine transmissible venereal tumors. Compend Contin Educ Pract Vet 1981;3:951.

Schutte AP. Vaginal prolapse in the bitch. J S Afr Vet Med Assoc 1967;38:197.

Soderberg SF. Vaginal disorders. Vet Clin North Am Small Anim Pract 1986;16:543.

Episioplasty

Dale E. Bjorling

Introduction

Episioplasty is a procedure performed most often to treat recessed or juvenile vulva in female dogs. This conformation results in deep perivulvar folds of tissue causing the vulva to be partially or totally hidden from view by overlapping perineal skin dorsal and lateral to the vulva. Older veterinary surgery texts indicate that ovariohysterectomy performed in dogs prior to the completion of puberty prevents normal development of secondary sex characteristics.[1] Although this association has never been proven, it has been postulated that this may result in recessed or juvenile vulva.[1,2] Particularly in obese female dogs, a recessed vulva in conjunction with redundant vulvar skin folds may prevent complete elimination of urine and vaginal secretions. However, this condition may be associated with clinical signs in young, relatively thin female dogs. Recessed or juvenile vulvar conformation can also be observed in female dogs in the absence of any associated clinical signs.

Retention of fluid within the vulva and perivulvar folds combined with frictional irritation predisposes the area to bacterial growth, infection, and ulceration.[3] In addition, urine dribbling has been reported in these dogs, possibly as a result of urovagina due to the conformation of the vulva and overlying skin folds that act as a dam to retain urine within the vagina.[4] Affected dogs may exhibit perivulvar dermatitis, pollakiuria, urinary incontinence, licking or other signs of irritation, chronic urinary tract infection (UTI), or vaginitis with or without discharge. In extreme cases, chronic perivulvar dermatitis leading to hyperpigmentation has been associated with neoplasia of the canine vulva.[2]

Recessed vulva is often accompanied by vaginal stricture located cranial to the urethral orifice. Vaginal stricture is usually diagnosed by positive contrast radiography (vaginourethrography) or by digital palpation. Although it has been suggested that vaginal stricture may contribute to persistent vaginitis or chronic urinary tract infection,[5] vaginal stricture is commonly observed in asymptomatic female dogs. It is my opinion that episioplasty should be performed prior to revision of vaginal stricture.

Many treatments have been used to palliate conditions that result from abnormal vulvar conformation, including weight reduction, regular cleaning of the affected perivulvar tissue, repeated vaginal flushes with antiseptics, and various topical or systemic medications to control dermatitis or urinary incontinence. Of the various techniques used, the most successful appears to

be removal of redundant tissue overlying the vulva (i.e., vulvar folds), a procedure referred to as episioplasty or vulvoplasty.[2] This procedure increases exposure of the external genitalia and eliminates redundant skin folds that overly the vulva, which appears to eliminate primary clinical signs such as dermatitis and urine dribbling, as well as secondary signs such as licking and self-induced trauma.[2]

Surgical Technique

The surgical procedure is relatively simple. The dog is placed in ventral recumbency with the hindquarters elevated. The skin dorsal and lateral to the vulva is compressed with the fingers to estimate the amount to be removed (Figure 34-4). Concentric crescent-shaped incisions are made between the vulva and the anus to remove redundant skin (Figure 34-5). These incisions extend laterally on either side of the vulva and meet at points lateral and ventral to the vulva. If insufficient skin is removed initially to satisfactorily improve the conformation of the vulva, additional skin is removed to achieve the desired effect. The crescent-shaped skin and associated subcutaneous fat are removed (Figure 34-6), taking care to avoid the dorsal wall of the vagina. The resultant wound is closed in 2 layers. Subcutaneous tissues are closed with synthetic absorbable suture (3-0 or 4-0) in an interrupted pattern, and the skin is closed with monofilament non-absorbable suture (3-0 or 4-0) in an interrupted pattern (Figure 34-7). Closure of the

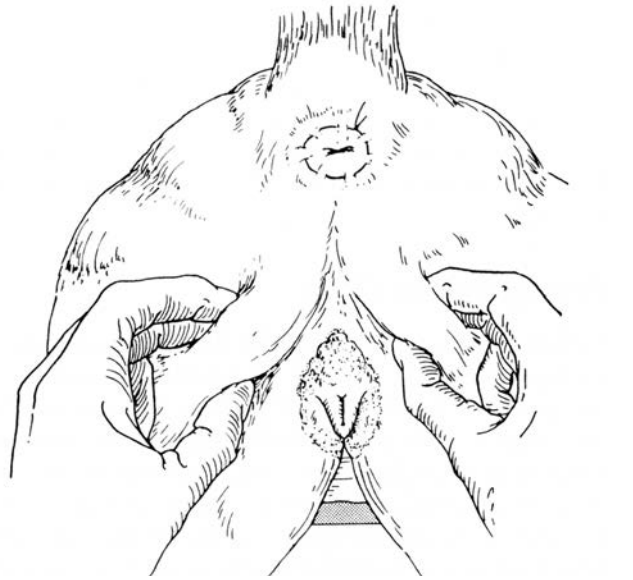


Figure 34-4. The extent of skin to be removed can be estimated by pinching the skin dorsal and lateral to the vulva between the thumb and index finger. It is often helpful to use a sterile marking pen to draw the lines of intended incision.

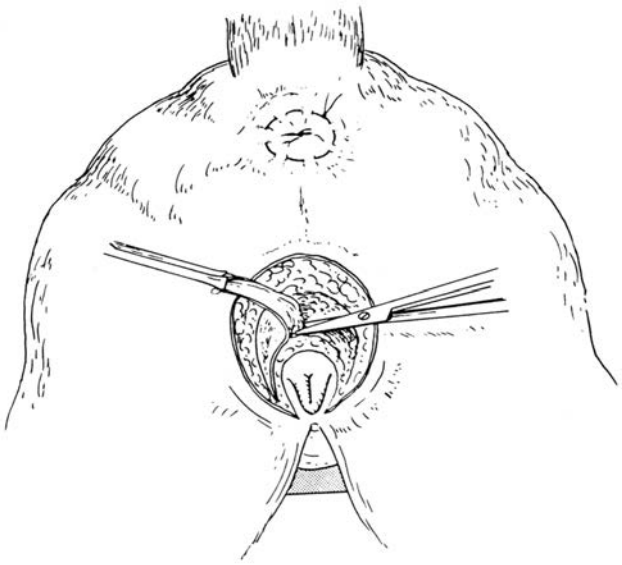


Figure 34-6. The isolated skin and associated subcutaneous fat are removed. The dorsal wall of the vagina should be avoided. Hemorrhage is primarily encountered from vessels dorsal to the vagina and lateral to the midline.

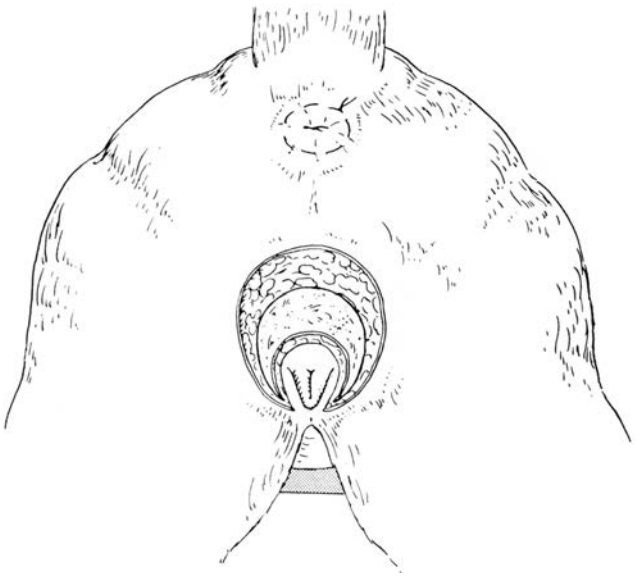


Figure 34-5. Two crescent-shaped incisions are made isolating the skin to be removed. Additional skin can be removed if the desired effect is not achieved.

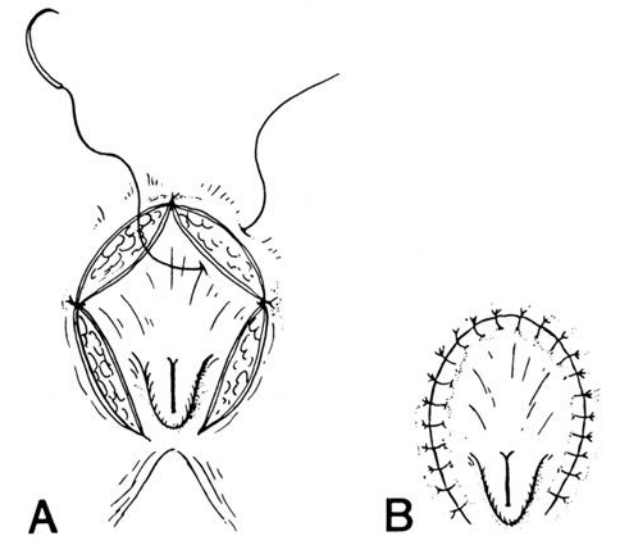


Figure 34-7. Placement of subcutaneous sutures facilitates wound closure. *A.* Skin sutures should be spaced to accommodate the differential length of the inner and outer incisions. *B.* Upon completion of the procedures, perivulvar skin folds should be eliminated, and the vulva should no longer appear recessed.

resultant skin defect eliminates the fold of skin that previously lay over the dorsal aspect of the vulva and also removes the depressions lateral to the vulva. Although removal of too much skin may complicate wound closure, failure to remove enough skin may result in persistence of the recessed conformation of the vulva. Closure of the defect is rarely a problem due to the large amount of redundant skin available in the area of the perineum and caudal aspects of the thighs. However, in heavily-muscled dogs, or dogs with a great deal of tension within the perineal skin, care should be taken to avoid removing too much skin.

Postoperative Care and Outcome

Wound infection rarely occurs. An Elizabethan collar should be used to prevent self-mutilation, if necessary.

In one study of the results of episioplasty in 34 dogs, the most common clinical signs at initial examination were perivulvar dermatitis 20/34 dogs (59%), and urinary incontinence and chronic urinary tract infection, each present in 19/34 dogs (56%).[6] Other common complaints included pollakiuria, irritation, and vaginitis. Most dogs developed clinical signs before 1 year of age. All dogs except one bichon frise were medium to giant breeds, suggesting that vulvar conformation may be related to growth rate or body conformation. Eighty-two percent of owners rated the outcome of the surgery as at least satisfactory. The incidence of urinary incontinence was reduced by vulvoplasty; however, it remained the most common residual sign after surgery, suggesting a multifactorial etiology. The incidences of urinary tract infection, vaginitis, and external irritation were greatly reduced after surgery. Wound dehiscence occurred in a Bull Mastiff, and multiple additional surgeries were performed to correct the resultant defect. This complication appeared to be due to removal of too much skin combined with a lack of mobility of skin in adjacent areas.

In another study of the outcome of episioplasty in 31 dogs, the primary complaint in 15 dogs was perivulvar dermatitis and repeated urinary tract infection in 16 dogs.[7] The mean weight of dogs with perivulvar dermatitis or chronic urinary tract infection was 26.7 $\pm$ 1.89 kg and 32.43 $\pm$ 4.02 kg, respectively, again suggesting that this condition predominantly affects medium and larger size dogs. Performance of episioplasty resulted in complete resolution of perivulvar dermatitis in 15/16 dogs, although 1 dog suffered recurrence of perivulvar dermatitis 2 years after surgery in association with a 9 kg weight gain. Episioplasty was followed by resolution of urinary tract infection in all 16 dogs in this study. Postoperative complications were limited to transient local swelling immediately after surgery.

Dogs with recessed or juvenile vulvas that are examined because of vaginitis, perivulvar dermatitis, or chronic urinary tract infection should be examined carefully for other abnormalities that may be contributing to these clinical problems. However, it is often difficult to control these disorders in the presence of conformational abnormalities of the vulva. Owners should be warned that failure to prevent weight gain may compromise the outcome of the surgery.

References

1. Archibald J. Canine Surgery, 2nd ed. Santa Barbara: American Veterinary Publications. 1974; p 757.

2. Dorn AS. Biopsy in cases of canine vulvar-fold dermatitis and perivulvar pigmentation. Vet Med Small Anim Clin 1978;73:1147.

3. Bellah JR. Intertriginous dermatitis. In Bojrab MJ, ed. Disease Mechanisms in Small Animal Surgery, 2nd ed. Philadelphia: Lea and Febiger. 1993; p 168.

4. Appeldoorn A, Lemmens P, Schrauwen E. Urinary incontinence due to urovagina. Vet Rec 1990;126:121.

5. Crawford JT, Adams WM. Influence of vestibulovaginla stenosis, pelvic bladder, and recessed vulva on response to treatment for clinical signs of lower urinary tract disease in dogs: 38 cases (1990-1999). J Am Vet Med Assoc 2002;221:995.

6. Hammel SP, Bjorling DE. Results of vulvoplasty for treatment of recessed vulva in dogs. J Am Anim Hosp Assoc 2002;38:79.

7. Lightner BA, McLoughlin MA, ChewDJ, et al. Episoplasty for the treatment of perivulvar dermatitis or recurrent urinary tract infections in dogs with excessive perivulvar skin folds: 31 cases (1983-2000). J Am Vet Med Assoc 2001;219:1577.

Episiotomy

Roy F. Barnes and Sandra Manfra Marretta

Introduction

Episiotomy is a surgical procedure that temporarily enlarges the vulvar cleft. This procedure provides exposure of the caudal female urogenital tract which cannot be reached with a conventional laparotomy or ventral pubic osteotomy. Indications for an episiotomy in the dog include vaginal and vestibular masses, vaginal prolapse, vaginal and vestibular trauma, congenital vaginal strictures, and dystocia from an inadequate vulvar cleft.

Preoperative Care

Depending on the stability of the patient and the underlying clinical disorder, episiotomies may be performed under local, epidural and general anesthesia. The patient is placed on a padded perineal stand in a manner to prevent neuropraxia, compromised circulation or exacerbate chronic osteoarthritis of the rear limbs. The rectum and anal sacs are emptied, and several gauze sponges are placed into the rectum. A purse string suture is placed in the anus to minimize contamination during surgery.

The hair from the perineal region is clipped and the vestibule and vagina are liberally flushed with a dilute antiseptic solution. Surgical scrub is avoided during lavage of the vestibule and vagina. The perineum is surgically prepared in a routine manner. A Foley catheter is aseptically placed through the urethral papilla into the urinary bladder to allow for exact identification and protection of the lower urinary tract throughout the procedure. Surgical draping includes the vulvar cleft and the perineal skin dorsal to the vulvar cleft with exclusion of the anus.

Surgical Technique

A digital examination precedes the surgical incision. During digital examination, the caudodorsal aspect of the horizontal vaginal canal is identified. To avoid incising the external anal sphincter, the episiotomy incision should not extend any further dorsally than the caudodorsal aspect of the horizontal vaginal canal.

A median skin incision is made from the level of the caudodorsal aspect of the horizontal vaginal canal, extending to the dorsal commissure of the vulvar cleft (Figure 34-8). A pair of thumb forceps or the handle of a scalpel blade can be inserted into the vaginal canal to aid in the stabilization of the incision site. The remaining layers of the episiotomy incision, including the thin musculature, subcutaneous tissue and mucosal layers are cut with Mayo scissors (Figure 34-9). Hemorrhage may be brisk. The

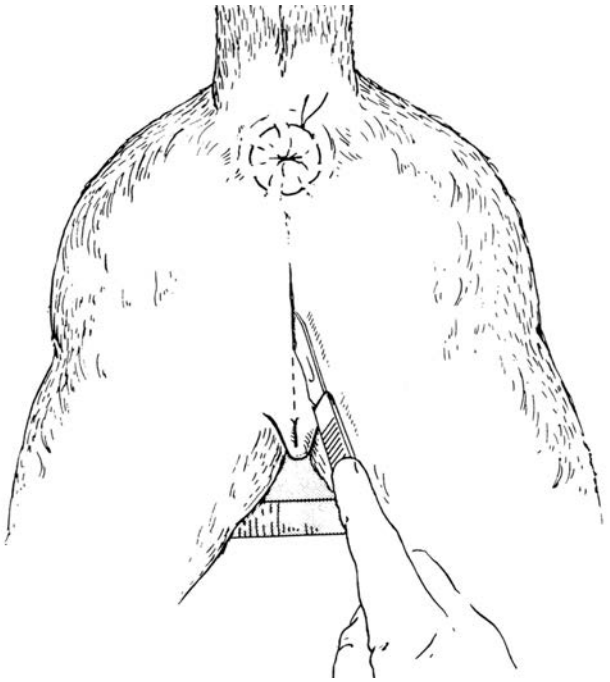


Figure 34-8. A median skin incision is made from the caudodorsal aspect of the horizontal vaginal canal to the dorsal commissure of the vulvar cleft.

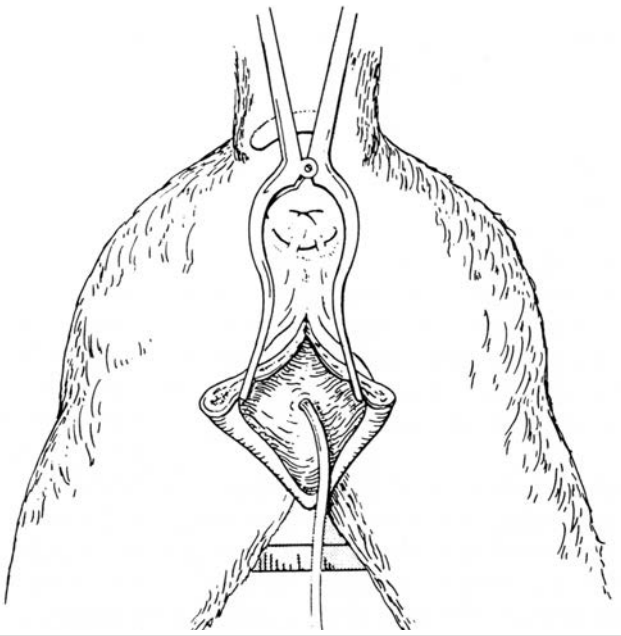


Figure 34-10. The episiotomy has been completed. A Foley catheter is in place in the urinary bladder to aid in the localization and protection of the urethral papilla and urethra during additional surgical procedures. A self-retaining retractor is in place to provide increased visibility of the vestibule and vagina.

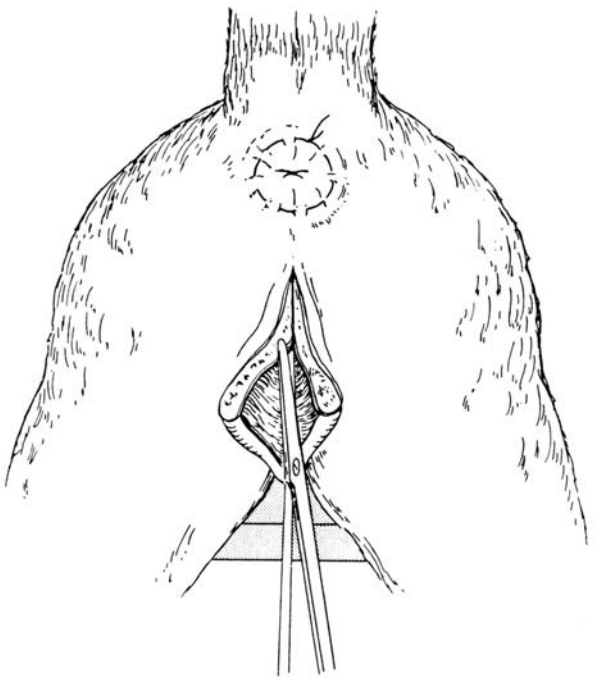


Figure 34-9. The musculature and mucosal layers are cut with Mayo scissors following the skin incision.

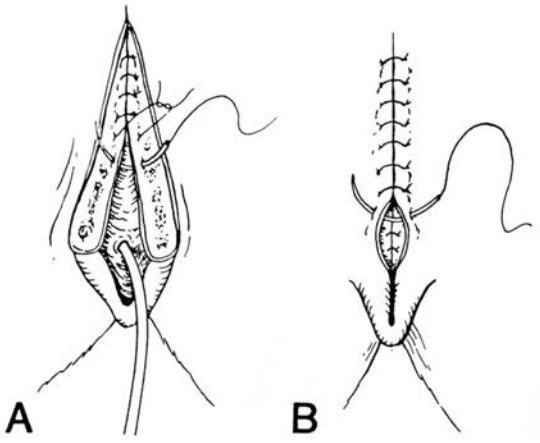


Figure 34-11. A. The mucosal layer of the episiotomy is closed with simple interrupted sutures. **B.** The skin edges are apposed with simple interrupted monofilament nonabsorbable sutures.

use of hemostats, ligatures and the judicious use of electrocautery will control hemorrhage and improve visualization of the surgical field. Alternatively, atraumatic intestinal forceps can be temporarily applied to the edges of the incision to achieve hemostasis.

The definitive surgical procedure that necessitated the episiotomy may be performed at this time. Self retaining retractors can be used to increase exposure at the surgical site. It is imperative that the position of the urethral papilla and the urethra should be visualized and protected at all times (Figure 34-10).

Closure of the episiotomy is completed in three to four layers, depending on the size of the dog. The mucosa is apposed using a simple interrupted suture pattern with 3-0 synthetic, monofilament, absorbable suture material (Figure 34-11A). If the vulvar cleft was congenitally shortened, the vestibular mucosa is directly sutured to the skin until the desired length is attained. The muscular and subcutaneous tissues are closed in one layer using a simple interrupted suture pattern of 3-0 or 4-0 synthetic, monofilament, absorbable suture material. In larger dogs, the muscular and subcutaneous tissues can be closed in separate layers. The skin is apposed with simple interrupted or cruciate mattress sutures of 3-0 synthetic, monofilament, nonabsorable material (Figure 34-11B). The purse string suture and gauze sponges are removed from the anus and rectum, respectively. The urinary catheter may be removed or left in place during the immediate postoperative period.

Postoperative Care

An Elizabethan collar is recommended to prevent self mutilation of the surgical site. Analgesia is a requirement. Full opioid agonists, such as oxymorphone or hydromorphone, should be administered for the first 24 hours. If medically appropriate, additional analgesia could be obtained using a non-steroidal anti-inflammatory agent. Cold compresses should be applied for the first 48 hours. Skin sutures should be removed in 10 to 14 days.

Complications

Postoperative complications associated with the performance of episiotomy are rare and are often associated with poor surgical technique or inappropriate postoperative care. Poor surgical technique during closure of the incision, including inaccurate suture placement, tight sutures or the use of through and through sutures, may result in unnecessary pain, self mutilation of the surgical site and inflammation. Urinary obstruction may occur if the urethral papilla and urethra were not identified during the initial incision, the definitive surgical procedure or during the closure of the episiotomy. Vestibular reconstruction for enlargement of the vulvar cleft may predispose to urinary tract infections by way of environmental exposure to gastrointestinal contents.

Suggested Readings

Hardie EM. Selected surgeries of the male and female reproductive tracts. Vet. Clinics of N. America, Small An. Practice. 1984; 14: 109-122.

Mathews KG. Surgery of the canine vagina and vulva. Vet. Clinics of N. America, Small An. Practice. 2001; 13: 271-290.

Chapter 35

Testicles

Prepubertal Castration

Lisa M. Howe

Introduction

Prepubertal castration of puppies and kittens (as early as six weeks of age) is slowly increasing in popularity in the United States, particularly in the shelter setting, as a result of mounting evidence of the safety of the procedure, on both a short and long-term basis. Puppies and kittens undergoing prepubertal castration have shorter recovery rates, lower morbidity, and similar mortality rates as compared to those neutered at a more traditional age (≥ six months of age). Although many safety concerns, including urethral obstruction in male cats, have been raised regarding early age castration, long-term outcome in cats and dogs undergoing early neutering is similar to those undergoing traditional age neutering. Early age castration in dogs and cats is a safe procedure when appropriate anesthetic and surgical principles and techniques are applied.

Surgical Procedures and Techniques

The surgical anatomy of the pediatric puppy or kitten reproductive tract is identical to that of the adult dog or cat; however, pediatric testes are extremely small, highly mobile, and the spermatic cords are susceptible to tearing if not handled gently.

Anesthetic and surgical considerations for the pediatric patient, differ somewhat from the adult patient, and include increased risk of hypoglycemia and hypothermia, a relatively small blood volume, and delicate tissues. Prolonged fasting may result in hypoglycemia because hepatic glycogen stores are minimal in neonates. Thus, food should be withheld no longer than 8 hours, with 3 to 4 hours recommended for the youngest patients (6 to 8 weeks).[1,2] Minimizing operative times and the use of warm water blankets can decrease hypothermia. The use of warmed scrub solution (chlorhexidine) and avoidance of alcohol or excessive wetting of the pediatric patient during the surgical site preparation will be beneficial in helping preserve body heat.[1,2] Because pediatric tissues are very friable, gentle tissue handling is mandatory. The relatively small blood volume of pediatric patients makes meticulous hemostasis very important. Fortunately, the small size of blood vessels in the spermatic cord makes precise and complete hemostasis easy to accomplish.

Pediatric castration is performed with modifications to the techniques used in adult dogs. Because puppy testes are mobile and can be difficult to identify, careful palpation is performed to determine whether both testicles have descended into the scrotal region before beginning surgery. If one or both testes have not descended, standard cryptorchidectomy techniques may be used for castration. The entire scrotal region is clipped and surgically prepared to permit the scrotum to be incorporated

in the surgical sterile field. Because of the mobility and small size of the puppy testes, including the scrotum in the surgical field can facilitate locating and manipulating the testes during surgery. Clipping and surgical preparation of the scrotum does not result in scrotal irritation in puppies as it does in adult dogs because the scrotal sac of puppies is not well developed as compared to adult male dogs. Puppies are positioned on the surgery table in a similar fashion as adult males, however, it is often useful to very *loosely* secure the hind legs to the table so as to facilitate testis identification and palpation after draping. Puppies may be castrated through a single midline (preferred) prescrotal or scrotal incision, or through two scrotal incisions positioned similarly to a feline castration. When a midline incision is used, the testicles must be securely held underneath the incision site to prevent iatrogenic penile or urethral trauma. Following exposure of the testicle and spermatic cord in a closed fashion, (testes remain enclosed in the parietal vaginal tunic during castration), the spermatic cord is doubly ligated with 3-0 absorbable suture material or stainless steel hemostatic clips. If the parietal vaginal tunic is inadvertently penetrated and the testis extruded, an open castration technique may be performed using standard adult canine castration techniques. Adequate hemostasis should be verified prior to return of the vascular pedicle to the inguinal region. The skin incision is closed using one or two buried interrupted sutures of absorbable suture in the subcuticular layer, or the incisions may be left open to heal by second intention healing. Closure of the incision is preferred and prevents postoperative wound contamination with urine or feces, and extrusion of subcutaneous fat from the incision.

Kitten castration is performed using identical techniques as in the adult cat. Two separate scrotal incisions are used to approach the testes. When preparing the surgical site of a kitten castration, it is often easier to shave the scrotal region than to pluck the scrotal region. Positioning and draping of the kitten is identical to positioning of the adult male cat prior to castration. As with the pediatric puppy, the testes of the pediatric cat are extremely small, highly mobile, and occasionally difficult to stabilize in the scrotal region in preparation for incision. The testis should be securely stabilized in the scrotal region and the incision made directly over the testis at the ventral most aspect of the scrotal "sac". After the incision, the testis is carefully exposed using *gentle* caudoventral traction. It is important to realize that the pediatric testis cannot be exteriorized to the same distance as in the adult cat without potential tearing of the spermatic cord. The closed castration technique is preferred, using a hemostat to place an overhand throw in the pedicle, or using suture or hemostatic clips for hemostasis. If the parietal vaginal tunic is inadvertently opened, an open technique using either a hemostat to place an overhand throw in the spermatic cord, or the use of spermatic cord tissues (vas deferens) for knot tying may be employed. Alternatively, sutures or hemostatic clips may be used to achieve hemostasis in an open castration. Care must be used when manipulating tissues to prevent rupture or tearing of the small and fragile spermatic cord. As with adult cat castrations, the scrotal skin incisions are left open to heal by second intention.

Postoperative Care

All animals undergoing early age castration should be tattooed to identify their neutered status so as to avoid unnecessary abdominal exploration in the future. The recommended tattoo site in males is the inguinal area. The male gender symbol along with an encircled "X" is used to denote the neutered status. Tattooing is best performed after the surgical site has been clipped but prior to the surgical prep of the area.

During recovery from anesthesia, pediatric patients should be monitored for hypoglycemia, hypothermia, pain, or dysphoria. Supplemental heat, glucose containing agents, or additional analgesics or sedatives may be used to ensure smooth recovery from anesthesia. These patients may be fed a small meal one to two hours after recovery since they tend to recover much more quickly from anesthesia and surgery.

Postoperative Complications

Veterinarians have long been concerned about the potential health risks of early age castration. These concerns have included increased risk of urethral obstruction in male cats, obesity, and abnormal long bone growth patterns in dogs and cats neutered at an early age. Concerns have also been expressed regarding the immune system of puppies and kittens and the effects of the stress of anesthesia and surgery at an early age. The development of neoplasia has also been a more recent concern. Recent studies have begun to clarify the long term health risks and benefits of early age castration as compared to traditional age castration.

Urethral, Penile, and Preputial Development in Male Cats

A major concern of veterinarians regarding performing early age neutering is that of feline lower urinary tract disease (FLUTD) and urethral obstruction in male cats. It was thought that early neutering of the male cat would result in a smaller diameter urethra thus predisposing the cat to urinary obstruction caused by FLUTD. Numerous experimental and clinical studies dating to the 1960's have studied this concern. Recently, two experimental studies examining cats castrated at seven weeks and seven months of age as compared to sexually intact cats have studied this concern.[3,4] The first study examined urethral development when cats were one year of age, and found that urethral diameters as determined by contrast retrograde urethrography were similar among both groups of neutered cats as compared to intact cats.[3] Additionally, no difference in urethral dynamic function as determined by urethral pressure profiles was seen among groups. In the second study, voiding cystograms were used to measure the diameter of the preprostatic and penile urethra when cats were 22 months of age.[4] As in the previous study, no differences were seen in urethral diameter of male cats neutered at seven weeks or seven months of age as compared to intact cats.

In addition to experimental studies, two recent long-term clinical studies have examined the effect of early age castration on the incidence of urinary tract disease. The first long-term (37 month

median follow-up) study examined 263 cats neutered at an early age (< 5.5 months) as compared to the traditional age ≥ 5.5 months.[5] There were 108 male cats which were divided into two groups based on age at the time of castration: early age (median age at castration = nine weeks; n = 70) and traditional age (median age at castration = 51 weeks; n = 38). In that study, *traditional age* neutered cats had significantly more overall urinary tract problems (17%) as compared to early age neutered cats (3%). "Cystitis" was the most common problem seen, and the incidence was significantly greater in cats neutered at an older age. There was no significant difference in the rate of urethral obstruction between groups although 2/38 (5%) traditional age neutered cats suffered urinary obstruction, while 0/70 (0%) early age neutered cats became obstructed. A second recent study examined 1660 cats neutered at an early age (< 5.5 months of age) as compared to the traditional age (≥ 5.5 months of age).[6] The median follow-up time for that study was 47 months, with follow-up available for as long as 11 years after surgery. That study found no association between the incidence of FLUTD or urethral obstruction and the age at gonadectomy.

Abnormal penile and preputial development in male cats castrated at an early age has also been a concern for many veterinarians. The balanopreputial fold is a fold of tissue (a continuous layer of epithelium) connecting the penis to the prepuce at birth. The balanopreputial fold separation process is androgen dependent and is complete at birth in some species, but not until after puberty in other species such as the cat. Concerns have been expressed that prepubertal castration in cats might delay or prevent dissolution of the membrane, and predispose to ascending urinary tract disease since these cats may not be able to fully extrude the penis for cleaning.[7] Recent studies examining separation of the balanopreputial fold have reported conflicting results. In one study of cats castrated at seven weeks and seven months of age, it was reported that at one year of age, the penis could be fully extruded in all males.[8] Penile spines were atrophied in those castrated at seven months, and were absent in those castrated at seven weeks of age. This is in contrast to another study reporting on penile extrusion in cats at 22 months of age.[4] In cats neutered at seven weeks of age, the penis could not be fully extruded in any cat, while in intact cats, the penis could be fully extruded in all cats. Of the cats neutered at seven months of age, the penis could be fully extruded in 60%. In those males incapable of complete penile extrusion, only 1/3 to 2/3 of the length of the penis could be visualized. It would appear, however, based upon the long-term clinical studies of 263 and 1660 cats,[5,6] that failure of separation of the balanopreputial fold (when present) does not cause a clinical problem in cats neutered early and does not lead to an increase in the incidence of FLUTD or urinary obstruction. Should cats neutered at an early age become obstructed however, penile manipulations for catheterization may be more challenging because of smaller penile size and the inability to fully extrude the penis.

All studies reported to date indicate that *urethral* development and diameter in male cats is not an androgen dependent process, even though *penile* size and development is androgen dependent. Therefore, it would appear that concerns about FLUTD, urinary obstruction, or potential failure of separation of the balanopreputial fold are not objective reasons to delay castration in male cats.

Obesity

Obesity is influenced by a number of factors, including neuter status, and studies suggest that gonadectomized cats may gain significantly more weight than intact cats. The literature regarding whether dogs are more likely to become obese after castration is less clear.

When comparing neutered cats to sexually intact cats, intact cats were found to weigh less than cats neutered at seven months, but there was no difference between intact cats and those neutered at seven weeks.[8] Another study[9,10] has assessed obesity by body mass index at 24 months of age in 34 cats. Body condition scores and body mass index values were higher in animals gonadectomized at seven weeks or seven months than in intact animals. This indicated that animals gonadectomized at either age were more likely to be obese than intact cats. Heat coefficient, a measure of resting metabolic rate, was higher in intact cats than in gonadectomized cats. Based on these data, the author suggested that neutered male cats require an intake of 28% fewer calories than intact males.[10]

In dogs, one study found no differences in food intake, weight gains, or back-fat depth among neutered (seven weeks or seven months) and intact animals during a 15-month prospective study.[11] A long-term study of 1842 dogs[12] actually found that the proportion of overweight dogs was *lowest* in the early age gonadectomized dogs, as compared to the traditional age neutered dogs.

Body and Long Bone Growth

Several research studies have refuted the concern that early neutering will "stunt" growth. In a 15-month study of 32 dogs, growth rates were unaffected by gonadectomy, but the growth period in final radial/ulnar length was extended in all neutered male dogs (neutered at seven weeks or seven months).[11] Thus, neutered animals were not stunted in growth but were actually slightly taller. In a similar study,[8] 31 cats were neutered at seven weeks or seven months or left intact. Distal radial physeal closure was delayed by approximately eight weeks in neutered cats as compared to intact cats, and no differences were detected between the two groups of neutered cats, for mature radius length or time of distal radial physeal closure. A third study in cats showed that male cats neutered at seven weeks or seven months of age reached the growth plateau on average 35% later, and achieved radial length of 13% longer than intact males.[13]

The clinical significance of delayed closure of growth plates is not clear, but it does not appear to render the growth plates more susceptible to injury. In the long term studies of 263 cats,[5] 269 dogs,[14] 1660 cats,[6] and 1842 dogs,[12] no differences in the incidence of musculoskeletal problems were seen between groups. Further, in the long term study of 1660 cats[6] and 1842 dogs,[12] age at gonadectomy was not associated with the frequency of long bone fractures. Based on the low incidence of long bone fractures in this study, it would seem that physeal

fractures are not a common problem in gonadectomized dogs and cats in general.

Long-term studies have examined the incidence of hip dysplasia and the association with age at gonadectomy. One study of 269 dogs[14] found no association between age at gonadectomy and hip dysplasia, however another study of 1842 dogs[12] found that early age gonadectomy was associated with a significant increased incidence of hip dysplasia. Puppies that underwent gonadectomy before 5.5 months of age had a 6.7% incidence of hip dysplasia, while those that underwent gonadectomy at, or after, 5.5 months of age had an incidence of 4.7%. However, those that were gonadectomized at the traditional age were three times more likely to be euthanized for the condition as compared to the early age group, suggesting that early age gonadectomy may be associated with a less severe form of hip dysplasia.

In the Golden Retriever breed, one study found that when dogs were neutered before 1 year of age (early neutered) the incidence of cranial cruciate ligament rupture was greater than in those neutered after 1 year of age or remaining intact.[16] When compared to intact dogs, the incidence of hip dysplasia was also increased in the male dogs of the early neutered group.

Infectious Diseases and Long-Term Immune Suppression

In the shelter environment, puppies and kittens neutered at early ages had no higher risk of infectious diseases than older animals according to one short-term (seven day) study. This study involved shelter source dogs and cats undergoing gonadectomy in association with the fourth-year student surgical teaching program at a university teaching hospital.[15] Twelve of 1988 (0.6%) animals died or were euthanized because of parvovirus infection or as a result of severe infections of the respiratory tract during the seven day postoperative period, and the deaths (or euthanasias) included similar numbers of animals from all age groups.

In long term studies of 263 cats[5] and 269 dogs,[14] prepubertal gonadectomy did not result in an increased incidence of infectious disease after adoption in cats, compared with traditional age gonadectomy. In dogs, however, gonadectomy before 5.5 months of age was associated with an increased incidence of parvoviral enteritis. In more recent studies of 1660 cats[6] and 1842 dogs,[12] those gonadectomized before 5.5 months of age were not significantly more likely than those gonadectomized after 5.5 months of age to have any conditions that might be presumably associated with long-term immune suppression. On a short-term basis, however, dogs from the study that were gonadectomized before 5.5 months had an increased incidence of parvoviral enteritis that often occurred soon after adoption. In both of the long-term dog studies[14,12] (269 dogs and 1842 dogs), the increased incidence of parvoviral enteritis on a short-term basis probably represented an increased susceptibility of the younger puppies during the periadoption period, rather than long-term immune suppression.

References

1. Faggella AM, Aronsohn MG: Evaluation of anesthetic protocols for neutering 6- to 14-week-old pups. *J Am Vet Med Assoc* 205:308, 1994.

2. Faggella AM, Aronsohn MG: Anesthetic techniques for neutering 6- to 14-week-old kittens. *J Am Vet Med Assoc* 202:56, 1993.

3. Stubbs WP, Bloomberg MS, Scruggs LS, *et al.*: Prepubertal gonadectomy in the domestic feline: effects on skeletal, physical, and behavioral development. *Vet Surg* 22:401, 1993.

4. Root MV, Johnston SD, Johnston GR, *et al.*: The effects of prepubertal and postpubertal gonadectomy on penile extension and urethral diameter in the domestic cat. *Vet Radiol & Ultrasound* 37:363, 1996.

5. Howe LM, Slater MR, Boothe HW, *et al.*: Long-term outcome of gonadectomy performed at an early age or traditional age in cats. *J Am Vet Med Assoc* 217:1661, 2000.

6. Spain CV, Scarlett JM, Houpt KA: Long-term risks and benefits of early-age gonadectomy in cats. *J Am Vet Med Assoc* 224:372, 2004.

7. Herron MA: A potential consequence of prepubertal feline castration. *Feline Pract* 1:17, 1971.

8. Stubbs WP, Bloomberg MS, Scruggs SL, *et al.*: Effects of prepubertal gonadectomy on physical and behavioral development in cats. *J Am Vet Med Assoc* 209: 1864, 1996.

9. Root MV: The effect of prepubertal and postpuberal gonadectomy on the general health and development of obesity in the male and female domestic cat. *PhD Thesis, University of Minnesota,* Saint Paul, MN, 1995.

10. Root MV: Early spay-neuter in the cat: effect on development of obesity and metabolic rate, *Veterinary Clinical Nutrition* 2:132, 1995.

11. Salmeri KR, Bloomberg MS, Scruggs SL, *et al.*: Gonadectomy in immature dogs: Effects on skeletal, physical, and behavioral development. *J Am Vet Med Assoc* 198:1193, 1991.

12. Spain, CV, Scarlett JM, Houpt KA: Long-term risks and benefits of early-age gonadectomy in dogs. *J Am Vet Med Assoc* 224:380, 2004.

13. Root MV, Johnston SD, Olson PN: The effect of prepubertal and postpubertal gonadectomy on radial physeal closure in male and female domestic cats. *Vet Radiol & Ultrasound* 38:42, 1997.

14. Howe LM, Slater MR, Boothe HW, *et al.*: Long-term outcome of gonadectomy performed at an early age or traditional age in dogs. *J Am Vet Med Assoc* 218:217, 2001.

15. Howe LM: Short-term results and complications of perpubertal gonadectomy in cats and dogs. *J Am Vet Med Assoc* 211(1):57, 1997.

16. De la Riva GT, Hart BL, Farver TB, et al.: Neutering dogs: effects on joint disorders and cancers in Golden Retrievers. *PLOS One* 8(2):e55937, 2013.

17. Cooley DM, Beranek BC, Schlittler DL, et al.: Endogenous gonadal hormone exposure and bone sarcoma risk. *Cancer Epidemiol Biomarkers Prev* 11(11):1434-1440, 2002.

18. Ru G, Terracini B, Glickman LT: Host related risk factors for canine osteosarcoma. *Vet J* 156(1):31-39, 1998.

19. Bryan JN, Keeler MR, Henry CJ, et al.: A population study of neutering status as a risk factor for canine prostate cancer. *Prostate* 67(11):1174-1181, 2007.

20. Sorenmo KU, Goldschmidt M, Shofer F, et al.: Immunohistochemical characterization of canine prostatic carcinoma and correlation with castration status and castration time. *Vet Comp Oncol* 1(1):48-56, 2003.

Orchiectomy of Descended and Retained Testes in the Dog and Cat

Stephen W. Crane

Introduction

Castration (orchiectomy) is performed frequently for reproductive neutering and for reducing or eliminating the behavior patterns characteristic of intact males. The procedure continues to be the first line of defense against the plague of animal overpopulation. Testicular neoplasia, severe traumatic injury, refractory orchitis, and epididymitis are primary medical indications for unilateral or bilateral orchiectomy. Removal of the primary endocrine sources of androgenic hormones are secondary reasons for castration in that androgens may be complicating mediators in benign prostatic hypertrophy, prostatitis, perianal adenoma, and perineal hernia. In addition, castration, coupled with scrotal ablation, is the initial surgical step in creating the perineal urethrostomy of the cat…a salvage procedure for a scar damaged urethra. Castration and scrotal ablation are the first steps in creating a permanent scrotal urethrostomy in dogs…a procedure to allow urolithic debris in urine to be discharged prior to the narrowing of the urethra within the os penis.

Surgical Anatomy

The spermatic cord must be exposed, exteriorized and transected in any castration. The cord originates at the vaginal ring as its individual components exit the abdominal cavity. In the center of the spermatic cord are the mesorchium, the testicular artery, the testicular vein and the associated pampiniform plexus. The lymphatic vessels, deferent duct and the testicular plexus of autonomic nerves complete the structure. Externally, the cord is wrapped in a double tunicae of the vaginal process which is covered by the spermatic fascia, an extension of the fascia of the abdominal wall. Between the visceral and parietal layers of the vaginal process the cavity is continuous with the peritoneal cavity. Two thin layers of spermatic muscle overlay the tunicae as flat extensions of the internal abdominal oblique muscle. The muscle runs along the external surface of the parietal tunica of the vaginal process to insert on the spermatic fascia and parietal vaginal tunic. Surgically, the cremaster is considered and handled as though it were part of the spermatic cord. Between the subcutaneous inguinal ring and the scrotum, the spermatic cords pass ventral and medial to the thigh adductor muscles in a subcutaneous position. When the spermatic cords are delivered into a surgical incision they are often covered with a thin layer of fat.

Surgical Preparation for Castration of the Dog

Canine orchiectomy is performed under general anesthesia with the dog positioned in dorsal recumbency and with tethering restraint of the pelvic limbs in a caudal direction. The hair of the prescrotal and medial thigh areas is clipped and these areas and the scrotum are washed with water and mild soap. The prescrotal area of the prepuce, but not the scrotum itself, is then further prepared for aseptic surgery with skin preparation soap and solution. (Should the scrotum be prepared with antiseptics there is a high incidence of contact dermatitis). Because the scrotum has not received aseptic preparation the fully prepared prescrotal operative field is quadrant toweled to cover the scrotum. A fenestrated drape is positioned over the prescrotal area and the remainder of the patient. All further manipulations of the testes and scrotum are performed through the sterile fabric layers of the towel and drape.

Surgical Procedure for Castration of the Dog

To begin the orchiectomy a skin and subcutaneous incision is made on the ventral midline of the prepuce at the cranial base of the scrotum (Figure 35-1). The length of the incision must allow for the outward expression of each testis (Figure 35-2A). Next, one testis is manipulated forward and into the incision by pressure on the scrotum through the drape and towel. The tissue that limits the outward extrusion of the testis at this point is the spermatic fascia which must be incised down to the parietal layer of the vaginal tunica. The latter structure is a white, dense glistening layer of fascia that closely surrounds the testis. Once the spermatic fascia has been divided, the tunica covered testis can be delivered ("popped") forward, outward and into the skin incision (Figure 35-2B). Shortly after the testis appears, however, its outward progress is again resisted this time by the additional attachment of the spermatic fascia which connects the tail of the epididymis to the scrotal wall. This ligament may be broken by traction but often requires isolation by blunt dissection and, then, sharp transection. Using a hemostatic forceps across the ligament to crush small vessels is good practice in younger dogs and is often sufficient for hemostasis. However, in the case of mature adults, testicular neoplasia or orchitis, the ligament should be ligated to preclude the potential complication of postoperative scrotal hematoma. After clamping or ligation of the ligament of the tail of the epididymis, the structure is divided to release the invagination of the scrotal skin and to allow further exteriorization of the testis (Figure 35-3). Steady caudal and outward traction is next applied to the testis to break down

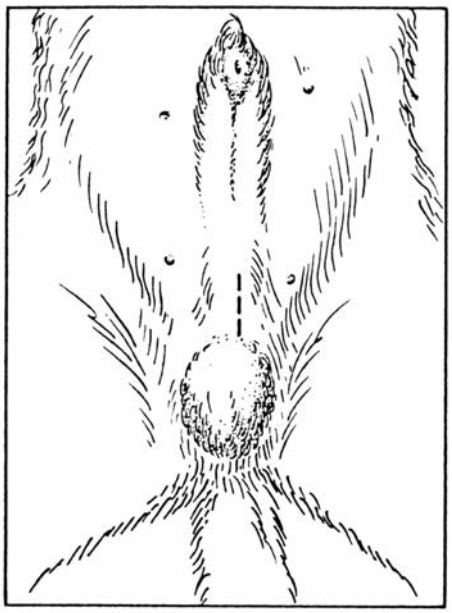


Figure 35-1. Location of the prescrotal incision for orchiectomy.

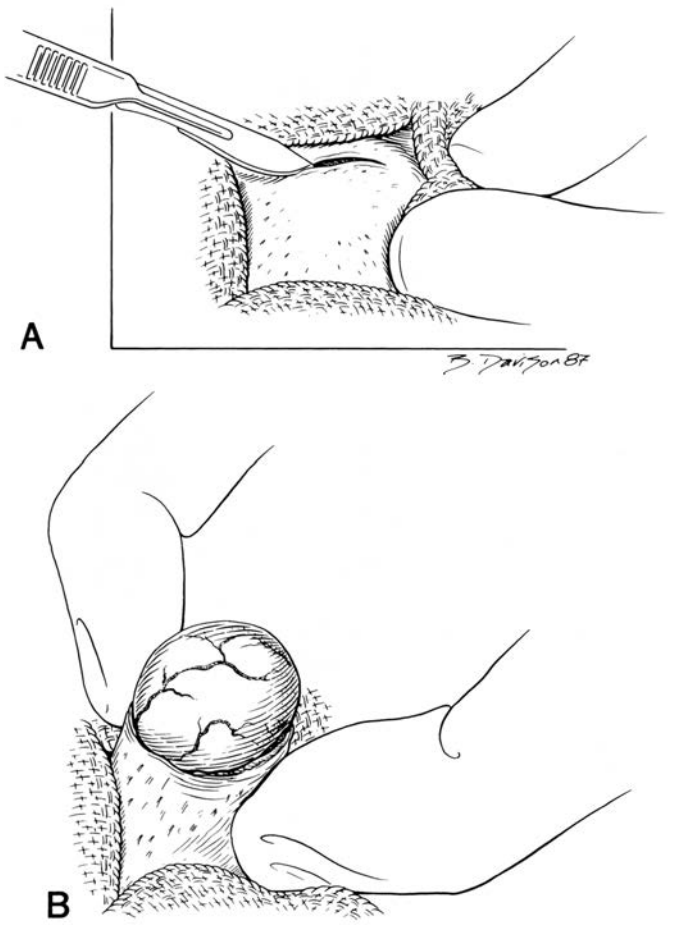


Figure 35-2. A. The skin, subcutaneous tissue, and the spermatic fascia are incised. The body of the penis is visible deep to the incision. **B.** Once the spermatic fascia has been completely divided, the testis, covered by the vaginal process, can be manipulated cranially into the incision. The scrotum is handled only through the sterile fabric of the towel and drape.



Figure 35-3. The spermatic fascia is fenestrated to identify and Isolate the ligament of the tail of the epididymis. This structure is clamped with hemostatic forceps before its sharp division. The clamp can be left in place until the incision is closed.

connective tissue attachments between the spermatic cord and the spermatic fascia. As the cord emerges into the operative field, any fat around the cord is removed by a proximal wiping and stripping action with a moist sponge. At this stage, the testis and a considerable portion of the spermatic cord have been exteriorized and the cremaster muscle is dearly seen on the external surface of the vaginal tunicae. The technique for cord transection depends on the patient's size.

Closed Castration

In patients under 20 kg, a "closed" castration technique is used. "Closed" means that the contents of the spermatic cord are triple clamped, ligated, and divided with the tunicae of the vaginal process intact around the cord (Figure 35-4). Additionally, the vaginal process is transfixed to the cremaster muscle to provide extra security in ligation. After triple hemostatic forceps are applied to the proximal portion of the exposed cord, the most proximal clamp is removed, and a slowly absorbable suture material, swaged to a taper needle, is passed through the

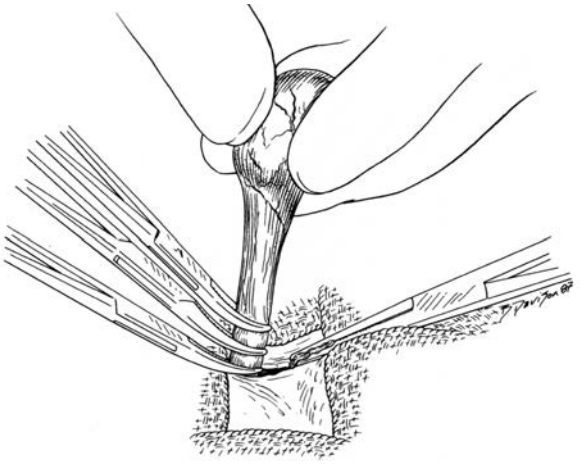


Figure 35-4. After exteriorization of the testis and most of the spermatic cord, any fat around the cord is removed. The initial step in closed castration is the application of triple hemostatic forceps across the unopened vaginal process and the cremaster muscle.

cremaster and tunica (Figure 35-5A). In placing this transfixation ligature, the surgeon must take care to miss the vascular structures of the spermatic cord. The ligature is tied over the cremaster and the ends of the suture are passed in opposite directions back around the spermatic cord to encircle it before forming a final knot (Figure 35-5B and Figure 35-6). The transfixation method of securing the hemostatic ligature prevents loosening or shifting of the ligature if the cremaster should contract. Ligature loosening could cause a retraction of the testicular artery away from ligature control. The middle clamp is removed and a second, non-transfixing ligature is placed in the clamp's crush mark. The spermatic cord is severed along the proximal edge of the distal clamp to prevent backfiow hemorrhage from the testis into the operative field (See Figure 35-6).

Open Castration

The "open" castration method is used for dogs over 30 kg. After each testis is exteriorized as described previously, the vaginal

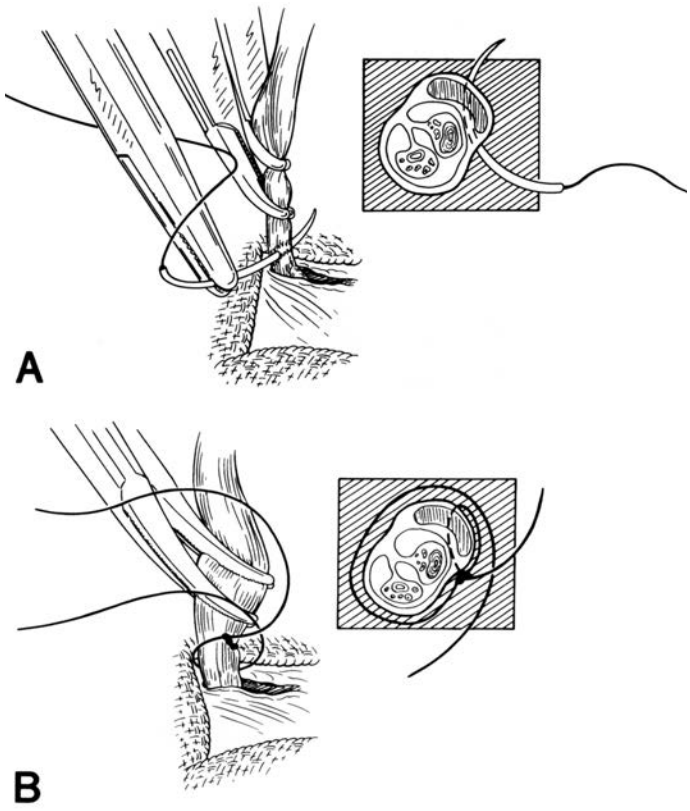


Figure 35-5. A. A transfixing ligature is applied between the cremaster muscle and spermatic cord in the closed castration. The needle passage incorporates the parietal tunica of the vaginal process and the cremaster. **B.** After the ligature transfixing the vaginal process and cremaster is tied, the entire cord is encircled with ligature before forming the final knot.

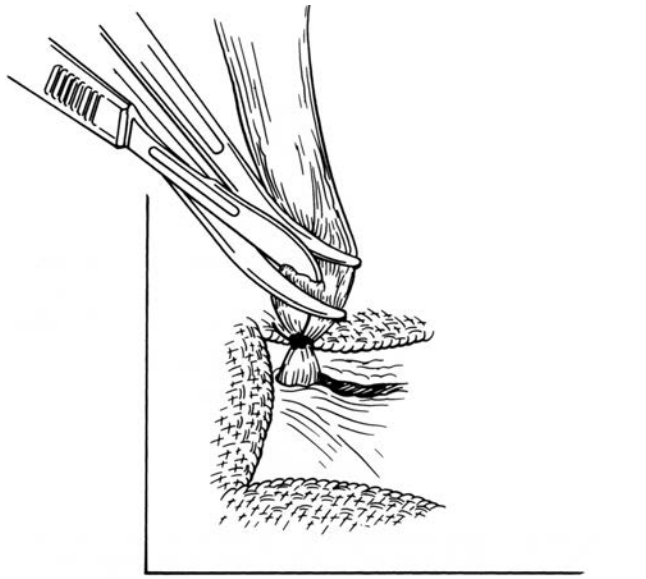


Figure 35-6. The spermatic cord is severed between the two most distal clamps to prevent backflow hemorrhage from the testis into the operative field and to retain control of the cord.

process is incised and opened longitudinally with scissors to expose the internal structures of the spermatic cord (Figure 35-7).

Proximally, most of the vaginal process and cremaster muscle are amputated; they are ligated only if large blood vessels are present. In returning to the spermatic cord itself, the testicular artery and vein and the deferent duct are ligated according to triple-damp technique with slowly absorbable suture material and are divided (Figure 35-8 and Figure 35-9). The advantages of the open method are that the vascular ligations are direct and, thus, more secure. The disadvantage is opening of an extension of the peritoneal cavity and a longer operative time.

After the spermatic cord is divided in either the open or closed castration technique, the remaining portion of the cord is released proximally into the subcutaneous tissue under direct

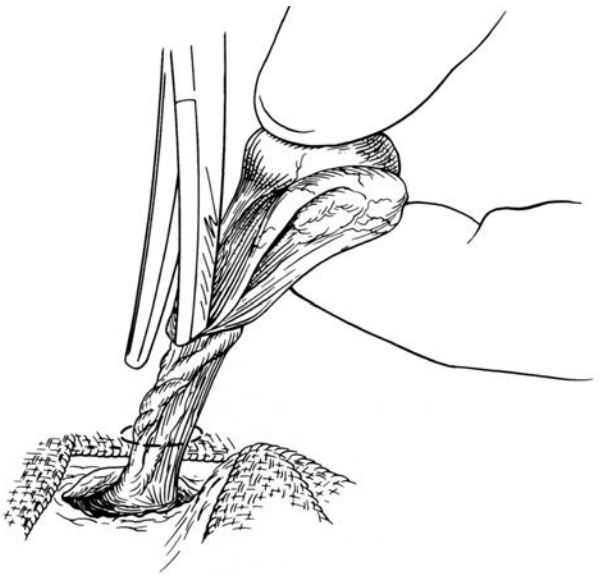


Figure 35-7. Open castration involves opening the parietal tunic of the vaginal process with scissors to directly reveal the internal vascular structures of the spermatic cord. The vaginal process and cremaster muscle are amputated proximally (*dotted line*). Ligation of the vaginal process and cremaster is not usually performed, but it may be required if larger blood vessels are present.

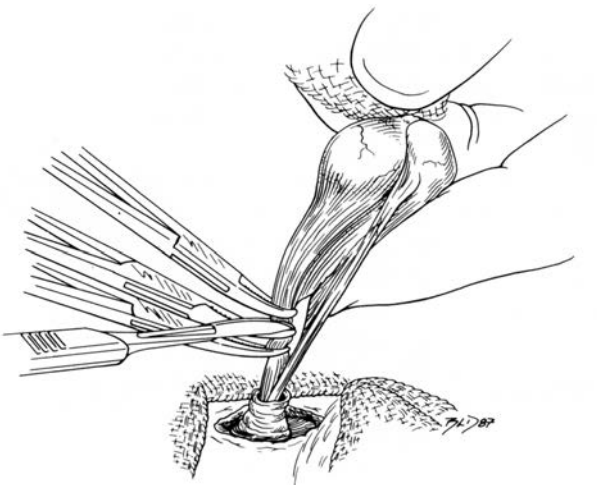


Figure 35-8. The testicular artery and vein and then the deferent duct are triple clamped. They are ligated just distal to the most proximal clamp.

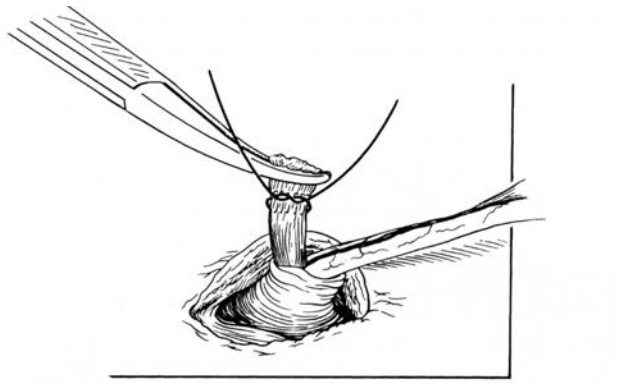


Figure 35-9. After division of the vessels, single or double ligations are securely placed directly on the testicular artery and vein, using slowly absorbable suture material. In this drawing, the arteriovenous complex is receiving its first ligature, and the ductus is yet to be clamped and ligated.

control of thumb forceps (Figure 35-10). Control during the release of the cord is important because the vessels shorten and dilate as tension on them is released. Any ligature slippage and hemorrhage will probably occur at this time. If bleeding occurs, the vessels or cord can be immediately retrieved for further attention if held by thumb forceps.

The remaining testis is produced by incising the contralateral spermatic fascia and the second gonad is removed in the same manner to complete the castration. At no time is invasion of the scrotal wall or scrotal septum necessary and any incision into the scrotum or the septum invites the complication of scrotal hematoma. After inspection for the complete arrest of bleeding, the deep and superficial subcutaneous layers and the subdermal skin are closed in one layer with an absorbable suture material. A simple interrupted or continuous pattern can be used but several of the suture bites should be placed laterally and deeply enough to "pick up" the connective tissue surrounding the retractor penis muscle to ablate potential dead space. Finally, the skin edges are gently and loosely apposed with a fine, nonabsorbable suture material in a simple interrupted pattern (Figure 35-11). Skin sutures that are placed too tightly often attract postoperative licking or self mutilation. In this case sutures will need to be removed if they are "cutting through" and can be replaced. New, looser skin sutures may also be complemented by the use of restraint devices such as a head collar or side bars, tranquilization, or topical preparations that are bitter to the taste. Skin edges can also be opposed with fine staples or surgical adhesive.

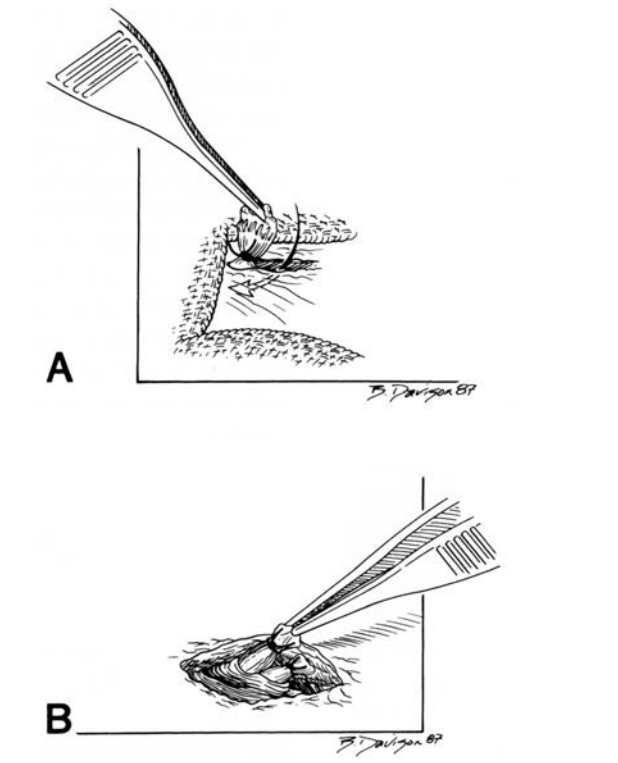


Figure 35-10. A. and **B.** In either the closed or open technique, the remaining portion of the amputated spermatic cord is released into the subcutaneous tissue under direct thumb forceps control. This allows retrieval of the vessels or cord if hemorrhage should begin when the stretched vessel is shortened.

Editor's Note: Intradermal closure of the skin is practiced by many surgeons instead of skin closure as it is believed that self-trauma of the incision by licking is less of a postoperative problem when skin sutures are omitted.

Ancillary Techniques to Orchiectomy

Scrotal Ablation

Veterinarians and clients may prefer scrotal ablation in the opinion that it cosmetically complements the orchiectomy. This is especially true in larger breed dogs with short hair coats. Preperation for surgery includes full antiseptic scrubbing of the scrotum and the inner thigh and perineal areas. Scrotal ablation is initiated by a circumfrential incision around the scrotum with the incision made slightly toward the scrotal side of the junction between the skin. Such an incision placement reduces skin tension and utilizes incision-induced spasms of the tunica dartos layer of the scrotum to help reduce intra-operative hemorrhage. The incision is extended through the entire subcutaneous tissue by sharp dissection where pinpoint electrocautery may be useful. After removal of the scrotum and following orchiectomy, attention to dead space ablation during the subcutaneous layer closure is important.

Implantation of Testicular Prostheses

Alternatively to scrotal ablation, veterinarians and clients may prefer preserving the appearance of a natural scrotal and testicular anatomy. In this case prosthetic testicular implants are available in various sizes, firmnesses and degrees of anatomic correctness. The implantation technique is a patented procedure and is described in literature supplied by the manufacturer of the implants. As with any implanted bioprosthesis strict adherence to aseptic technique is a critical facet of the procedure.

Orchiectomy Through a Caudal Approach

A caudal approach is a choice for canine orchiectomy when the patient is already positioned in sternal recumbency on a "head-down" elevated platform for perineal surgery (see pages 581-582). Before the other perineal procedure is performed a transverse incision is made dorsal to the scrotum at its junction

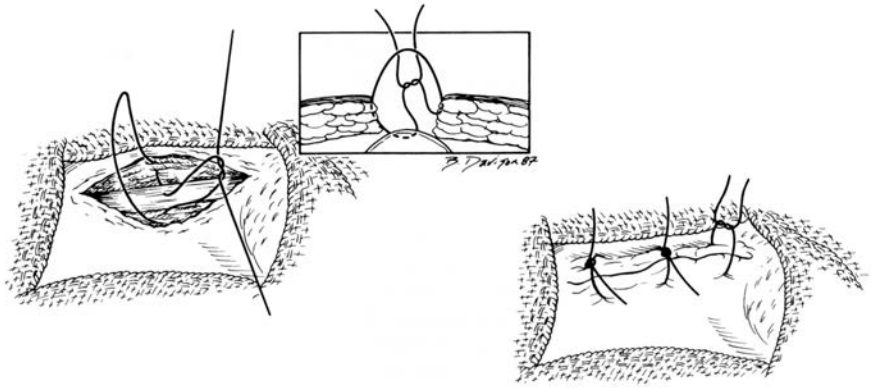


Figure 35-11. Simple interrupted intradermal sutures, with the knots buried, are used to ablate dead space and to appose wound edges. Each suture is just "catching" superficial portions of the retractor penis muscle. Ablation of dead space helps to prevent post operative hematoma or seroma. Skin suture should loosely approximate wound edges.

with the perineal skin. After the spermatic fascia is incised, the testes are delivered dorsocaudally into the operative field by upward pressure on the toweled scrotum. With outward traction applied the ligament of the tail of the epididymis is identified, isolated, clamped, and divided. The spermatic cord and testis are then delivered into the incision and the remainder of the operation is performed as previously described for a closed or open technique.

Castration of the Cat

Male cats are usually neutered at or before sexual maturity. The intact male cat is usually not well tolerated as an indoor companion animal because of marking and spraying with an odoriferous urine. Nocturnal fighting and roaming are other behavior patterns of male cats that are often successfully controlled by orchiectomy.

The only instruments needed for cat castration are two mosquito forceps, a pair of smaller, sharp sharp scissors, a No. 10 scalpel blade, absorbable ligature material, and a nonfenestrated paper drape. The cat is placed under ultrashort acting general anesthesia and positioned in dorsal, ventral, or lateral recumbency. While in dorsal recumbancy the cat's perineal area is conveniently exposed by bringing the hindquarters to the edge of a table and allowing the tail to fall toward the floor. The patient's pelvic limbs are secured in a laterally abducted position, and the hair covering the scrotum is either plucked with the fingers or clipped with a No. 40 clipper blade. The scrotal area is prepared with scrub soap and skin antiseptics. A drape is easily and economically made from paper drape material that is sterilized with the other instruments and a fenestration about the size of a dime is cut in the center of the drape. The prepared scrotum is expressed through the hole to create an acceptably draped surgical area without any exposure of hair.

The skin, tunica dartos and spermatic fascia over each testis are vertically incised with a No. 10 scalpel blade. The incision should extend amply from the dorsal to the ventral aspect of the scrotal compartments. With a pinching maneuver the testis, still enclosed in the vaginal process, is "popped" out of the incision. The testis is pulled caudoventrally until considerable exposure of the spermatic cord is obtained and resistance to further traction is met. Any fat investing the spermatic cord is stripped from the cord and, in a proximal position, two Halstead mosquito forceps are placed across the spermatic cord. As the proximal forceps is removed a ligature of absorbable suture material is tied tightly in the crush mark. The spermatic cord is then transected and released up into the scrotum under direct control of the remaining mosquito forceps. As an alternative to ligature placement, kittens and juveniles, but not adults, can have their spermatic cord looped with an overhand knot and cinched tight (Figure 35-12). After the testes are removed, both scrotal incisions are dilated by spreading the tips of mosquito forceps between the wound edges to preclude an early fibrin seal across the incision. The application of topical ointments or systemic antibiotics are unnecessary.

Cryptorchidism

Unilateral or bilateral cryptorchidism is encountered frequently in dogs and is transmitted as a hereditary disorder in a simple, autosomal recessive manner. The condition occurs most frequently in small purebred dogs, with a right to left ratio of 2.3:1. Unilaterally cryptorchid males are typically fertile and possess normal libido so the trait is widely disseminated.

Testicular descent should be complete shortly after birth and testes not located within the scrotum by 2 months of age should be considered permanently retained. Veterinarians should strongly recommend the castration of cryptorchid animals because testes retained in an inguinal or abdominal position are predisposed to the malignant changes of seminoma and Sertoli cell tumor. Orchiopexy or prosthetic testicular implantation is illegal and unethical for show purposes and can contribute to the perpetuation of cryptorchidism.

The palpable absence of one or both testes during several examinations confirms the diagnosis of cryptorchidism. Once a diagnosis of cryptorchidism has been established, the surgeon must determine at what point along the normal path of testicular descent migration became arrested. This point can be anywhere from just cranial to the scrotum in the subcutaneous tissue of the groin all the way up to the position of embryonic organogenesis

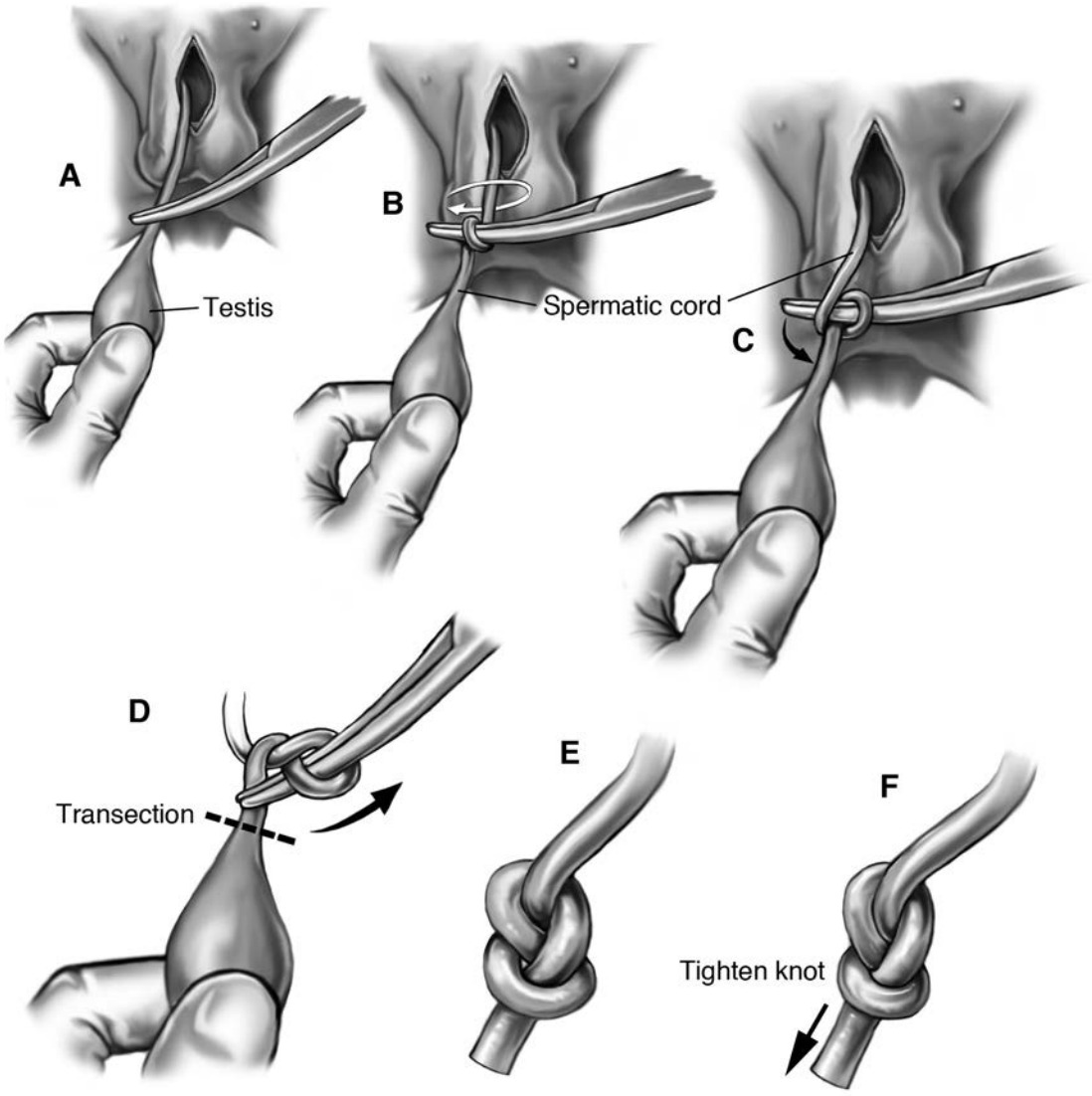


Figure 35-12. Feline Castration-Closed technique. This is a six step technique where the spermatic cord is tied on itself using a mosquito hemostat. This technique is applicable to a closed castration for kittens and juvenile aged males. The spermatic cord should be well exteriorized, free of tension and stripped of fat prior to forming the loop and pulling tissue with a curved mosquito hemostat.

just caudal to the kidney. Careful palpation usually enables the examiner to detect most gonads if they are distal to the superficial inguiinal ring in the subcutaneous tissue of the groin.

Many retained canine testes are located within the abdominal cavity and exploratory celiotomy or laparoscopy is required for their removal. With the patient under general anesthesia and the ventral abdominal wall prepared for aseptic surgery, a midline celiotomy is performed through the linea alba from the umbilicus to the prepuce. Frequently, the testis is located in the mid abdominal region as a highly movable organ smaller than the descended gonad. Arterial supply from the testicular artery, a direct branch of the aorta, and a small artery in the gubernacular remnant or the deferential fold of the peritoneum are typically visualized. Also, the ductus deferens courses toward the caudal aspect of the abdomen and can be a reliable primary landmark for tracing to the retained testis.

If the testis cannot be located initially in the mid abdominal area, the area of the inguinal ring is next examined. When testicular descent is arrested at this location, the testis can usually be palpated by moving a finger along the abdominal wall toward the ring. After the cryptorchid testis is located, the testicular vessels and ductus are isolated, triple clamped, and doubly ligated either collectively or individually with a slowly absorbable ligature material. After division of vascular structures, the abdominal cavity is checked carefully for bleeding, and the celiotomy is closed. True agenesis of the testis and vas deferens is reported, but it is rare. If the testis has descended through the inguinal canal and is located in the subcutaneous tissue of the groin, removal is by a standard prescrotal incision with manipulation of the testis into the incision by digital pressure.

Selected Readings

Baumans V. Dijkstra G, Hensing CJG. Testicular descent in the dog. Zentralbi Veterinaermed [A] 1981;10:97.

Evans HE. Miller's anatomy of the dog. 3rd ed. Philadelphia: WB Saunders, 2005.

Hates HM, Wilson GP, Pendergrass TW, et al. Canine cryptorchidism

and subsequent testicular neoplasia: case control study with epidemiologic update. Teratology 1-85;32:51.

Hudson LC, Hamilton WP. Atlas of feline anatomy for veterinarians. Philadelphia, WB Saunders, 1993.

Knecht CD. An alternative approach for castration of the dog. Vet Med Small Arnm Clin 1976;71:469.

Reif JS, Moquire TG, Kenney RS. A cohort study of canine testicular neoplasia. J Am Vet Med Assoc 1979;175:719.

Chapter 36

Penis and Prepuce

Surgical Procedures of the Penis

H. Phil Hobson

Amputation Techniques

Partial or "complete" amputation of the penis may be indicated in certain congenital, traumatic, or neoplastic conditions. The most common neoplasm of this area, transmissible venereal tumor, is generally responsive to chemotherapy or radiotherapy. Thus, amputation of the penis should be considered rarely, if ever, as a corrective measure for this condition. Cryotherapy has also been used successfully for removal of benign tumors of the penis.

Partial Amputation

The exact location of the amputation is determined by the site of the lesion. In most cases, the penis can be extruded (Figure 36-1A) and held in the extruded position by clamping the preputial orifice with a towel clamp just caudal to the bulbus glandis. The sheath can be opened full thickness on the ventral midline, when necessary, to expose the penis. The penis can be extruded through a ventral opening in the prepuce, or the entire length of the prepuce can be opened for better exposure. A Penrose drain tube works well as a tourniquet around the base of the penis.

Amputation of the tip of the penis may be necessary in patients with chronic or recurrent prolapse of the urethra (Figure 36-1). Placing a catheter in the urethra helps to identify the limits of the lumen. The surgeon should make the incision partway across the tip, place a stay suture to unite the mucosa of the urethra with the

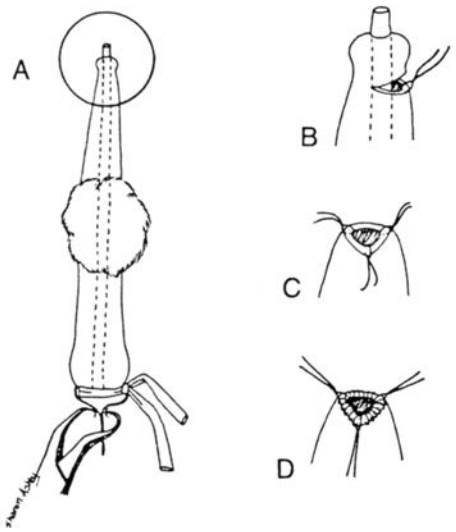


Figure 36-1. A. Amputation of the tip of the penis. **B.** Securing the urethral mucosa to the penile mucosa. **C.** Triangulating the urethral orifice with stay sutures. **D.** Placement of a simple continuous pattern between the stay sutures with the orifice in maximal dilatation.

mucosa of the penis, and then complete the excision of the tip of the penis (Figure 36-1B). The triangula-tion technique (Figure 36-1C and D) conserves a patent lumen to the tip of the urethra. Careful apposition of the cut mucosal edges to the penile tunica helps to avoid excessive scar tissue proliferation and stricture. A continuous suture pattern helps to control seepage from the cavernous erectile tissue. Synthetic absorbable suture is used for mucosal closure.

An Elizabethan collar or a side-bar restraint device should always be used to prevent the patient from licking the wound. Castration or careful hormone therapy may be indicated to help to prevent erection during healing.

Amputations of the main body of the penis require the severing of the os penis, as well as the salvaging of enough urethra distal to the severed os penis for a distance of 1 cm. The os penis and urethra are severed with bone-cutting forceps and a scalpel. The urethra is isolated subperiosteally from the groove of the os penis with a small dental chisel. The urethra is split, flared, trimmed, and sutured to the infolded tunica albuginea, as shown in Figure 36-2. Care should be taken to appose the mucosal surfaces. Although it is perhaps easier to achieve excellent apposition with fine, closely placed interrupted sutures, a continuous pattern is more likely to control bleeding. Some bleeding, especially at the end of urination, is common, even for several days after the operation. It is difficult to identify and to ligate individual vessels in this area. Releasing the tourniquet while the wound is open, in an effort to identify and to ligate the vessels within the corpus spongiosum penis, may prove unrewarding.

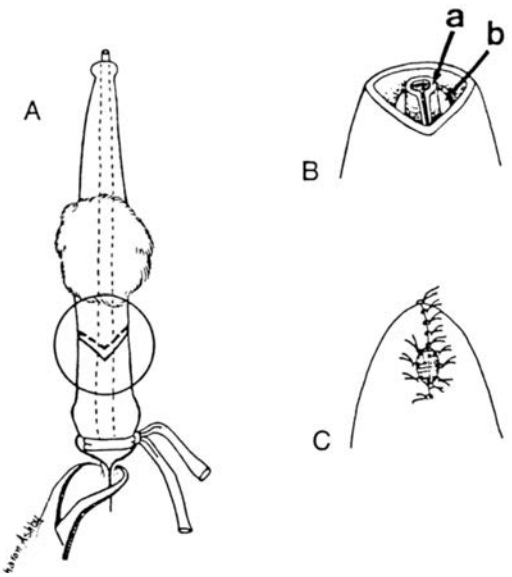


Figure 36-2. A. Amputation of the penis proximal to a lesion. The corpus spongiosum penis is incised at a 45° angle. The os penis and urethra are incised I cm further distal than the corpus spongiosum penis. **B.** The urethra (*a*) is elevated subperiosteally from the groove in the os penis. The os penis (*b*) is trimmed away with a rongeur to the level of the corpus spongiosum penis. **C.** The urethra is sutured to the penile mucosa, and the remainder of the penile stump is closed.

Preputial Amputation

When pooling of urine within the prepuce becomes a concern after partial amputation of the penis, shortening of the entire prepuce may be desirable. For the best cosmetic results, a full-thickness section of the prepuce can be removed (Figure 36-3). The length of prepuce to be removed should be the same as the length of the penile resection. In patients with congenital micro-penis, the tip of the prepuce should cover the tip of the penis by approximately 1 cm. The cranial transverse incision is made 2 cm caudal to the cranial junction of the prepuce and the body wall, to allow adequate circulation to the cranial end of the prepuce. The location of the caudal transverse incision is determined by the length of the penis. The two incisions are extended laterally in an elliptic fashion to facilitate a smooth closure of the skin.

Next, the dorsal aspect of the section of prepuce to be removed is dissected free from the body wall with scissors. With careful dissection, most of the preputial vessels, which lie immediately subcutaneously on both sides of the sheath, can be identified and preserved. To close the amputation, the preputial mucosa is apposed with 4-0 absorbable suture, using a submucosal pattern. If a continuous pattern is used around the circumference of the prepuce, care should be taken to avoid a pursestring effect, which limits the movement of the penis. The veterinarian may find it easier to close the dorsal mucosa if the penis is allowed to protrude through the incision site during this phase of closure.

Complete Amputation

The initial skin incision is made in an elliptic fashion around the entire external genitalia (Figure 36-4A). The preputial vessels are ligated, as are any additional branches of the caudal superficial epigastric vessels that cross the incision line. The spermatic cords are isolated, ligated, and severed. Care must be taken to place the ligatures tightly enough to prevent retraction of the severed spermatic artery if the tunicae are incorporated in the ligature. When the penis and the prepuce have been stripped from the body wall in a caudal direction, the dorsal penile vessels are identified and ligated just caudal to the level of the desired penile amputation site. The retractor penis muscle is reflected from the urethra, and, with a catheter in place, a midline incision is made into the urethral lumen at the desire urethrostomy site. A 1-0 absorbable, ligature, which circumscribes the penis, is placed just caudal to the amputation site and just cranial to the urethrostomy site (Figure 36-4B), to control seepage bleeding from the erectile tissue further, if necessary. The shaft of the penis is amputated in a wedge fashion, and the tunica albuginea is apposed over the amputation stump. The urethrostomy should be located in the scrotal area whenever possible. Careful apposition of penile urethra and skin edge, as the urethrostomy is completed, minimizes postoperative bleeding and scar tissue formation (Figure 36-4C). Although suture patterns and materials are a matter of choice, a continuous pattern aids in controlling hemorrhage from any incised erectile tissue. The use of synthetic absorbable suture eliminates the need for suture removal.

Particular care should be taken to obliterate dead space, especially cranial to the stump of the amputated penis, when closing the subcutaneous tissue. The use of a restraint device to prevent licking of the surgery site by the patient is imperative.

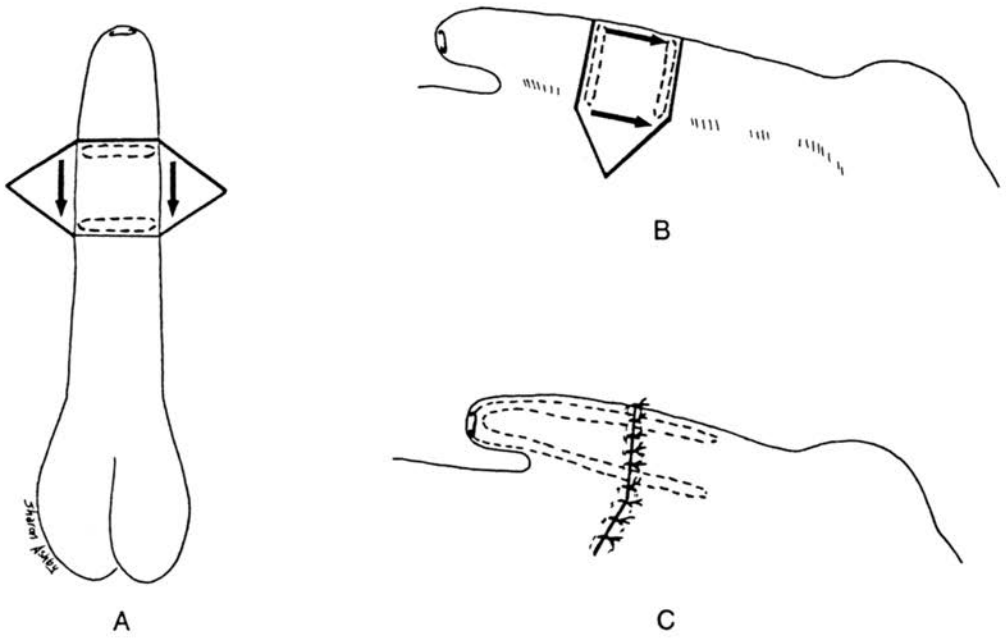


Figure 36-3. Shortening of the prepuce in cases of pooling of the urine within its lumen. **A.** Removal of a section of the entire prepuce. **B** and **C.** Reapposition of the mucosa and skin.

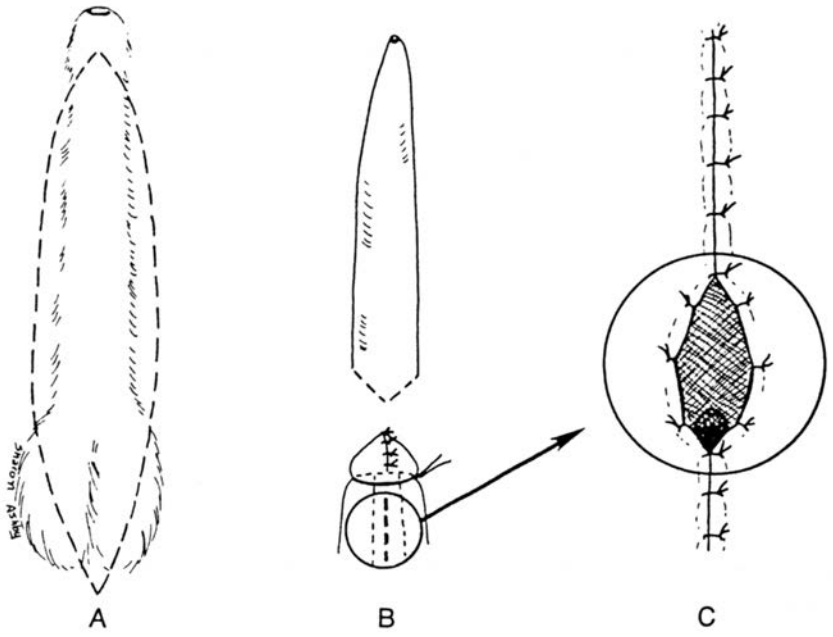


Figure 36-4. Ablation of the external male genitalia. **A.** The skin incision extends from cranial to the prepuce to caudal to the scrotum. **B.** Amputation of the shaft of the penis in the area of the scrotum. The penis is ligated, incised, and sutured. **C.** The urethrostomy is established by careful apposition of the urethral mucosa to the edge of the skin.

Correction of Hypospadias

Hypospadias is a congenital anomaly of the external genitalia in which the penile urethra terminates caudal to its normal opening. The urethra can terminate at any level from the perineum to the tip of the penis (Figure 36-5) because the urethral folds fail to fuse (See Figure 36-9). In severe cases, the two halves of the scrotum can fail to fuse, the penis fails to develop normally, and the urethra fails to close in the perineal area (Figure 36-6). Frequently, the analog of the urethra can be present as a fibrous cord that runs from the glans penis to the urethral opening and pulls the penis into a deforming ventral curvature (chordae) (See Figure 36-6).

Minimal defects usually require no urethral surgery. The constant extrusion of the tip of the glans penis can often be relieved by closing the prepuce to its normal extent (Figures 36-7 and 36-8) on its caudoventral aspect. Should the resulting orifice be too small to allow extrusion of the penis, the opening can be increased to the desired diameter by enlarging the lumen of the craniodorsal aspect. Simply leaving the orifice larger by not

closing the caudoventral defect to its fullest extent can cause the tip of the penis to continue to droop from the prepuce and may thus subject it to continual drying, licking, and trauma.

Caudoventral closure is accomplished by incising the mucocutaneous junction, separating the mucosa from the skin, and closing the two layers individually (Figure 36-8A). Sutures of 4-0 to 6-0 absorbable synthetic material are preferred. Should the orifice need to be enlarged dorsally, one scissor jaw is inserted into the lumen of the prepuce, and the orifice is cut to the needed extent. With a minimum of undermining, the cut mucosal and skin edge can be apposed (Figure 36-8B). Failure to appose the skin and mucosal edges adequately may result in closure by granulation, or, should the patient be allowed to lick out the sutures, stricture formation is likely to follow.

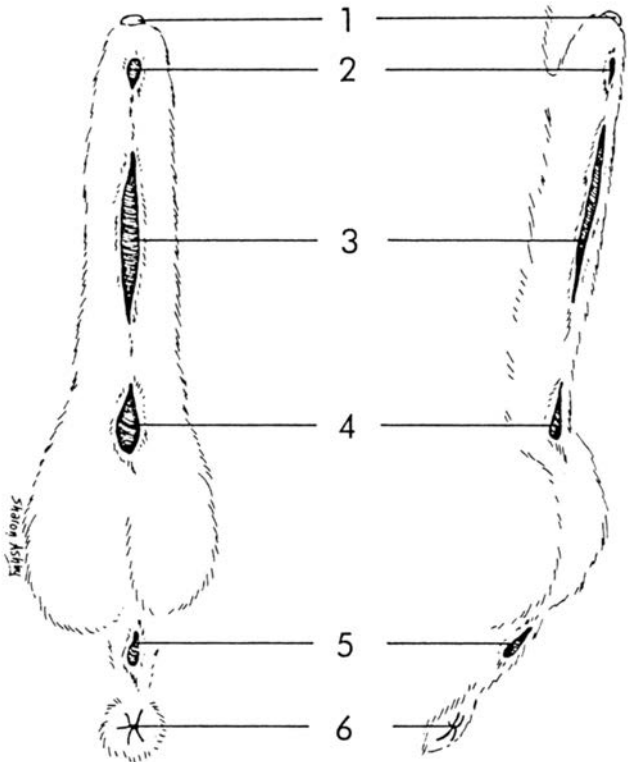


Figure 36-5. Normal urethral meatus *(1)* and types of hypospadias: glandular *(2)*; penile *(3)*; scrotal *(4)*; perineal *(5)*; and anal *(6)*.

Small urethral defects can be closed successfully with a two-layer closure (Figure 36-9). A catheter is inserted past the defect, and an incision is made at the open mucocutaneous junction around the perimeter. The mucosa is undermined and is closed, as is the skin. Care must be taken not to create a stricture. Skin can be invaginated to close the urethral defect, provided the hair follicles have been destroyed previously.

Rectangular full-thickness bladder wall sections, rolled into a tube, have been used to replace surgically sacrificed sections of urethra (i.e., urethral neoplasms). Oral mucosa has been used as well. After suturing of the grafts into the urethral defect (over a catheter), the skin is undermined as in Figure 36-9C and is closed over the urethral graft. The catheter is left in place for 7 to 10 days. If open-ended catheters are used as stents, the catheter need not be introduced all the way to the bladder. Catheters remain in place much better if they are cut flush with the urethral orifice and are sutured in place by passing one or two sutures through the catheter and the tip of the penis. For major urethral defects, excision of the external genitalia and urine diversion by urethrostomy are the treatments of choice (See Figure 36-4). An elliptic incision is made around the rudimentary penis, prepuce, and scrotum. Dissection from the body wall is carried out in a cranial-to-caudal direction; the surgeon should ligate preputial vessels as they are identified and isolated. Should penile tissue

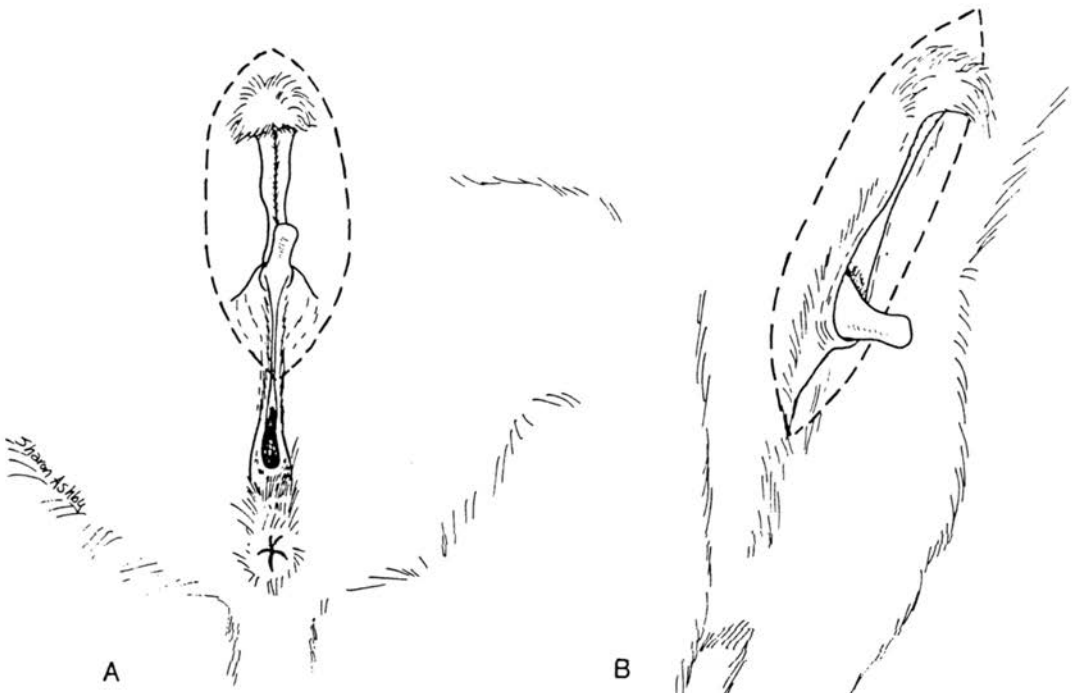


Figure 36-6. A. and **B.** Severe hypospadias with concurrent defects of penile and preputial development. Excision of the entire external genitalia is the approach of choice.

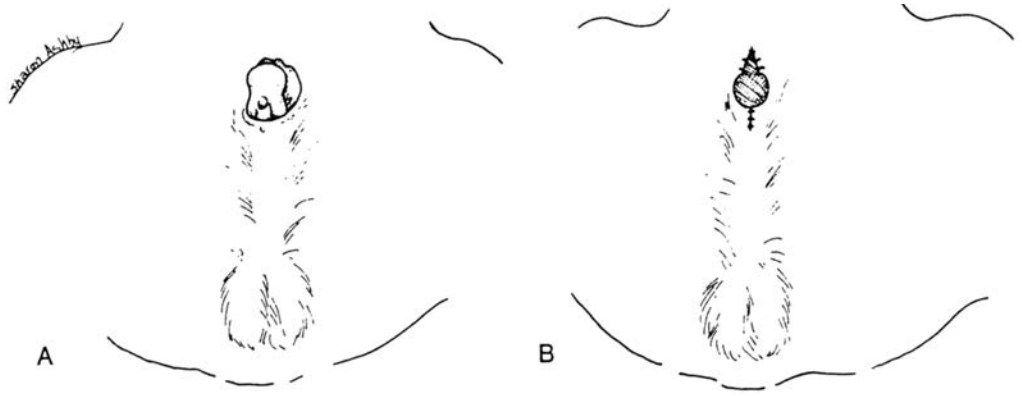


Figure 36-7. A. Glandular hypospadias with a concurrent preputial defect. **B.** The defect is closed ventrocaudally. If the resulting orifice is too small, it is enlarged by incising the prepuce dorsocranially. The preputial mucosa is sutured to the skin edge.

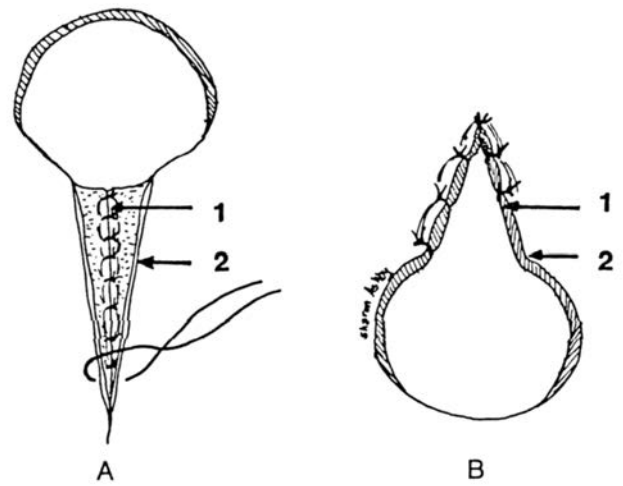


Figure 36-8. A. Closure of a ventrocaudal preputial defect. The mucocutaneous junction is trimmed away, the skin is undermined, and the mucosa *(1)* and the skin edges *(2)* are closed as separate layers. **B.** Enlargement of the dorsocranial aspect of the preputial orifice. The prepuce is cut at full thickness. The mucosa *(1)* is sutured to the skin edge *(2)* along the margin of the incision.

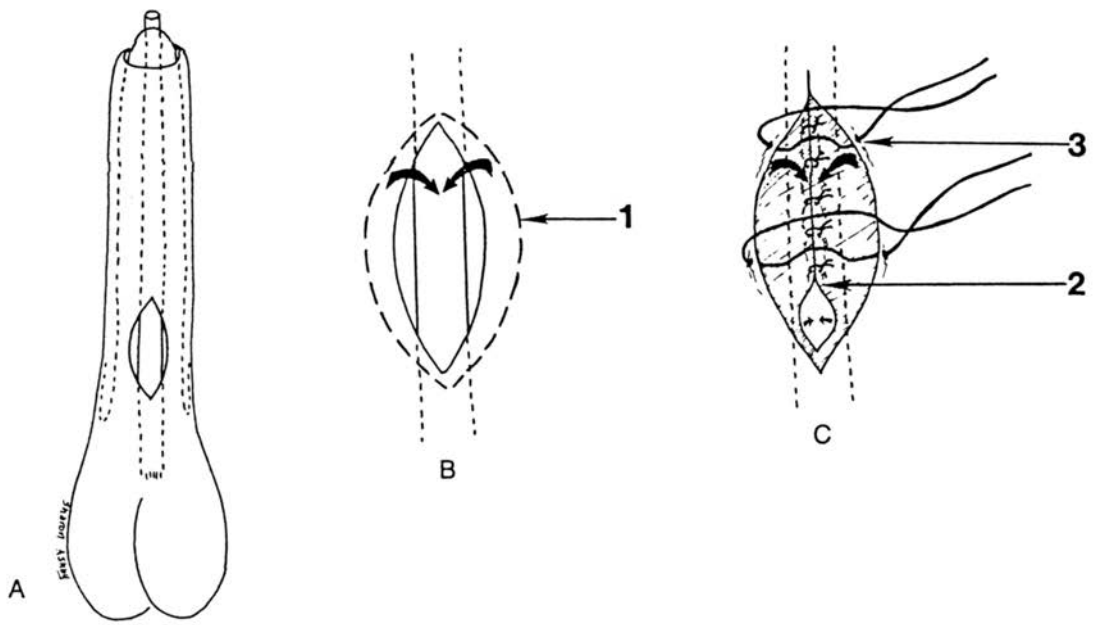


Figure 36-9. A. Penile hypospadias with a catheter in the urethra. **B.** Incisions are made lateral to the defect (*1*). Skin can be used to reconstruct the ventral wall of the urethra if mucosa is insufficient. Hair follicles need to be destroyed if skin is invaginated. **C.** The tissue is undermined sufficiently to allow the ventral urethral wall to be reconstructed (*1*) and the skin to be closed (*2*) without undue tension.

be present near the caudal end of the incision, it can be ligated in its entirety and excised. Ligation of the dorsal artery of penis is accomplished when necessary. The subcutaneous tissue and skin are closed in a routine fashion.

Correction of Phimosis

The inability to extrude the penis from the sheath (phimosis) is usually the result of too small a preputial orifice. Because surgical enlargement of the orifice with a ventrocaudal preputial incision can cause persistent extrusion of the glans, the orifice should be enlarged on the craniodorsal surface. A full-thickness incision is made to the desired length with heavy scissors. The severed preputial mucosa is then undermined sufficiently to allow apposition to the ipsilateral skin edge (See Figure 36-8B). The use of a restraint device to prevent licking or chewing is imperative.

Correction of Paraphimosis

The inability to return the penis to the sheath can result in severe trauma or circulatory compromise. The animal can develop necrosis or injury sufficient to require penile amputation. Persistent exposure of the glans can also result in chapping and excessive licking.

Many patients with acute paraphimosis can be managed by noninvasive methods to return the penis to the lumen of the sheath. The extruded and visually edematous penis should be cleansed, and the sheath should be thoroughly irrigated with nonirritating soaps. A combination of massage and locally applied hypertonic and hygroscopic agents, such as sugar, can help to reduce swelling. Once swelling is reduced, the constricting preputial orifice can usually be pulled over the lubricated penile shaft. Preputial enlargement can be accomplished by incision and primary repair of the mucosal and skin layers, to reduce refractory paraphimosis.

On occasion, the tip of the penis can remain exposed when no obvious orifice defects are present. Once the mucosa has been exposed for some time and has become dry and cornified, the skin of the prepuce rolls inwardly as attempts are made to return the penis to its sheath. After adequate cleansing and lubrication, the penis can be returned to its sheath. If the tip of the penis is well covered by the prepuce (at least 1 cm), narrowing of the preputial orifice will probably prevent recurrence (See Figure 36-8A). Should the prepuce not cover the tip of the penis well, cranial movement of the prepuce should be performed (Figure 36-10). This translocation can be accomplished by removing a crescent-shaped piece of skin from the ventral body wall just cranial to its juncture with the prepuce. Care should be taken to preserve the preputial vessels. The preputial muscles, which lie superficial to the rectus abdominis muscles, can then be shortened by either an overlapping technique (Figure 36-10A) or simple excision followed by reapposition (Figure 36-10B). The closure of the subcutaneous tissue and skin is routine.

Preputial Reconstruction

A hypoplastic prepuce can be lengthened in a two-step surgical procedure. The first step involves transplanting oral mucosa to a prepared graft site on the ventral body wall immediately cranial to the hypoplastic prepuce; in the second step, the lateral sides of the grafted mucosa are freed, are formed into a tube, and are anastomosed to the isolated mucosa of the cranial end of the prepuce. Single pedicle skin flaps are advanced to the ventral midline from both sides of the ventral body wall to cover the mucosal tube and to complete the cranial extension of the prepuce.

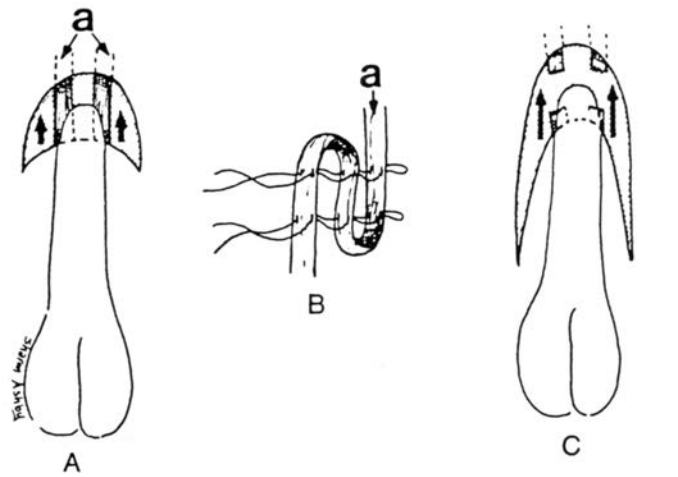


Figure 36-10. A and **B.** A crescent-shaped piece of skin is removed with subsequent cranial movement of the cranial aspect of the prepuce by folding the preputial muscles *(a)*. **C.** Excision of a segment of the preputial muscles.

Correction of Ventral Deviation of the Penis

Wedge osteotomies reportedly have been successfully performed to correct ventral penile deviation. The os penis is approached on the dorsal midline over its greatest curvature. The os penis is fractured with a bone cutter, and a small pie-shaped wedge of bone is excised to allow for straightening of the os penis. After wound closure, an open-ended catheter is sutured in place within the urethra and is left for a minimum of 3 weeks. One disadvantage of this procedure is possible damage to the penile urethra at the time of surgery or during healing. Rigid fixation of the os penis should definitely be maintained to help alleviate the likelihood of nonunion or malunion. Animals with congenital anomalies should not be used for reproductive purposes.

Removal of Penile Urethral Calculi

Most urethral calculi causing impairment of urine flow are lodged just proximal to the os penis. On rare occasion, particularly when the groove within the os penis is narrowed, calculi lodge within the penile urethra. This narrowing can be the result of a congenital deformity or injury, with or without fracture of the os penis. Whenever possible, these calculi should be hydropulsed into the bladder. Extraordinary efforts should not be used to relocate these stones, however, because debridement of the urethral mucosa is likely to result in stricture formation.

The penile urethra is approached from a ventral midline incision, after exposure of the penis as in Figure 36-1A or by splitting the prepuce. A catheter is advanced from the urethral orifice caudally to determine the exact location of the obstruction. Ideally, the incision is made exactly on the ventral midline of the penis, to avoid the erectile tissue. The incision is extended

caudally 1 to 2 cm, exposing the calculi. On rare occasion, the surgeon may need to rongeur away a part of the wall of the groove in the os penis after carefully elevating the soft tissue, including the urethra, from the bone.

The calculi are grasped with forceps and carefully are removed. The area is flushed with sterile saline, and the catheter is advanced to the bladder, while one checks for the presence of more calculi. A cystotomy is performed if indicated. The penile urethral incision is closed with fine absorbable suture over a catheter with a continuous suture pattern. The penile incision is then closed over the urethra in similar fashion.

Correction of Penile Urethral Strictures

Minimal stricturing of the penile urethra can often be managed by dilating the stricture and leaving an indwelling open-ended catheter in place for 7 to 10 days. More extensive strictures may be better managed with a prescrotal or scrotal urethrostomy, as discussed previously and in Chapter 31, because the urethra is immobile within the groove of the os penis and does not lend itself well to reconstruction.

Correction of Persistent Penile Frenulum

On rare occasions, the penile mucosa may fail to separate from the prepucial mucosa as the puppy matures, and it may serve as an irritant to the pup or may even impair breeding in the mature male. Rarely is this persistent attachment more than a narrow band of tissue that is easily severed.

Suggested Readings

Ader PL, Hobson HP. Hypospadias: a review of the veterinary literature and a report of three cases in the dog. J Am Anim Hosp Assoc 1978; 14:721.

Bennett D, Baugham J, Murphy F. Wedge osteotomy of the os penis to correct penile deviation. J Small Anim Pract 1986;27:379.

Burger RA, Muller SC, et al. The buccal mucosal graft for urethral reconstruction: a preliminary report. J Urol 1992;147:662.

Chaffee VM, Knecht CD. Canine paraphimosis: sequel to inefficient preputial muscles. Vet Med Small Anim Clin 1975;70:1418.

Hayes AG, Pavletic MM, et al. A preputial splitting technique for surgery of the canine penis. J Am Anim Hosp Assoc 1994; 30:291.

Leighton RL. A simple surgical correction for chronic penile protrusion (dog). J Am Anim Hosp Assoc 1976; 12:667.

Pope ER, Swaim SF. Surgical reconstruction of hypoplastic prepuce. J Am Anim Hosp Assoc 1986,22:73.

Poppas DP, Mininberg LH, et al. Patch graft urethroplasty using dye enhanced laser tissue welding with a human protein solder: a preclinical canine model. J Urol 1993; 150:648.

Proescholdt TA, DeYoung DW, Evans LE. Preputial reconstruction for phimosis and infantile penis. J Am Anim Hosp Assoc 1977; 13:725.

Smith MM, Gourley IM. Preputial reconstruction in a dog. J Am Vet Med Assoc 1990,196:1493.

Varshney AC, Sharma VK, et al. Surgical management of carcinomatous urethral obstruction in a dog. Indian Vet J 1985; 62:1073.

Section F

Endocrine System

Chapter 37

Endocrine System

Adrenalectomy

Stephen D. Gilson, Lillian Brady Rizzo and Akiko Mitsui

Introduction

Adrenalectomy is most often performed for treatment of primary adrenal tumors (adrenal cortical adenoma, carcinoma, and pheochromocytoma). Rarely, adrenal resection may be used for treatment of metastatic tumors, sex hormone imbalances, and treatment of pituitary-dependent hyperadrenocorticism refractory to medical therapy. Adrenal tumors are often biologically active resulting in adverse physiologic alterations, and may invade the adjacent great vessels (vena cava, aorta, renal vein or artery). Clinical management and resection can be challenging. Surgeons must have a thorough understanding of the pathophysiology associated with adrenal diseases, be suitably familiar with the regional anatomy and make appropriate perioperative preparations to minimize complications and maximize treatment success.

Preoperative Management

Routine diagnostic and staging tests recommended for adrenal masses include: complete blood count and serum biochemistry profile, thoracic radiographs, and abdominal ultrasound (including Doppler flow evaluation of great vessels for presence of tumor thrombus). For the majority of patients this collection of diagnostic tests is adequate for preoperative assessment. In selected patients, further imaging evaluation may be deemed necessary and abdominal CT (with contrast) and MR imaging provide excellent assessment of the adrenal glands and surrounding tissues.

Adrenal cortical tumors may produce excess cortisol and symptoms of Cushing's disease. Where indicated by clinical findings, patients are evaluated by low dose dexamethasone suppression test (or similar assessment) prior to surgery. Hyperadrenocorticism can predispose patients to complications resulting from hypertension, delayed wound healing, immune suppression, and thrombosis. If testing confirms hyperadrenocorticism, preoperative adrenal suppression may reduce the risk of complications. Ketoconazole therapy (10 mg/kg q 12hours) is a rapid and safe method for suppression. The optimal duration of preoperative therapy to reverse adverse effects remains unknown, and further study would be valuable. Empirically, the authors find a 10 day course of treatment is effective. When significant hypertension is present, concurrent use of vasodilator therapy is also indicated (Table 37-1).

Pheochromocytomas can produce excess catecholamines resulting in hypertension, tachycardia, arrhythmias, and chronic myocardial changes. Patients should have blood pressure measured, and where indicated by relevant clinical signs, echocardiographic evaluation. For cases where definitive diagnosis remains difficult, catecholamine by-products can be measured in the urine (vanillylmandelic acid, metanephrine and normetanephrine).[1] When hypercatecholaminemia is present preoperative treatment with phenoxybenzamine and atenolol or propranolol can reduce anesthetic complications (Table 37-1). The optimal duration of preoperative catecholamine suppression is also unknown, however empirically the authors have found a 10-day course of treatment to be effective. When significant hypertension is present concurrent use of vasodilator therapy is also indicated (Table 37-1).

Table 37-1. Pharmacologic agents used for preoperative preparation for catecholamine producing tumors.

Alpha-adrenergic Antagonism
Phenoxybenzamine: 0.25 mg/kg PO BID initially; (range 0.2-2.5 mg/kg BID) for 7-10 days before surgery.
Treatment of hypertension, hypovolemia associated with chronic vasoconstriction, and reduces cardiovascular events related to tumor manipulation induced acute catecholamine release.
Beta-adrenergic Antagonism
Atenolol: 0.2 -1 mg/kg PO q12-24 hours for 7-10 days before surgery.
Treatment of severe tachycardia/arrhythmia. Administer ONLY AFTER phenoxybenzamine has been initiated to prevent severe hypertension.
OR
Propranolol: 0.2 -1 mg/kg PO TID for 7-10 days before surgery.
Treatment of severe tachycardia/arrhythmia. Administer ONLY AFTER phenoxybenzamine has been initiated.
Chronic Vasodilator
Enalapril (ACE inhibitor): 0.5 mg/kg once to twice daily.
Treatment of refractory hypertension.
OR
Hydralazine (Direct acting vasodilator): 1-3 mg/kg twice daily.
Treatment of refractory hypertension.

Surgical Anatomy

The adrenal glands are located craniomedial to the pole of each kidney in the retroperitoneal space. The left adrenal gland lies in loose collagenous connective tissue, is generally well localized, and easily visualized with retraction of the mesocolon. The right adrenal is less well localized from the adjacent structures and the capsule is often continuous with the outer tunic of the vena cava. In some animals the gland lies dorsal to the vena cava. Deep chested animals require substantial retraction of the mesoduodenum for adequate visualization. The adrenals have a rich blood supply and it is often significantly enhanced by tumor neovascularization. The renal artery and vein run along the caudal boundary of each adrenal gland and these vessels can be encroached upon and invaded as tumors enlarge. The phrenicoabdominal veins course dorsoventrally across the center of each gland and are frequently invaded by a tumor thrombus. The right adrenal vein empties into the caudal vena cava, and the left adrenal vein enters the left renal vein. Clinically relevant arterial supply is by multiple short branches located on the dorsomedial side of the glands arising from the aorta, renal, lumbar, and phrenicoabdominal arteries. Innervation is by preganglionic sympathetic nerve fibers from the splanchnic supply, and medullary cells are the postganglionic neurons (Figure 37-1).[2]

Surgical Approach

Adrenalectomy is best performed via ventral midline laparotomy. Though a paracostal retroperitoneal approach is described, the field of view is small making resection of larger tumors difficult or impossible. The ventral approach allows exposure to both adrenal glands, permits complete exploration of the abdominal cavity for identification and biopsy of suspected metastatic lesions, and provides exposure for intravascular thrombus resection or nephrectomy if necessary. Disadvantages are minimal but include risk of iatrogenic pancreatic injury and more severe consequences of wound dehiscence. On rare occasions in deep chested dogs, a right paracostal extension is needed. The laparotomy incision is continued dorsolaterally from the xiphoid cartilage, following 1cm caudal to the last rib. The rectus abdominis, external and internal abdominal oblique, and transverses abdominis muscles are incised respectively. Care is taken to avoid inadvertent incision of the diaphragm and creation of a pneumothorax. The formed abdominal muscle flap is retracted caudodorsally, exposing the craniolateral abdomen. Closure is by approximation of the abdominal wall at the junction of the combined ventral and paracostal incisions near the xiphoid cartilage followed by routine closure of the linea alba and each muscle layer of the paracostal incision.[3]

Patient preparation for caudal median sternotomy and anesthesia provisions for ventilatory support are readied if a tumor thrombus extends cranial to the diaphragm and access to the thoracic vena cava is needed. The neck may also be prepared to harvest a jugular venograft if significant caval involvement is suspected.[4] Intraoperative complications should be anticipated and prepared for (Table 37-2).

Surgical Technique

Abdominal viscera are covered and padded with laparotomy sponges and retracted by hand or with malleable retractors. Retraction must be gentle in animals with hyperadrenocorticism as tissues are often friable and easily torn. The adrenal

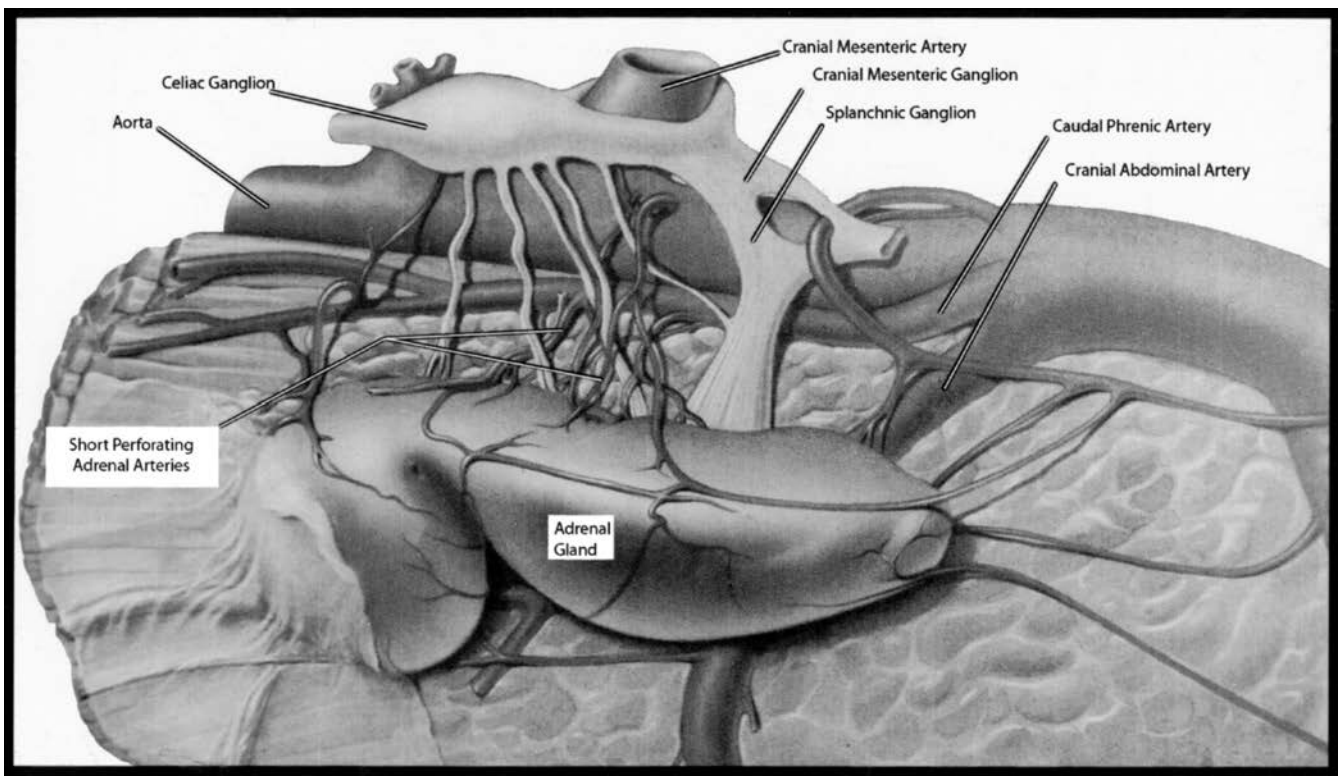


Figure 37-1. Surgical anatomy of the medial surface of the adrenal gland, depicting the neurovascular structures to be encountered during dissection. (Modified from Evans HE, Christensen GC. Miller's anatomy of the dog. Philadelphia: WB Saunders, 1993: 578.)

Table 37-2. Pharmacologic agents used for management of intraoperative complications for adrenal tumors.

Hypertension (systolic pressure > 200 mmHg)
Phentolamine (Alpha-adrenergic antagonist): 0.02-0.1 mg/kg IV PRN.
Sodium nitroprusside (Direct acting vasodilator): Dose to effect at 0.5-10 µg/kg/minute constant infusion.
Hypotension (systolic pressure < 70 mmHg)
Dobutamine (Positive inotrope): 2-10 µg/kg/minute IV.
Cardiac dysrhythmias
Esmolol (short acting Beta 1-adrenergic antagonist): slow bolus 0.5 mg/kg, then 50-200 µg/kg/minute infusion.
Propranolol (Beta-adrenergic antagonist): 0.02-0.1 mg/kg slow IV over 2-3 minutes.
Lidocaine (ventricular antiarrhythmic agent): 2 mg/kg bolus, up to 8 mg/kg; if responsive then CRI of 50-100 µg/kg/minute.

gland and retroperitoneal tissues are inspected for extent of local invasion, and the abdomen inspected for metastasis to the liver, regional lymph nodes, and along the sympathetic chain (pheochromocytoma). Biopsy specimens are procured from any suspected metastases.[5,6] The phrenicoabdominal vein, vena cava, ipsilateral renal artery and vein, and aorta are palpated for evidence of tumor thrombus. In the authors' experience thrombus formation is by far most common in the phrenicoabdominal vein and vena cava. Renal vein thrombi are uncommon and aortic or renal artery thrombus formation is rare. After surgical staging is complete a resection plan is made and initiated.

Wide incision is made in the peritoneum around the mass and a combination of blunt and sharp dissection of surrounding fatty tissue and ventral paralumbar muscle fascia are utilized to isolate the mass in an envelope of normal tissue (Figure 37-2). It is generally easiest to work from the periphery of the mass towards the great vessels. If a tumor thrombus is present the authors prefer to completely dissect the adrenal tumor first, and then perform venotomy while using the tumor to tether the thrombus for manipulation. Attention to hemostasis is paramount to visualize fine anatomy, and keeping the tissues under constant tension allows delicate layer-by-layer dissection. The phrenicoabdominal vein is ligated, and hemostatic clips and electrocautery are used for occlusion of smaller perforating arteries (Figure 37-3). Though difficult, an attempt is made to isolate and ligate tumor blood supply as much as possible prior to extensive tumor manipulation to minimize iatrogenic hormone release. Careful technique and barrier sponges/material are utilized to avoid seeding the abdominal cavity with neoplastic cells.

When a tumor thrombus is present, additional preparation is made. If the thrombus is confined to the phrenicoabdominal vein a standard adrenalectomy is performed and the thrombus removed by ligation and en bloc removal of the phrenicoabdominal vein. Intracaval or aortic thrombi are removed by isolating the affected segment of vessel (and renal vessels if

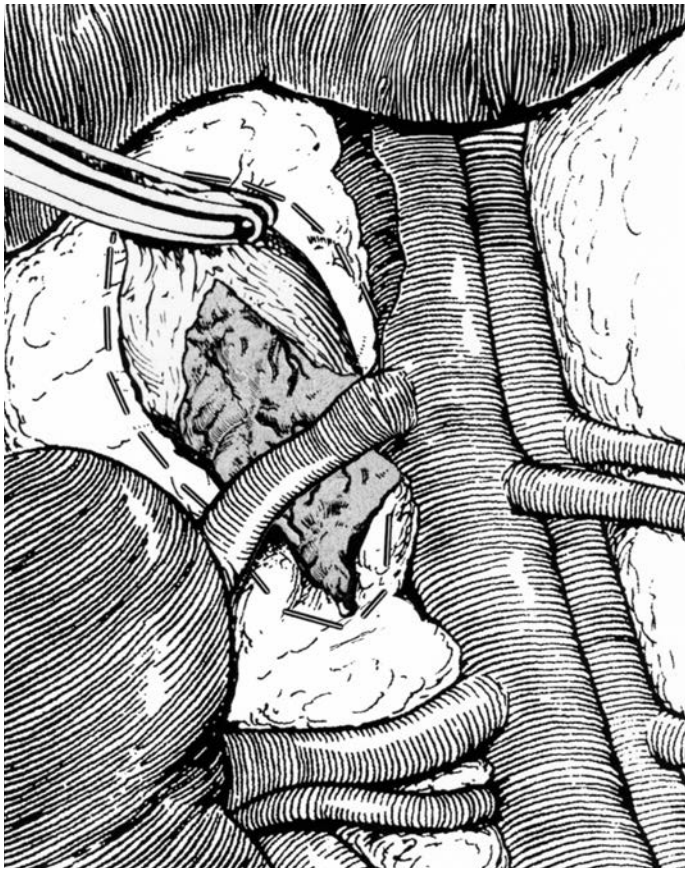


Figure 37-2. Surgical anatomy indicating the plane of dissection within the peritoneum necessary for isolation of the mass within an envelope of normal tissue. (Modified from Birchard SJ. Adrenalectomy. In: Slatter D. Textbook of Small Animal Surgery. 3rd ed. Philadelphia: WB Saunders, 2003:1697.)

thrombus proximity requires occlusion more caudally) with Rumel tourniquets (Figure 37-4). Following complete tumor dissection, occlusion of blood flow is quickly implemented and the vessel wall at the site of tumor penetration is circumferentially incised with a #11 scalpel blade. The thrombus is removed by exerting traction on the tumor base and tethered thrombus with one hand, while the other hand is used to "milk" the thrombus out by extramural manipulation.[5] The incision is extended as needed to allow thrombus removal without tearing the vessel wall. The lumen is lavaged and a partial occlusion clamp (Satinski or similar) is placed to permit vascular flow during suturing. The vessel wall is closed with a continuous suture pattern using 4-0 or 5-0 polypropylene. Air is displaced from the lumen by releasing the caudal Rumel tourniquet prior to tightening the final suture. The cranial tourniquet is released and the suture line checked for bleeding. Minor leakage is controlled with gentle pressure, and more significant leakage with placement of additional interrupted sutures. Vessel occlusion must be as brief as possible to avoid visceral injury.

Special Surgical Considerations

If the tumor thrombus extends cranial to the diaphragm, a caudal median sternotomy is performed to allow placement of a Rumel tourniquet cranial to the thrombus; removal is as described above.

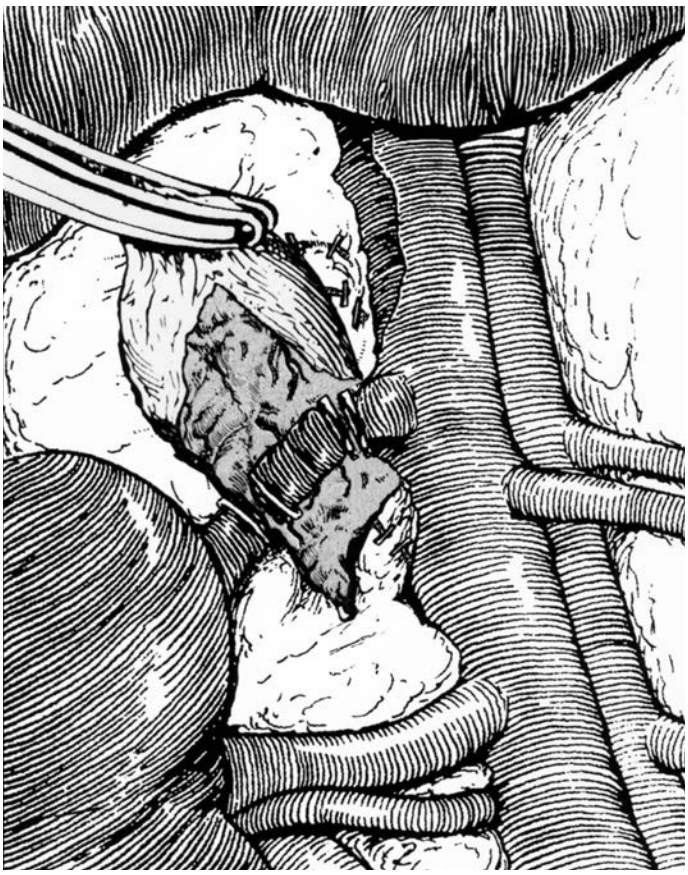


Figure 37-3. The surgical field during ligation of the phrenicoabdominal vein and smaller perforating arteries. Attention to hemostasis is paramount, therefore, use of hemostatic clips and electrocautery is recommended. (Modified from Birchard SJ. Adrenalectomy. In: Slatter D. Textbook of Small Animal Surgery. 3rd ed. Philadelphia: WB Saunders, 2003:1697.)

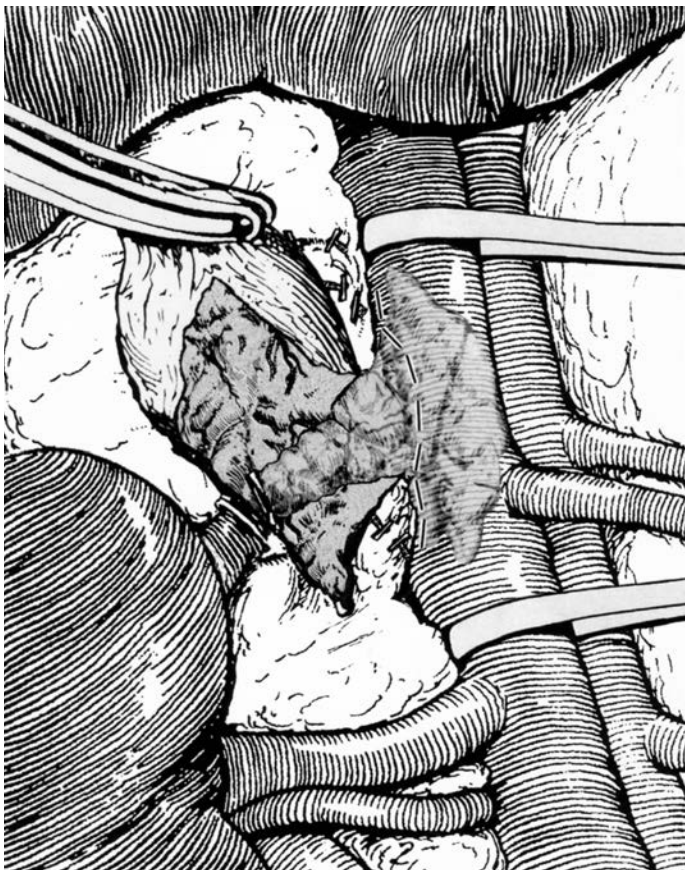


Figure 37-4. Thrombusectomy of an intracaval thrombus. Following complete tumor dissection the affected segment of vessel is isolated with Rumel tourniquets. Occlusion of blood flow is implemented. The dotted line indicates the site of circumferential incision of the vessel wall at the site of tumor penetration. The thrombus is removed by exerting traction on the tumor base with one hand, while the other hand is used to "milk" the thrombus out. The incision is extended as needed to prevent tearing the vessel wall. The vessel wall is closed as air is displaced from the lumen by releasing the caudal Rumel tourniquet prior to tightening the final suture. Finally, the cranial tourniquet is released. (Modified from Birchard SJ. Adrenalectomy. In: Slatter D. Textbook of Small Animal Surgery. 3rd ed. Philadelphia: WB Saunders, 2003:1697.)

En bloc nephrectomy is occasionally required because of tumor invasion into the renal vessels or parenchyma. The tumor and kidney are isolated en bloc before great vessel incision to minimize occlusion time and facilitate rapid thrombus removal.

When pheochromocytoma is suspected but tumor location is not evident, identification can be aided by a palpation induced increase in arterial blood pressure of a suspected mass, and subsequent decrease in pressure following removal (even if preoperative adrenergic blocking agents have been used). If blood pressure fails to decline, unidentified metastases are likely.

Nonresectable tumors are debulked if possible to decrease circulating cortisol or catecholamines and improve the efficacy of long-term medical management.[6]

Consider jejunostomy tube placement before closure when iatrogenic pancreatitis is of concern.

Complications and Postoperative Management

Adrenalectomy (particularly with thrombusectomy) is a demanding surgery. Minor complications are almost always expected, and provisions always made in preparation for major complications.

Intraoperative complications include bleeding, arrhythmias, hypotension, hypertension, and air embolism. Bleeding can arise from the adrenal (usually from dorsomedial short perforating arteries), or from retraction injury to the liver and pancreas. Adrenal artery hemostasis is best controlled with vascular clips or electrocautery. Organ parenchymal injuries are prevented by gentle retraction and padded covering with thick laparotomy sponges. Parenchymal bleeding is generally mild and easily stopped with pressure or application of topical hemostatic sponges. Cardiovascular complications mostly arise from catecholamine secretion and are largely preventable (Table 37-1). Use of crystalloid and colloid fluid supplementation will adequately manage most abnormalities; for more severe fluctuations in pressure or rhythm, drug therapy is indicated (Table 37-2). Air embolism occurs if the vascular lumen is not purged before final closure of vessel wall sutures.

Postoperative complications include adrenal insufficiency, pulmonary thromboembolism, infection, and delayed wound healing for adrenal cortical tumors; and arrhythmia, hypotension,

and hypertension for medullary tumors.[7] General complications include persistent organ parenchymal bleeding and pancreatitis from iatrogenic trauma.

Following unilateral adrenalectomy for cortisol producing tumors, glucocorticoid supplementation is required during and for a short period after surgery. Dexamethasone is administered parenterally until the animal is eating, and then oral prednisone is used for ongoing management. Glucocorticoid supplementation can generally be tapered by 6 to 8 weeks. Permanent glucocorticoid and mineralocorticoid replacement therapy is necessary in patients undergoing bilateral adrenalectomy (Table 37-3).[6,8,9] Risk of thromboembolic disease is reduced with heparin and low dose aspirin therapy and treatment is generally tapered as the patient stabilizes over 2 to 5 days. Supplementation with Vitamin A is used to offset cortisol induced delayed wound healing; treatment is generally discontinued at the time of suture removal. Infection is prevented by routine use of perioperative antibiotics; prolonged therapy is avoided except in cases where infection is documented or risk is significant.

Table 37-3. Postoperative management of cortisol producing tumors.

Vitamin A	800-1500 U/kg SID.
Heparin	250 U/kg initial dose and 100 U/kg TID. Dose is adjusted according to daily evaluation.
Dexamethasone	0.1 mg/kg SC daily for 24-72 hours after surgery THEN
Prednisone	0.2-0.4 mg/kg PO daily; gradually tapered over 6-8 weeks.
Following bilateral adrenalectomy	
Fludrocortisone acetate	0.02 mg/kg PO daily maintenance.
OR	
DOCP (desocycorticosterone pivalate)	2.2 mg/kg every 25 days AND
Prednisone	0.2-0.4 mg/kg PO daily.

Paradoxically, following adrenalectomy for catecholamine producing tumors, persistent or episodic hypertension or hypotension can occur. The cause remains unknown, but in people the fluctuations can be severe. Though arrhythmias can occur, incidence generally decreases after tumor removal since peptide hormones have a short half life. Adjustments to crystalloid and colloid fluid supplementation are adequate for management of most abnormalities; for more severe fluctuations drug therapy is indicated (Table 37-2).

Management of persistent parenchymal bleeding is by transfusion and conservative treatment such as abdominal pressure wrap. In severe cases reexploration may have to be considered. Pancreatitis is managed by traditional supportive therapy.

Prognostic factors remain incompletely defined for adrenal tumors, and even histologic grading and determination of malignancy can be difficult. In one study neurologic signs, abdominal distension, and weight loss were more frequently associated with advanced disease and a poorer prognosis.[10] Prognostic factors in humans with pheochromocytomas that indicate malignancy are large tumor size, local tumor extension at surgery and DNA ploidy.[11] In dogs as in humans, clinical evidence of metastasis defines malignancy and the sites reported in the dog are lung, liver, spleen, kidney, bone, heart, pancreas and lymph nodes. About 50% of reported pheochromocytomas are considered malignant and long-term prognosis is undoubtedly poorer with metastatic or invasive disease. However reported survival times following successful resection, even with the presence of metastasis, range from 18 months to 2 years.[5,10,12] The frequency of caval invasion with pheochromocytomas in one report was 54%, and 11% with adrenocortical tumors. The right side was affected in 35% of cases and the left side in 20%. This study also determined that adrenalectomy with thrombusectomy did not significantly increase morbidity and mortality, provided appropriate surgical technique was used.[13] The long term prognosis is generally favorable for cure of adrenal adenoma, and for adrenal carcinoma reported median survival time in one study was 778 days.[14]

References

1. Maher ER, McNiel EA. Pheochromocytoma in dogs and cats. Vet Clin North Am Small Anim Pract 1999; 27:359-380.

2. Evans HE, Christensen GC. Miller's anatomy of the dog. 2nd ed. Philadelphia: WB Saunders, 1993: 578-579.

3. Smith MM, Waldron DR. Atlas of Approaches for General Surgery of the Dog and Cat. Philadelphia: WB Saunders, 1993: 171.

4. Axlund TW, Winkler JT. Surgical Treatment of Canine Hyperadrenocorticism. Compend Contin Educ Pract Vet 2003; 25(5):334-346.

5. Gilson SD, Withrow SJ, Orton C. Surgical Treatment of Pheochromocytoma: Technique, Complications, and Results in Six Dogs. Vet Surg 1994; 23:195-200.

6. Locke-Bohannon LG, Mauldin GE. Canine pheochromocytoma: Diagnosis and management. Compend Contin Educ Pract Vet 2001; 23(9); 807-814.

7. Scavelli TD, Peterson ME, Matthiesen DT. Results of surgical treatment for hyperadrenocorticism caused by adrenocortical neoplasia in the dog: 25 cases (1980-1984). J Am Vet Med Assoc 1986; 189:1360-1364.

8. Feldman EC, Nelson RW. Canine hyperadrenocorticism (Cushing's syndrome). In: Feldman EC, Nelson RW. Canine and Feline Endocrinology and Reproduction, Third Edition. Philadelphia: WB Saunders Co., 2004: 252-357.

9. Kirk RW: Current Veterinary Therapy IX. Philadelphia, W. B. Saunders Co, 1986: 972-981.

10. Gilson SD, Withrow SJ, Wheeler SL, et al: Pheochromocytoma in 50 dogs. J Vet Intern Med. 1994: 8; 228-232.

11. Werbel SS, Ober KP: Pheochromocytoma: Update on diagnosis, localization and management. Med Clin North Am. 1995: 79; 131-153.

12. Twedt DC, Wheeler SC: Pheochromocytoma in the dog. Vet Clin North Am Small Anim Pract. 1984: 14; 767-782.

13. Kyles AE, Feldman EC, De Cock HE, et al. Surgical management of adrenal gland tumors with and without associated tumor thrombi in dogs: 40 cases (1994-2001). J Am Vet Med Assoc 2003; 223;654-662.

14. Anderson CR, Birchard SJ, Powers BE, et al. Surgical Treatment of Adrenocortical Tumors: 21 Cases (1990-1996). J Am Anim Hosp Assoc 2001; 37:93-97.

Thyroidectomy in the Dog and Cat

Stephen J. Birchard and Joao F. de Brito Galvao

Introduction

Thyroid neoplasia is the primary indication for thyroidectomy in dogs and cats. Thyroid tumors in dogs are usually malignant and non-functional, whereas in cats they are usually benign and functional. Thyroidectomy can range from a straightforward to complex surgical procedure, depending on the invasiveness and size of the tumor. A working knowledge of the regional anatomy, pathophysiology of thyroid and parathyroidectomy disorders, and the principles of pre and postoperative care is necessary for successful patient management. Animals with thyroid tumors tend to be geriatric and frequently have disorders of other organ systems that should be recognized and treated appropriately. This is particularly true for cats with hyperthyroidism, a potentially severe multi-system disorder that can increase the risks associated with anesthesia and surgery.

The purpose of this chapter is to provide an overview of the pathophysiology of thyroid neoplasia, to review the anatomy of the thyroid and parathyroid glands, and to describe the surgical technique for thyroidectomy. Postoperative care and complications are also covered.

Surgical Anatomy

The thyroid gland in the dog and cat is divided into two lobes which are located adjacent to the trachea and just caudal to the larynx. The left lobe is slightly caudal to the right.[1] The normal gland is pale tan. The principle blood supply to each lobe is the cranial thyroid artery, a branch of the common carotid artery[1] (Figure 37-5). The caudal thyroid artery in the dog arises from the brachiocephalic trunk or common carotid artery. The caudal thyroid artery is absent in the cat.[2] Venous drainage of the thyroid is through the cranial and caudal thyroid veins.[1] The thyroid has a distinct capsule that can be bluntly separated from glandular tissue. Small blood vessels may be located on the capsule surface and between the capsule and the parenchyma of the gland. Two parathyroid glands are usually associated with each thyroid lobe. The external parathryoid gland usually lies in the loose fascia at the cranial pole of the thryoid lobe.[2] The internal parathyroid gland is usually embedded in the thyroid parenchyma and is variable in location. The external parathyroid glands are much smaller than the thyroid lobe and can be distinguished from the thyroid tissue by their lighter color and spherical shape. The blood supply to the parathyroid glands also arises from the cranial thyroid artery.[1]

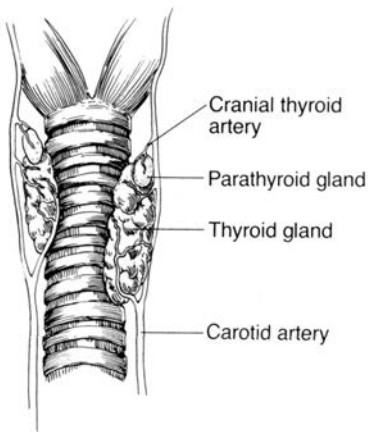


Figure 37-5. Gross appearance of bilateral thyroid tumors in a cat. (From Panciera DL, Peterson ME, Birchard SJ. Diseases of the thyroid gland. In Saunders Manual of Small Animal Practice, 3rd ed., Birchard SJ, Sherding RG, eds. Elsevier, St. Louis, 2006, pgs. 325-340.)

Thyroid Tumors in Dogs

Pathophysiology

Thyroid tumors in dogs account for 1.2% of all canine tumors.[3] The majority of the tumors are malignant, and adenocarcinoma is the most common tissue type reported.[4] Less than 20% of dogs with thyroid tumors have hyperthyroidism.[5] Boxers, beagles, and golden retrievers appear to have a greater risk of developing thyroid carcinoma.[3]

The most common presenting signs in dogs with thyroid tumors are the presence of a palpable neck mass and coughing or respiratory distress.[4] Other reported clinical signs are vomiting, dysphagia, anorexia, and weight loss.[5] Signs of hyperthyroidism are usually not present because elevation of thyroid hormone level is infrequent in dogs with thyroid neoplasia. However, the author has seen 2 dogs with functional thyroid adenocarcinomas that had elevated triiodothyronine (T_3) and thyroxine (T_4) levels but did not have signs of hyperthyroidism. Most thyroid tumors in dogs are malignant and are carcinomas. Thyroid carcinomas in dogs most frequently metastasize to the lungs.[4] Studies have indicated that over 50% of all thyroid carcinomas produce lung metastases.[3,6] The larger the primary tumor, the greater the chance for lung metastasis.[6] The second most common site of metastasis is the cervical lymph nodes.

A key factor in the preoperative evaluation of a dog with suspected thyroid neoplasia is determining whether or not the affected gland or mass is movable. Thyroid masses that are freely movable on palpation tend to be less invasive into surrounding tissues, are surgically resectable, and have a better long-term prognosis than those masses that are invasive and non-movable. One study found that, of 82 dogs with thyroid carcinoma, 20 had movable tumors.[7] These tumors were resected and median survival of the group was 20.5 months. A more recent study evaluated dogs with bilateral thyroid tumors that underwent thyroidectomy. As with unilateral tumors, long-term postoperative survival was good but many dogs required treatment for hypoparathyroidism.[8]

Diagnosis

Diagnosis of thyroid neoplasia in dogs is by physical examination (palpation of a neck mass), and biopsy of the tumor. Fine needle aspiration of the mass should yield cells characteristic of a carcinoma but may be inconclusive due to hemorrhage. A Tru-cut needle biopsy of the tumor may be considered if

cytology is inconclusive but may cause hemorrhage due to the extensive neovascularization of the tumor and therefore is not recommended. Thoracic radiographs are mandatory to rule out pulmonary metastases. Thyroid function should be evaluated with a thyroid- stimulating-hormone stimulation test or free T_4 assay if the dog is showing signs of hyperthyroidism or hypothyroidism. Routine preoperative tests, such as complete blood count, serum chemistry profile, and urinalysis are also recommended.

Preoperative Considerations

Surgical thyroidectomy is indicated for those dogs with small, movable thyroid masses that are not invasive. Treatment options other than surgery should be considered for dogs with large, fixed neoplasms. Radiation therapy has recently been shown to be effective in several dogs with infiltrative thyroid carcinoma.[9] Chemotherapy can also be used and may benefit dogs with nonresectable tumors, or with tumors that have been incompletely excised. Consultation with an oncologist is recommended in such cases.

Surgical Technique

The dog is placed in dorsal recumbency with the front legs tied caudally and the neck slightly hyper extended over a rolled towel or other cushion. The ventral cervical region from the caudal mandible to the manubrium is prepared for aseptic surgery. A ventral midline cervical skin incision is made from the caudal aspect of the larynx to 2 to 3 cm cranial to the manubrium. The paired sternohyoideus and sternothyroideus muscles are separated on the midline and retracted with self-retaining retractors. The trachea is gently retracted and both thyroid lobes are carefully examined.

An attempt should be made to identify the parathyroid glands, although visualization of the glands may be impaired by larger neoplasms (Figure 37-6). The tumor is carefully dissected from surrounding tissues (Figure 37-7). The author usually starts at the caudal aspect of the lobe and works cranially. Care is taken to avoid injury to the esophagus, carotid artery, jugular vein, vagosympathetic trunk, and recurrent laryngeal nerves.

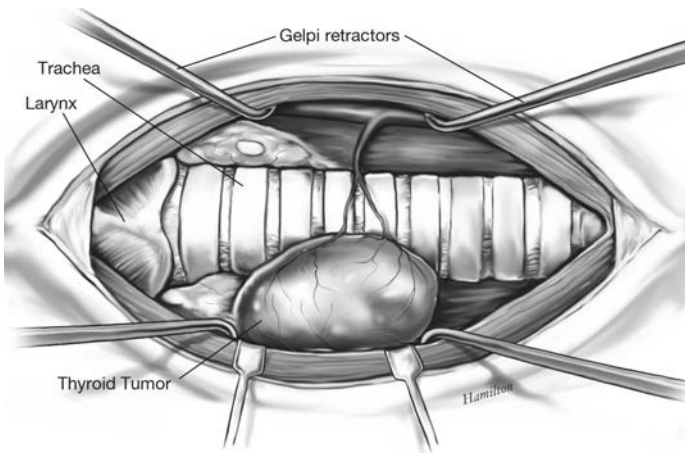


Figure 37-6. Gross appearance of a thyroid carcinoma in a dog. (From Panciera DL, Peterson ME, Birchard SJ. Diseases of the thyroid gland. In Saunders Manual of Small Animal Practice, 3rd ed., Birchard SJ, Sherding RG, eds. Elsevier, St. Louis, 2006, pgs. 325-340.)

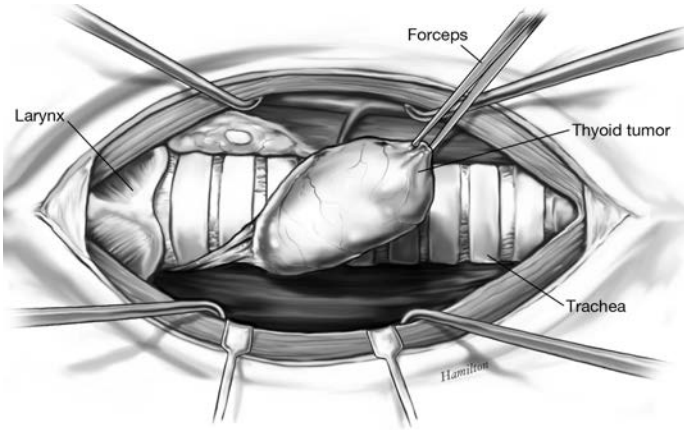


Figure 37-7. Removal of a canine thyroid tumor with a combination of blunt and sharp dissection. The surgeon must identify and preserve the recurrent laryngeal nerve. (From Panciera DL, Peterson ME, Birchard SJ. Diseases of the thyroid gland. In Saunders Manual of Small Animal Practice, 3rd ed., Birchard SJ, Sherding RG, eds. Elsevier, St. Louis, 2006, pgs. 325-340.)

If involved with the mass, the carotid artery, jugular vein, vagosympathetic trunk, and recurrent laryngeal nerve may be removed unilaterally. These tumors are extremely vascular and strict hemostasis is important to prevent serious blood loss. The Ligasure® vessel sealing device is a very useful tool for hemostasis of the highly vascular thryroid tumors in dogs. Even small vessels should be ligated or cauterized since surgery is hampered by a bloody field. Removal of large tumors results in dead space in the tissues; a closed suction drain (e.g. Jackson-Pratt) should be placed in the area of resected tumor to prevent hematoma or seroma formation. The sternohyoideus and sternothyroideus muscles are closed with absorbable suture, such as, (3-0 poliglecaprone 25 (Monocryl) or polydioxanone (PDS)) in a simple continuous pattern. The subcutaneous tissues are closed in the same fashion. Skin is closed with non-absorbable suture (4-0 nylon) in a simple interrupted pattern or with 4-0 absorbable intradermal suture in a simple continuous pattern.

The thyroid tissue should always be submitted for histologic examination. Results of histologic examination help to determine the need for adjunctive therapy, such as chemotherapy, and to evaluate the patient's long-term prognosis. One study found that surgery and chemotherapy did not improve survival in dogs compared to surgery alone.[10]

Postoperative Care

Post-operatively, the animal should be closely observed during recovery for bleeding at the surgical site. Serum calcium levels should be monitored daily for 2 to 4 days post-operatively if a bilateral tumor is resected. Hypocalcemia due to hypoparathyroidism is treated according to the protocol in Table 37-4.[11]

The animal should be reevaluated at 2 weeks, 3 months, 6 months, and 1 year and radiographs of the thorax should be obtained at these rechecks to monitor for metastasis. Prognosis for the individual patient depends upon tumor type and completeness

Table 37-4. Treatment of Hypocalcemia

	N	Content		
Parenteral Calcium*				
Calcium Gluconate	10% solution	9.3 mg of Ca/mL	a. acute crisis: 50-150 mg/kg over 20-30 min	Stop if bradycardia or shortened QT interval occurs
			b. following acute crisis: 1000-1500 mg/kg/day or 42-63 mg/kg/hr	Infusion to maintain normal Ca
				SQ calcium salts–Not Recommended. Can Cause Severe Skin Necrosis/Mineralization
Calcium chloride	10% solution	27.2 mg of Ca/mL	5–15 mg/kg/h IV	Only given IV as extremely caustic perivascularly
Oral Calcium†				
Calcium carbonate	Many sizes	40% tablet	25–50 mg/kg/day	Most common calcium supplement
Calcium lactate	325, 650 mg tabs	13% tablet	25–50 mg/kg/day	
Calcium chloride	Powder	27.2%	25–50 mg/kg/day	May cause gastric irritation
Calcium gluconate	Many sizes	10%	25–50 mg/kg/day	

Vitamin D		**Time for Maximal Effect to occur:**	*Time for Toxicity Effect to Resolve:*
Vitamin D_2 (ergocalciferol)	Initial: 4000–6000 U/kg/day; Maintenance:1000–2000 U/kg once daily to once weekly	5-21 days	1-18 weeks
Dihydrotachysterol	Initial: 0.02-0.03 mg/kg/day Maintenance: 0.01-0.02 mg/kg q 24-48 hrs	1-7 days	1-3 weeks
1,25-$(OH)_2$ D_3 (calcitriol)‡	Initial: 20-30 ng/day Maintenance: 5-15 ng/kg/day	1-4 days	2-14 days

*** Do not mix calcium solution with bicarbonate-containing fluids as precipitation may occur.**

† Calculate dose on elemental calcium content.

‡ Calcitrol is the perferred form of vitamin D for treatment of hypocalcemia.

Table reprinted from: Schenck PA, Chew DJ. Diseases of the Parathyroid Gland and Calcium Metabolism, in: *Saunders Manual of Small Animal Practice, 3rd edition,* eds. Birchard SJ, Sherding RG. Elsevier, St. Louis, 2005, pg. 353

of surgical excision. As previously mentioned, even thyroid carcinoma can be associated with a good prognosis if the tumor is mobile and is completely excised.

Thyroid Tumors in Cats

Pathophysiology

Thyroid masses in the cat are usually benign and functional. The disease can be unilateral or bilateral and histologically the tumors are usually adenomatous hyperplasia. Rarely, (in 1 to 2% of cases), the tumors are carcinomas.[6] Thyroid tumors in cats produce excessive amounts of thyroxine and cats develop the clinical syndrome of hyperthyroidism. Classic clinical signs of hyperthyroidism include tachycardia, hyperactivity, weight loss, polyphagia, and polyuria/polydipsia.[5] In addition to tachycardia a gallop rhythm, systolic murmurs, and arrhythmias can occur due to the catecholamine like effects of the excessive thyroxine on the myocardium. Some cats have apathetic hyperthyroidism, a syndrome characterized by signs opposite to the classic presentation for hyperthyroidism, such as depression, lethargy, and anorexia.[5]

Diagnosis

Diagnosis of feline hyperthyroidism is based on the history and clinical signs, palpation of a neck mass, and elevated serum triiodothyronine and thyroxine concentrations.[5] One or more thyroid nodules are palpable in approximately 85 to 90% of affected cats. The cats may also have leukocytosis, higher than normal packed cell volume, and high alkaline phosphatase.[5] Hyperthyroid cats may also have hypertrophic cardiomyopathy with hypertrophy of the left ventricular free wall and ventricular septum.[5] Renal function should be carefully evaluated prior to treatment of hyperthyroidism in cats. Hyperthyroidism may mask chronic renal failure by increasing renal blood flow.[12] Treatment

of the hyperthyroidism can result in exacerbation of the renal dysfunction when renal blood flow returns to normal. Some clinicians recommend a thirty-day therapeutic trial course of methimazole to assess the effect of decreased renal blood flow on kidney function.

Radionuclide scan of the thyroid gland in cats with hyperthyroidism reveals increased uptake and size of the affected lobes. Nuclear scan can be a useful diagnostic tool in cats that do not have a palpable thyroid nodule or that have had relapse of hyperthyroidism after thyroidectomy.[5] However, nuclear scans have limited practicality because of the specialized equipment and expertise needed to perform the studies.

Treatment options for hyperthyroidism in cats include use of methimazole, which lowers thyroxine by blocking uptake of iodine by the thyroid, radioactive iodine treatment, or surgical removal of the gland (s).[5] Reported success rates are high with all of these treatment methods. Medical treatment with methimazole is the least invasive and least expensive method and may be a reasonable option in high-risk anesthetic patients or where radioactive iodine is not available. However, side effects to methimazole have been reported and problems with owner adminstration may complicate long-term use of the drug.[13] Radioactive iodine therapy has been repeatedly shown to be safe and effective. Anesthetic and surgical complications (e.g. hypoparathyroidism) are avoided with this therapy, however, specialized facilities and expertise limit this to a referral procedure. Thus, availability may be a limiting factor. When this treatment option is not possible, and assuming the cat is a good anesthetic and surgical candidate, surgical thyroidectomy may be an option for long-term resolution of the condition.

Perioperative Considerations

There are several aspects of feline thyroidectomy that should be considered prior to performing surgery. Preoperatively, affected cats are treated with methimazole to establish euthyroidism which makes the animal a better candidate for anesthesia and surgery. Methimazole (Tapazole®, 5 mg orally twice a day) is administered for 7 to 10 days before surgery. The patients thyroxine levels are rechecked and, if normal or significantly reduced, surgery is scheduled. Cats that are only mildly affected by hyperthyroidism (i.e., only mildly elevated thyroxine, normal weight, not severely tachycardic) are operated without pretreatment with methimazole.

In an attempt to prevent postoperative hypocalcemia in dogs or cats undergoing bilateral thyroidectomy, some clinicians administer oral calcitriol (20ng/kg q12h) for 3 to 4 days preoperatively. Calcitriol administration is continued at 5-10ng/kg q12h for 1 week or more postoperatively depending on results of repeated serum ionized calcium assays.

Anesthesia in hyperthyroid cats can be challenging. Anesthetic facilities should allow for adequate monitoring of the cat, particularly since intraoperative electrocardiographic abnormalities are common. If premature ventricular contractions occur during anesthesia and do not resolve by increasing oxygenation, propanolol (0.1 mg IV) can be given to control the arrhythmia.

The surgeon should be comfortable with the regional anatomy, and with performing fine dissection of very small anatomic structures. Surgical instruments that are helpful include tenotomy scissors, DeBakey or Simkin thumb forceps, sterile cotton tipped applicators, and bipolar electrocautery.

Adequate postoperative monitoring is mandatory for recognizing and managing potential complications, such as hypocalcemia.[11] It is recommended that facilities and personnel be suitable for providing intensive postoperative care that is occasionally required.

Surgical Techniques

Thyroidectomy in the cat is performed by a ventral midline cervical approach.[14] Even if only one thyroid lobe appears grossly abnormal bilateral thyroidectomy is recommended since most cats have or will develop disease in both glands. Several techniques for thyroidectomy in cats have been described, some allowing for resection of the capsule (extracapsular dissection) and others preserving the capsule (intracapsular dissection).[14,15] The author typically performs the extracapsular technique because of the reduced incidence of recurrence of hyperthyroidism due to remnants of thyroid tissue left behind that can occur with the intracapsular technique. However, in cats where the parathyroid glands are not visible, the modified intracapsular technique is performed in order to be sure of preserving at least one of the parathyroid glands. Both techniques are described here.

An alternative surgical approach is staged bilateral thyroidectomy.[16] In order to reduce the incidence of postoperative hypocalcemia, one affected thyroid lobe is removed, then the remaining affected lobe removed several weeks later. This technique has been shown to be associated with a reduced incidence of postoperative hypoparathyroidism. However, considering the low risk of this complication in the hands of an experienced surgeon, and the increased cost and morbidity of a second operation, the author prefers to perform bilateral thyroidectomy in one procedure.

Extracapsular Technique

The thyroid lobes are exposed through a ventral midline cervical approach as described in the dog. The affected thyroid lobe is dissected free from surrounding fascia, working from caudally to cranially. The external parathyroid gland is identified at the cranial aspect of the thyroid gland. The thyroid gland capsule is incised adjacent to the parathyroid gland (Figure 37-8). Pinpoint electrocautery is used on any vessels encountered during this dissection with care taken to avoid damage to the parathyroid gland or its blood supply. The parathyroid gland is then carefully separated from the thyroid using sterile cotton-tipped applicators. Once the parathyroid gland is completely separated from the thyroid, the thyroid gland is completely removed using blunt and sharp dissection and pinpoint electrocautery on all vessels. Minor hemorrhage adjacent to the parathyroid glands can be controlled using small amounts of hemostatic gelatin sponge. Closure of the incision is by simple continuous suture pattern

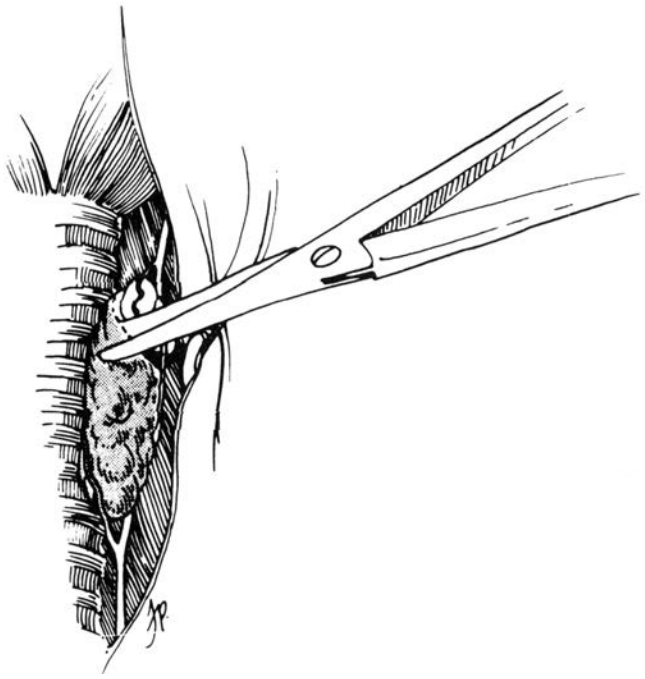


Figure 37-8. Extracapsular dissection for removal of a thyroid lobe in a cat. (From Graves TK, Peterson ME, Birchard SJ. Thyroid gland. In: Birchard SJ, Sherding, eds. Saunders manual of small animal practice. Philadelphia: WB Saunders, 1994:218-228.)

in the sternohyoideus muscle using absorbable suture, simple continuous pattern in the subcutaneous tissues with absorbable suture, and interrupted sutures in the skin with non-absorbable sutures. As an alternative to skin sutures, a continuous absorbable intradermal suture layer may be placed.

Modified Intracapsular Technique

A small nick incision is made in an avascular area of the thyroid capsule (Figure 37-9). This incision is extended with small scissors. The thyroid tissue is then gently separated from the capsule with sterile cotton tipped applicators. Meticulous hemostasis is critical to maintain good visualization of the surgical field. Hemorrhage from small capsular vessels is controlled using pinpoint electrocautery. Extreme care is required during manipulation of the cranial pole of the thyroid to avoid injury to the blood supply of the extracapsular parathyroid gland. If the thyroid gland becomes fragmented during dissection, the surgical field is carefully examined for remnants of thyroid tissue that were not removed. These remnants and associated capsule are removed. Remaining remnants of capsule are also removed since microscopic thyroid tissue may be attached to them. The incision is closed as described under the extracapsular technique. All resected tissue is submitted for histologic evaluation.

Postoperative Care

Postoperatively, the cat is closely monitored for evidence of hemorrhage from the surgical site. Serum calcium levels are monitored for at least 2 days postoperatively. If hypocalcemia develops due to removal or damage to the parathyroid glands, the cat is treated with calcium (parenteral and/or oral administration) and vitamin D as described in Table 37-4. Calcium supplementation potentiates the effect of calcitriol, but calcium supplements alone are not effective for control of hypocalcemia. Early signs of hypocalcemia are muscle soreness or spasm, anorexia, and depression. Later signs are collapse and tetany. Thyroid replacement therapy (L-thyroxine, 0.1 mg orally once daily) is not given routinely but it may be indicated for cats that have had bilateral thyroidectomy and show clinical signs of hypothyroidism (e.g. lethargy, weight gain, skin problems).

Renal function should be monitored closely in cats after thyroidectomy, especially if they have evidence of chronic renal failure preoperatively. As previously described, renal function in some cats worsens after thyroidectomy, presumably due to a decrease in renal blood flow after lowering the thyroxine levels.[12]

The prognosis for hyperthyroid cats after thyroidectomy is good. Treated cats show improved behavior and significant weight gain. Histologic examination of the thyroid tissue usually reveals adenomatous hyperplasia. Rarely, histologic exam of the excised mass reveals thyroid carcinoma.[17] These tumors are much larger and more vascular than the more common benign adenomatous hyperplasia.

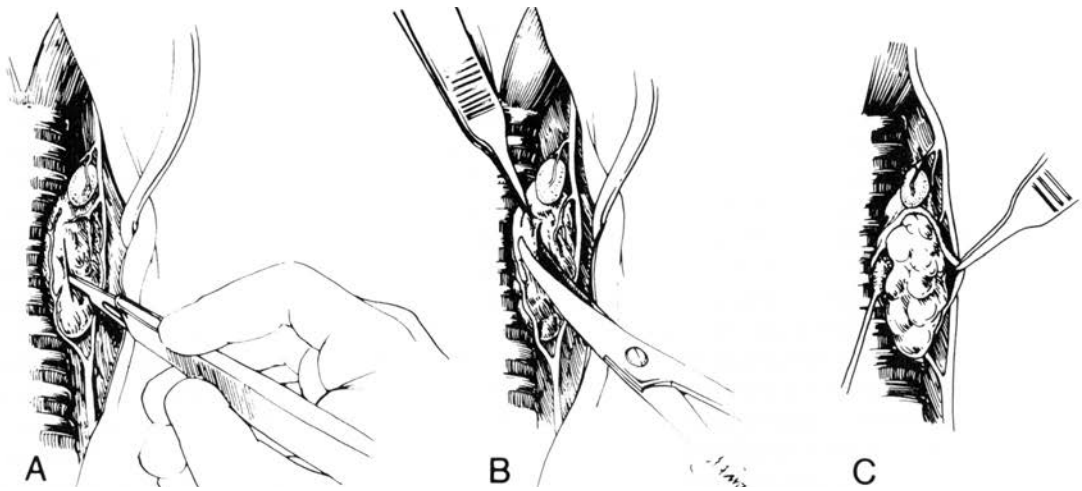


Figure 37-9. A.-C. Intracapsular dissection for removal of a thyroid tumor in a cat. (From Graves TK, Peterson ME, Birchard SJ. Thyroid gland. In: Birchard SJ, Sherding, eds. Saunders manual of small animal practice. Philadelphia, WB Saunders, 1994:218-228.)

Rarely, relapse of hyperthyroidism can occur 1 to 2 years postoperatively due to regrowth of the adenoma.[18] This may be due to incomplete removal of the adenomatous tissue during the first surgery. Postoperative hypocalcemia is more common after reoperation for thyroidectomy.

References

1. Evans HE, Christensen GC: Miller's Anatomy of the Dog, The Endocrine System, WB Saunders, Philadelphia, 1979, pp. 611-618.

2. Nicholas JS, Swingle WW: An experimental and morphological study of the parathyroid glands of the cat. Am J Anat 34:469-508, 1925.

3. Brodey TS, Kelly DF: Thyroid neoplasms in the dog. Cancer 22: 406-416, 1968.

4. Birchard SJ, Roesel OF: Neoplasia of the thyroid gland in the dog: A retrospective study of 16 cases. JAAHA 17:369-372, 1981.

5. Panciera DL, Peterson ME, Birchard SJ. Diseases of the thyroid gland. In Saunders Manual of Small Animal Practice, 3rd ed., Birchard SJ, Sherding RG, eds. Elsevier, St. Louis, 2006, pgs. 327-342 .

6. Leav I, Shiller AC, Rijnberk A, Legg MA, derKinderen PJ: Adenomas and carcinomas of the canine and feline thyroid. Am J of Path 83:61-93,1976.

7. Klein MK, Powers BE, Withrow SJ, et.al. Treatment of thyroid carcinoma in dogs by surgical resection alone: 20 cases (1981-1989) JAVMA 206:1007-1009, 1995.

8. Tuohy JL, Worley DR, Withrow SJ,. Outcome following simultaneous bilateral thyroid lobectomy for treatment of thyroid gland carcinoma in dogs: 15 cases (1994-2010). J Amer Vet Med Assoc 241: 95-103, 2012.

9. Pack L, Roberts RE, Dawson SD, et.al. Definitive radiation therapy for infiltrative thyroid carcinoma in dogs. Vet Radiol Ultrasound 42:471-474, 2001.

10. Nadeau ME, Kitchell B E. Evaluation of the use of chemotherapy and other prognostic variables for surgically excised canine thyroid carcinoma with and without metastasis. Can Vet J 52: 994-998, 2011.

11. Schenck PA, Chew DJ, Van Gundy T. Diseases of the parathyroid gland and calcium metabolism. In; Saunders Manual of Small Animal Practice, 3rd. ed. Birchard SJ, Sherding RG, eds., Elsevier, St. Louis, 2006, pgs. 343-356.

12. DiBartola SP, Broome MR, Stein BS, et. al. Effect of treatment of hyperthyroidism on renal function in cats. J Am Vet Med Assoc 208:875-878, 1996.

13. Peterson ME, Kintzer PP, Hurvitz AI. Methimazole treatment of 262 cats with hyperthyroidism. J Vet Intern Med 2:150-157, 1988.

14. Birchard SJ, Peterson ME, Jacobson A: Surgical treatment of feline hyperthyroidism: Results of 85 cases. JAAHA 20:705-709, 1984.

15. Welches CD, Scavelli TD, Matthiesen DT, et. al. Occurence of problems after three techniques of bilateral thyroidectomy in cats. Vet Surg 18:392-396, 1989.

16. Flanders JA, Harvey HJ, Erb HN. Feline thyroidectomy: A comparison of postoperative hypocalcemia associated with three different surgical techniques. Vet Surg 16:362-366, 1987.

17. Turrel JM, Feldman EC, Nelson RW, et. al. Thyroid carcinoma causing hyperthyroidism in cats: 14 cases (1981-1986).

18. Swalec KM, Birchard SJ. Recurrence of hyperthyroidism after thyroidectomy in cats. J Am An Hosp Assoc 26:433-437, 1990.

Section G

Hernias

Chapter 38

Hernias

Incisional Hernias

Daniel D. Smeak

Definition and Etiology

An incisional hernia results from disruption of an abdominal wall closure. Acute incisional hernias generally develop within the first 5-7 days after surgery, whereas chronic hernias are seen weeks to years postoperatively.[1] Incisional hernia incidence is reported to be between 0.2 and 5% in humans and up to 16% in large animals depending on the surgical approach to the abdomen, certain predisposing factors, and overall patient status.[2,3,4] Incisional herniation in small animals is uncommon averaging less than 1% of abdominal closures in two large retrospective studies.[5,6]

Predisposing causes for acute and chronic incisional hernia vary and are interrelated. Reported risk factors for acute incisional hernia include increased intra-abdominal pressure from pain, entrapped fat between hernia edges, inappropriate suture material use, infection, long-term steroid treatment, and poor postoperative care.[7] Technical error in surgery, however, is felt to be the most common cause of acute wound disruption.[8,9] Factors associated with chronic incisional hernia in humans include: obesity, hypoproteinemia, cardiopulmonary complications, abdominal distention, skin wound dehiscence, and deep fascial infection. Local wound complications, especially deep infection, appear to be the most important predisposing cause of chronic incisional hernias.[10,11]

Incisional hernias result from either excessive forces acting on the abdominal incision or poor holding strength of the sutured wound. Forces acting to disrupt the abdominal incision are mainly derived from excessive intraabdominal pressure or muscle tension. Increased intra-abdominal pressure is observed in such conditions as obesity, abdominal effusions, pregnancy, or organ distension from ileus or obstruction; all these problems dramatically increase incisional hernia risk.[10,11] Poor control of postoperative pain, or uncontrolled exercise early in the postoperative period, increases the risk of wound breakdown due to excess force on abdominal wound edges.

The choice of suture material used for abdominal closure is rarely the sole cause of incisional hernia, provided the appropriate size is used.[8,12] However, choice of suture type may be critical in patients that have prolonged wound healing or are severely catabolic and when wound infection is present, particularly when an unpredictable, rapidly absorbable suture such as chromic gut is used.[8] Inappropriate knot tying technique or inadequate number of throws for suture knots in an abdominal wall closure increases the risk of herniation.[13] If a continuous pattern is selected for closure it is critical that the suture strand not be kinked, clamped, or knotted, all of which drastically reduce suture strength.[5] The only hernia found in one retrospective study of incisional hernias was due to a broken suture strand in a continuous abdominal wall closure.[5] Consequently, many surgeons choose one size larger suture when closing the abdominal wall with continuous patterns since the entire wall closure could disrupt from breakage of the single suture line.[6]

Whether suture is placed in an interrupted or continuous pattern, or the abdomen is closed in a single or double layer has little significance in incisional hernia formation provided the strength holding layer is incorporated.[5,6,12,13] Knotted interrupted sutures have a lower breaking strength than when unknotted. More shear forces are activated in the simple interrupted pattern than in the continuous pattern when tension is applied to the wound. Tension along the entire suture line becomes equally distributed when using a continuous pattern particularly when appropriate suture spacing is utilized.[5] A suture length to wound length ratio of 4:1 for laparotomy closure has proven in human clinical studies to reduce hernia incidence.[14] However, interrupted suture patterns in abdominal wall closure may be safer to use if wound edges have questionable viability or strength.[1] Excess intrinsic or extrinsic suture tension leads to significantly weaker abdominal closures, so sutures should be placed to appose, not crush, fascia.[14]

The most common cause of incisional hernia in small animals is failure to place sutures in the strength holding layer of the abdomen, with appropriately sized tissue bites.[1,6,8] Successful lasting abdominal wall closures must include the external rectus fascia (the main strength holding layer of the abdominal wall).[5] Sometimes the subcutaneous tissue or suspensory fascia of the prepuce overlying the external rectus fascia is mistakenly incorporated in the abdominal closure, causing incisional hernia. In other instances, sutures do not include at least 0.5 cm of fascia rendering the wound susceptible to breakdown with even minor wound tension.[1] Closure of the internal rectus fascia (including peritoneum) with the external fascia not only prolongs the procedure time and increases trauma from tissue manipulation, but may also increase postoperative pain.[5,15,16] In addition, suture material penetrating the peritoneum is a known potent stimulus for adhesion formation.[5,16] Even without suturing, the peritoneum rapidly covers and seals exposed muscle within several days. Furthermore, the peritoneum is a rather delicate membrane, so it does not offer appreciable strength when included in the abdominal closure. Thus, inclusion of internal rectus fascia or peritoneum in abdominal closure is not required or recommended to ensure successful abdominal repair.[5,15]

Clinical Signs and Diagnosis

Signs of acute incisional herniation usually develop within the first three to five days after surgery.[8] Wound edema and inflammation are signals of altered wound healing from any cause, and these signs may be seen early in the sequence of events leading to herniation. Serosanguineous drainage from the incision and swelling are important and consistent signs of impending acute abdominal wound dehiscence across animal species.[4,17] Swelling is usually soft and painless unless infection or organ compromise is present. Incisional drainage often occurs from a benign problem after surgery such as a seroma, however, this condition must be differentiated from those patients with acute incisional hernia. Early diagnosis and treatment of incisional hernias are vital to reduce the possibility of complete wound dehiscence and evisceration (organ protrusion).[1]

Any wound exhibiting signs of altered wound healing (edema, swelling, inflammation) should be examined carefully for incisional herniation.[1] Seroma, hematoma, cellulitis, or excessive foreign body response to buried suture material are differential diagnoses for acute incisional hernias. The skin incision line should be manipulated laterally during deep palpation over the muscle wall closure to aid in definition of the abdominal suture line. Further diagnostic testing (radiography, ultrasound, and fine needle aspiration) may be required for definitive diagnosis if displaced viscera or a hernial ring cannot be identified. Small amounts of omentum herniated through a small defect cause persistent wound swelling and is rarely diagnosed without wound exploration.

Treatment

Acute Incisional Hernias

Most incisional hernias should be repaired without delay unless they are chronic and freely reducible. Prognosis dramatically worsens if evisceration occurs. Immediate hospitalization and support of the hernia with bandages should be performed as the patient is prepared for surgery. Early surgical intervention is recommended for those patients with eviscerated hernias, or those with overlying skin incision breakdown or devitalization because exogenous contamination could result in fatal septic peritonitis.[1]

The approach is made over the original incision unless organ damage is present; otherwise, a ventral midline approach may be used. When technical failure is suspected (knot, suture, or tissue failure) the entire wound is reopened and repaired. If one significant technical error is present in the hernial ring area, other adjacent areas are also at risk of impending breakdown. The surgeon should pay particular attention to identification of the strength-holding layer and include appropriately sized tissue bites (at least 5 mm) during suturing of this layer. Acute incisional hernias are repaired with primary musculofascial reconstruction if adequate tissue is present to close the hernia without undue tension. The surgeon should remove fat completely between edges to be approximated. Knots are carefully tied with the appropriate number of snug square throws and attention is paid to intrinsic suture tension to avoid crushing tissue. Debridement is contraindicated during repair of acute incisional hernias unless wound edges are nonviable or necrotizing fascial tissue is present. Removing healthy wound edges creates excessive and unnecessary tissue trauma and spreads contamination into sterile areas. Debridement of this actively healing tissue sets the wound back to the substrate phase and delays the onset of rapid wound strength gain.

Chronic Incisional Hernias

Chronic incisional hernias that are not incarcerated have enough strength in the overlying hernia sac and skin to prevent evisceration, so these hernias may be repaired on an elective basis or conservatively managed.[1] Palpable adhesions to protruding organs are, however, indications for early surgical intervention because adhesions may cause obstruction, torsion and vascular compromise of entrapped tissue.

Conservative management of asymptomatic patients with small hernias should be considered only if the patient's owners can be trusted with wound monitoring. Affected patients require daily hernia palpation. Pain, discoloration, incarceration, and rapid increase in hernia size are indications for immediate examination of the animal by the veterinarian. Chronic hernias usually do not cause significant patient discomfort, however, they may be of concern when the animal is used for breeding.[4] Large hernias may prevent delivery (causing dystocia) because of uterine incarceration or lack of adequate abdominal contraction during labor.

Chronic incisional hernias are usually approached surgically over the original incision area. Muscle edges may retract some distance away from the defect, producing a functional loss of abdominal wall. This results in excessive tension during primary hernia repair and thus increases recurrence risk.[7,18]

A major technical difficulty in repair of chronic incisional hernias is accurate identification of normal tissue layers. Surgical dissection and accurate identification of primary strength-holding tissue at hernia margins are critical for lasting repair. Simple imbrication of the hernial sac without extensive scar excision from the hernial ring usually results in recurrence of the hernia because of attenuation of the relatively weak scar tissue. In chronic hernias, muscle and subcutaneous tissues are usually scarred together in one layer. Conservative excision of surrounding scar tissue is recommended until identification of the strength-holding layer is possible.

A condition termed "loss of domain" occurs when the abdominal cavity has become accustomed to a smaller intra-abdominal volume than normal. A functional loss of abdominal wall occurs in this instance. As a result, reduction of the hernial contents and primary closure of the (usually large) defect may be impossible. Closure of the abdominal wall by forcing herniated contents back into the abdomen results not only in excessive tension on the repair, but also in acute pulmonary compromise from restriction of diaphragm function.[7] In most veterinary patients with large chronic defects or areas of abdominal tissue loss, surgical repair is performed with prosthetic materials such as polypropylene mesh.[7,19]

Evisceration

Patients presenting with evisceration require early aggressive supportive therapy. Control hemorrhage and cover exposed organs with sterile bandages to reduce further contamination and tissue damage until vital diagnostic tests are performed and stabilization is attempted. In addition, an Elizabethan collar is placed on the patient if constant monitoring is not possible. Exposed organs are quickly mutilated by animals, and the result is shock from fluid and blood loss. Sepsis may occur from severe wound contamination, particularly when intestines have been violated. Therefore, appropriate crystalloid and colloidal fluid and antibiotic therapy are critical for patient stabilization.

Wound preparation is performed in a clean area after anesthetic induction. The surgeon should avoid contact between potentially irritating and toxic antiseptics and cleansing agents, and the patient's exposed organs during skin preparation. Exposed tissue is covered with saline soaked laparotomy sponges and a larger area of the abdomen is clipped, if necessary. The skin surrounding the wound is prepared routinely. In an aseptic area, the original abdominal wound is extended, if necessary, to explore abdominal viscera completely. The surgeon copiously lavages exposed but viable organs outside the abdominal cavity before further exploration. After isolating damaged areas from the rest of the viscera with laparotomy sponges, the surgeon resects nonviable and irreversibly damaged areas, and repairs organs when necessary. Appropriate specimens are submitted for culture and susceptibility testing. The abdomen is copiously lavaged to help remove particulate foreign material and gross contamination. The decision whether to close the abdominal wall and superficial tissues depends on the amount and location of tissue damage and wound contamination observed at surgery. Primary repair is appropriate for acute herniation with little tissue damage or contamination. Patients with minimal intraperitoneal but significant superficial tissue damage or contamination should have routine abdominal wall closure with closed suction drainage.[20] Superficial tissue layers are best left open for necessary drainage and tangential debridement. Deep, severely contaminated wounds may be managed by an open peritoneal drainage technique.[21]

Aftercare and Prognosis

Postoperative management of patients after repair of acute, closed, incisional hernias is similar to postoperative care of patients that have undergone elective abdominal surgery. Exercise is strictly limited for at least 2 weeks. Extended exercise restriction should be considered if the wound developed complications such as seroma or infection, or if synthetic mesh was used in the repair. Careful observation of the wound is critical for detection of early signs of infection. If infection occurs, the skin and subcutaneous tissue sutures are removed and the wound is left open for second intention healing. A superficial infection is not necessarily fatal to the success of the repair but the longer the infection is present before treatment the more likely the wound will disrupt.[19]

When evisceration has occurred, the nature of the organ damage and repair, and patient status dictate postoperative treatment and monitoring. Intense monitoring and treatment are needed if shock and septic peritonitis are present. Fluid deficits are replenished and infection is treated with antibiotics and appropriate wound drainage. Nutritional management in these critical patients often is the major factor influencing prognosis.

Most patients with incisional hernias have a good prognosis after repair provided initiating causal factors were eliminated and minimal damage occurred to deep structures. Consequently, since most incisional hernias are usually closed and a result of technical failure, most patients have an excellent prognosis as long as appropriate repair was performed. Septic patients with severe peritoneal contamination and organ damage warrant a poor prognosis.[21]

References

1. Smeak DD: Abdominal hernias. In Slatter DH, ed.: Textbook of Small Animal Surgery. Philadelphia: W B Saunders Co., 2003, p 449.

2. Akman PC: A study of five hundred incisional hernias. J Int Coll Surg 37:125, 1962.

3. George CD, Ellis H: The results of incisional hernia repair: A twelve year review. Ann R Coll Surg Engl 68:185, 1986.

4. Gibson KT, et al: Incisional hernias in the horse. Incidence and predisposing factors. Vet Surg 18:360, 1989.

5. Rosin E: Single layer, simple continuous suture pattern for closure of abdominal incisions. J Am Anim Hosp Assoc 21:751, 1985.

6. Crowe DT: Closure of abdominal incisions using a continuous polypropylene suture: Clinical experience in 550 dogs and cats. Vet Surg 7:74, 1978.

7. Larson GM, Vandertoll DJ: Approaches to repair of ventral hernia and full thickness losses of the abdominal wall. Symposium of hernias. Surg Clin North Am 64:335, 1984.

8. Alexander HC, Prudden JF: The causes of abdominal wound disruption. Surg Gynecol Obstet 122:1223, 1966.

9. Ponka JK: Herniation of the Abdominal Wall. W.B. Saunders, Philadelphia, 1980.

10. Fisher GD, Turner FW: Abdominal incisional hernias: A ten year review. Can J Surg 17:202, 1974.

11. George CD, Ellis H: The results of incisional hernia repair: A twelve year review. Ann R Coll Surg Engl 68:185, 1986.

12. Nilsson T: Abdominal wound repair: An experimental study of the wound healing mechanism in the rabbit. Dan Med Bull 30:394, 1983.

13. Rosin E, Robinson GM: Knot security of suture materials. Vet Surg 18:269, 1989.

14. Hoer J, Klinge U, Schachtrupp A, et al.: Influence of suture technique on laparotomy wound healing: an experimental study in the rat. Langenbecks Arch Surg 386:218, 2001.

15. Smedberg SG, Broome AE, Gullmo A: Ligation of the hernia sac? Surg Clin North Am 64:299, 1984.

16. Ellis H: The cause and prevention of postoperative intraperitoneal adhesions. Surg Gynecol Obstet 133:497, 1971.

17. Ingle-Fehr JE, Baxter GM, Howard RD, et al.: Bacterial culturing of ventral midline celiotomies for predication of postoperative incisional complications in horses. Vet Surg 26:7, 1997.

18. Boyd JB: Tissue expansion in reconstruction. South Med J 80:430, 1987.

19. Smeak DD: Management and prevention of surgical complications associated with small animal abdominal herniorrhaphy. Gastrointestinal surgical complications. Probl Vet Med 1:254, 1989.

20. Mueller MG, Ludwig LL, Barton LJ: Use of closed-suction drains to treat generalized peritonitis in dogs and cats: 40 Cases (1997-1999). J Am Vet Med Assoc 219:789, 2001.

21. Woolfson JM, Dulisch ML: Open abdominal drainage in the treatment of generalized peritonitis in 25 dogs and cats. Vet Surg 15:27, 1986.

Inguinal Hernia Repair in the Dog

Paul W. Dean, M. Joseph Bojrab and Gheorghe M. Constantinescu

A hernia is an abnormal protrusion of an organ or tissue through a normal body opening. True hernias have a hernial ring and a sac formed of peritoneum surrounding the hernia contents; false hernias lack the peritoneal sac. Hernias are either reducible or irreducible. Irreducible hernias can become strangulated if the circulation to the contents becomes interrupted.

Inguinal hernias are formed when an organ or tissue protrudes through the inguinal canal. Indirect inguinal hernias, the most common type, occur when tissue protrudes through the normal evagination of the vaginal process in females or the vaginal tunica in males. A direct inguinal hernia occurs when the peritoneal evagination occurs separate from, and lies alongside the vaginal process or vaginal tunica as a separate outpouching of tissue.

Surgical Anatomy

The inguinal canal is a passage through the abdominal wall. During development, it is occupied by the gubernaculum of the testis, the vaginal tunic that will ensheathe the descended testis, the descending testis, and the spermatic cord, which consists of the vessels, nerves, and ductus deferens. In the bitch, the gubernaculum persists within the broad ligament of the uterus as the round ligament that traverses the inguinal canal.[1] In the female cat the vaginal process is absent.[2] In veterinary anatomy, it is customary to consider the inguinal canal as the passage between the internal inguinal ring and the external inguinal ring.[1] The cranial boundary of the internal inguinal ring is formed by the caudal edge of the insertion of the internal abdominal oblique muscle. It is bordered ventromedially by the rectus abdominis muscle and the prepubic tendon and caudally and laterally by the edge of the pelvis and the arcus inguinalis.[3] The external inguinal ring is formed as a slitlike orifice in the insertion of the external abdominal oblique muscle and overlies the internal inguinal ring. The anatomy of the inguinal canal varies among species, depending on the caudal extent of the internal abdominal oblique muscle.[1]

Etiopathogenesis

The exact etiopathogenesis of inguinal hernias is unknown. Congenital inguinal hernias have been noted in certain breeds. Inguinal hernias have been shown to be hereditary in the basenji, regressing spontaneously by 12 weeks of age.[2] Other breeds exhibiting a greater risk of inguinal hernias include the basset hound, cairn terrier, Pekingese, and West Highland white terrier. The Pekingese also exhibits a greater incidence of concurrent umbilical hernia.[3] The cause of congenital inguinal hernias is unknown, but the disorder has been attributed to normal anatomic variations, polygenic inheritance, and infectious diseases.[3]

Acquired inguinal hernias are noted most often in the middle-aged intact bitch.[4-6] Most cases of herniation occur in the estral or pregnant bitch, suggesting hormonal involvement. Inguinal hernia has not been reported in the neutered bitch.[6] Other factors that may be involved include weakening of the abdominal wall, trauma, obesity, and the accumulation of fat in the vaginal process.[1,5]

Clinical Signs and Diagnosis

Most dogs with inguinal hernias have a soft, doughy mass in the inguinal region that is usually not painful on palpation. The mass can have been present for up to a year and may or may not be reducible on palpation. Elevation of the patient's hindquarters may aid the examiner in reducing the hernia and allows palpation of the defect in the abdominal wall. The hernia can contain a gravid or infected uterus that is unable to be reduced. Other tissues and organs that can be contained within the hernia include omentum, intestine, bladder, prostatic fat, and spleen. Diagnosis of inguinal herniation is aided by radiography demonstrating gas-filled loops of intestine or the appearance of the ossifying fetal skeleton after 43 to 45 days of gestation. The bladder can be identified by contrast radiography after catheterization and aspiration of bladder contents. Inguinal hernia must be differentiated from subcutaneous fatty tissue accumulation, abscess, hematoma formation, and mammary gland neoplasia. The hernia can appear as a swelling lateral to the vulva and must be differentiated from a perineal hernia.[7]

Surgical Techniques

A ventral midline incision can be used for all inguinal hernias. This approach allows visualization of both inguinal rings and repair of bilateral herniation through a single incision. It also permits extension of the incision cranially, when necessary, without invasion of mammary tissue or its blood supply.[5,8]

The surgical incision extends from the cranial brim of the pelvis as far cranially as necessary to allow exposure of the hernial sac. This incision is continued through the subcutaneous tissue down to the ventral rectus sheath. Dissection proceeds bluntly under the mammary tissue, and the mammary tissue is undermined and retracted laterally to expose the superficial inguinal ring and hernial sac (Figure 38-1). After the hernial sac is dissected from the subcutaneous tissue, the hernial sac is opened, and the contents are inspected (Figure 38-2). Any adhesions between the sac and the viscera are broken down, and the contents are returned to the abdominal cavity.

In some cases, it may be necessary to enlarge the hernial ring cranially to facilitate reduction of the hernia. If the urinary bladder is included in the hernia, aspiration of urine facilitates reduction. When one or both horns of the uterus are included and ovariohysterectomy is performed, extending the incision in a cranial and medial direction may be necessary to complete the procedure.[4,5]

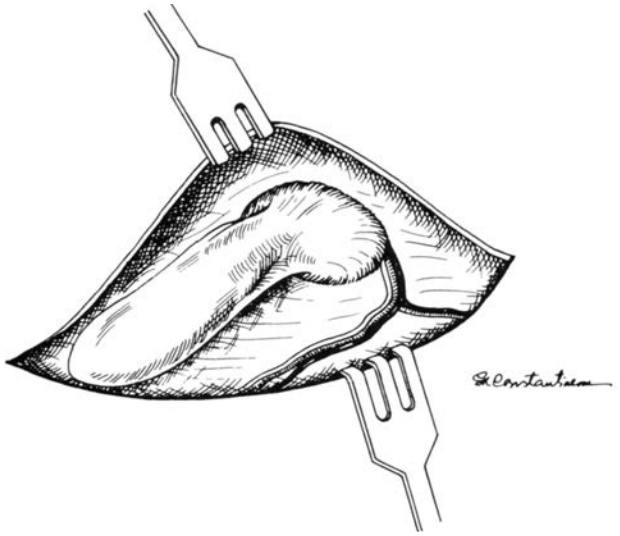


Figure 38-1. Lateral retraction of the midline incision exposes the hernial sac and its contents.

Should the hernia contain a gravid uterus, up to the seventh week of pregnancy the hernia can be replaced into the abdomen and the pregnancy can be allowed to continue to completion. After the seventh week of pregnancy, ovariohysterectomy is recommended, depending on the age and value of the bitch as a breeding animal.[5]

After replacement of viscera into the abdomen, the redundant sac is trimmed at the margins of the superficial inguinal ring. Twisting the redundant sac may help to maintain reduction of the contents within the abdomen (Figure 38-3). The hernial ring is sutured with simple interrupted sutures of 2-0 nonabsorbable suture material (Figure 38-4).[9] Care must be taken during closure to avoid the external pudendal vessels and genitofemoral nerve, which exit from the caudomedial aspect of the ring. In males, the inguinal ring must be closed without compromising the spermatic cord as it traverses the inguinal canal.

The inguinal ring on the other side is inspected, the vaginal process in female dogs or the vaginal tunic in males is removed, and the ring is sutured closed. The mammary tissue is then drawn back to the midline, and the subcutaneous tissues are closed using absorbable sutures, with care taken to eliminate potential dead space. If necessary, a Penrose drain can be placed before closure and made to exit from a separate stab incision ventrally if a large amount of dead space in which fluid could accumulate is present. The skin is closed routinely.

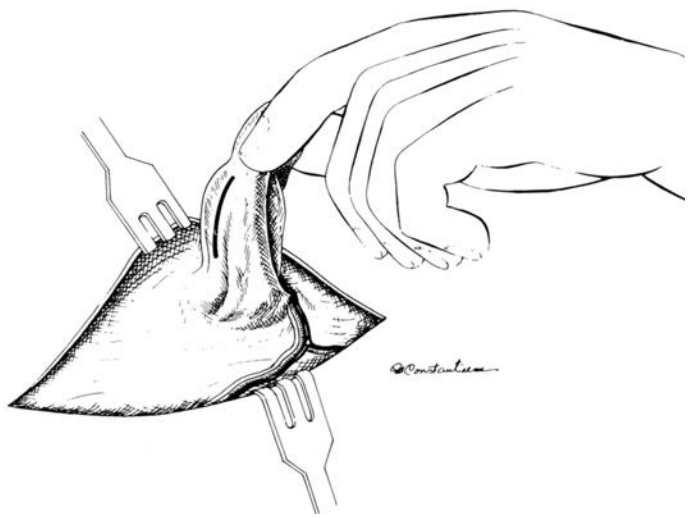


Figure 38-2. The hernia sac is incised, and its contents are inspected and returned to the abdomen. (The line indicates the incision in the sac.)

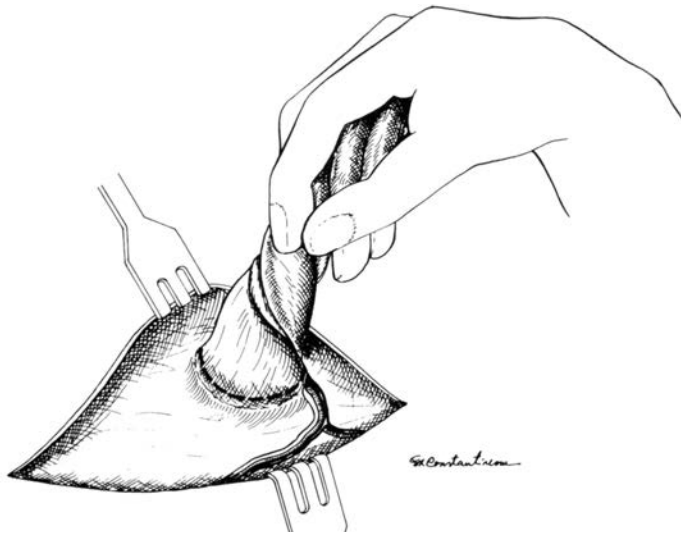


Figure 38-3. The edges of redundant sac are excised. Twisting of the sac facilitates maintenance of the reduced contents within the abdomen.

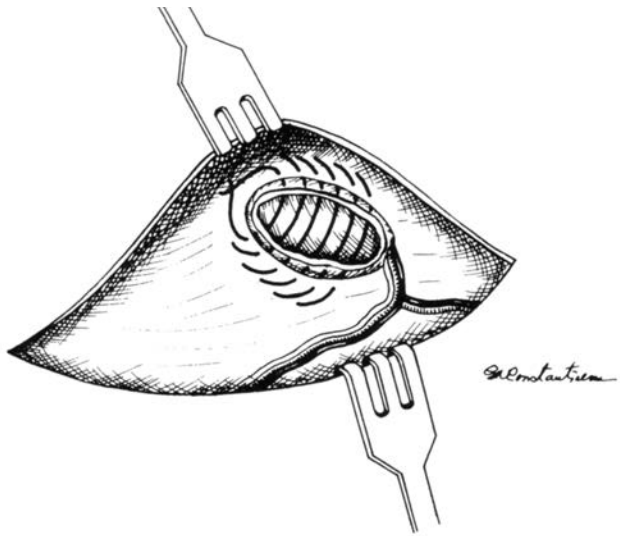


Figure 38-4. The edges of the inguinal ring are apposed using nonabsorbable suture material in a simple interrupted pattern. Care must be taken not to compromise the external pudendal vessels and genitofemoral nerve as they exit the caudomedial border of the ring.

Postoperative Care

The caudal abdomen is bandaged immediately after the procedure. Bandaging helps to eliminate dead space and increases the comfort of the patient. If used, drains should be covered with an absorbent dressing and bandage and can be removed 3 to 5 days postsurgicaly, before the patient's discharge from the hospital. Broad-spectrum antibiotic treatment is used if a drain is in place and for 3 days after drain removal.

References

1. Ashdown RR. The anatomy of the inguinal canal in the domesticated mammals. Vet Rec 1983;75:1345-1351.

2. Fox MW. Inherited inguinal hernia and midline defects in the dog. J Am Vet Med Assoc 1963,143:602-604.

3. Hayes HM Jr. Congenital umbilical and inguinal hernias in cattle, horses, swine, dogs, and cats: risk by breed and sex among hospital patients. Am J Vet Res 1974;35:839-842.

4. Archibald J, Sumner-Smith G. Hernia. In: Archibald J, ed. Canine surgery. 2nd ed. Santa Barbara, CA: American Veterinary Publications, 1974.

5. North AF Jr. A new surgical approach to inguinal hernias in the dog. Cornell Vet 1959;49:379-383.

6. Smeak DD. Caudal abdominal hernias. In: Slatter DH, ed. Textbook of small animal surgery. 2nd ed. Vol. 1. Philadelphia: WB Saunders, 1985.

7. Blakely CL. Perineal hernia. In: Mayer K, LaCroix JV, Hoskins HP, eds. Canine surgery. 4th ed. Evanston, IL: American Veterinary Publishers, 1957.

8. Peddie JF. Inguinal hernia repair in the dog. Mod Vet Pract 1980;61:859-861.

9. Bojrab MJ. Inguinal hernias. In: Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Feb-iger, 1983.

Surgical Techniques for Treatment of Perineal Hernia

F. A. Mann, G. M. Constantinescu and Mark A. Anderson

Introduction

The perineum is the region that closes the pelvic outlet, surrounding the anal and urogenital canals.[1] On the surface of the dog, the perineum is limited by the tail dorsally, the scrotum or beginning of the vulva ventrally, and the ischiatic tuberosity on both sides. Deeply, the perineum is bounded by the third caudal vertebra dorsally, the sacrotuberous ligaments on both sides (absent in cats), and the arch of the ischium ventrally. The pelvic diaphragm is the vertical closure of the pelvic canal through which the last segments of the digestive and urogenital viscera pass.[2]

Perineal hernia is the result of weakness and separation of the muscles and fascia that make up the pelvic diaphragm. The pelvic diaphragm is composed of levator ani and coccygeus muscles, and the internal and external perineal fascia.[1] The exact cause of the muscular weakness is unknown but several factors have been proposed.[3-14] As a result of the muscular weakness, caudal displacement of intra-abdominal organs or deviation or dilation of the rectum into the perineum can occur.[3,4] Retroflexion of the urinary bladder occurs in approximately 20% of the cases.[15,16] Other intra-abdominal contents found within the hernial sac include jejunum, colon, and prostate.[16] The hernial space often contains retroperitoneal fat and fluid with or without abdominal and/or pelvic organs.[17]

Perineal hernia has been reported in multiple species, but is most problematic in dogs. Some breeds of dogs are over-represented in the occurrence of perineal herniation. Boston terriers, Pekingese, collies, boxers, Welsh corgis, kelpies, miniature poodles, German shepherd dogs, Bouviers de Flandres, old English sheepdogs, dachshunds, and mongrels have all been shown to have an increased incidence.[9,15,17] Perineal hernia occurs commonly in the male dog, particularly in sexually intact males, and rarely in females. Most dogs with perineal hernia are between 7 and 9 years of age.[9,18]

Perineal herniation may be unilateral or bilateral. Some investigators have reported an increased incidence of perineal herniation on the right side, but the criteria used to determine unilateral versus bilateral and left versus right are subjective. In fact, the occurrence of the hernia on one side versus the other may be related to the rate and extent of tissue deterioration rather than one side being affected preferentially.[17]

Clinical Signs

Tenesmus, constipation and perineal swelling are the three most consistent clinical features of dogs presented with perineal hernia.[3,17] In as high as 80% of dogs presented for perineal hernia, straining to defecate was the primary complaint. Tenesmus is the result of excessive feces that collect in a rectal dilatation or sacculation in the perineal hernia.[4] Furthermore, the perineal swelling may be the combination of abdominal contents and/or a feces-filled rectum.

Retroflexion of the urinary bladder into the perineal hernia may result in urinary obstruction. The obstruction results from an abrupt change in direction of the urethra.[16] Clinical signs associated with bladder retroflexion include stranguria, dysuria, and anuria.[16] Although perineal hernia is not considered a surgical emergency, immediate repositioning of the bladder or urine evacuation is required. If the bladder cannot be reduced and urine evacuation cannot be achieved, surgical intervention on an emergency basis may be required.

Other less commonly reported clinical signs have been depression/lethargy, vomiting, anorexia, perineal pain, stringy stool, weight loss, and fecal incontinence.[15]

Diagnosis

The diagnosis of a perineal hernia is based on the history, clinical signs, physical examination, and radiography. The diagnosis may be difficult during the early stages when the hernia is forming.[3] However, with progression of the clinical signs, the diagnosis usually becomes more obvious. Rectal palpation is the most important part of the physical examination when diagnosing perineal hernia. When performing a rectal examination, the index finger is directed cranially into the middle of the herniated rectum which lies lateral to the anus and medial to the wall of the pelvic canal.[19] Generally, the rectum is filled with feces making identification of the extent (unilateral versus bilateral) of the hernia difficult. Manual removal of the fecoliths from the rectum allows better assessment of the pelvic diaphragm muscles. When evaluating the rectum for abnormalities such as a deviation, sacculation, or diverticulum, a rectal barium enema[4] may be helpful, but is usually not necessary. Differentiation

between rectal sacculation (full-thickness outpouching of the rectal wall) and diverticulum (protrusion of mucosa/submucosa through a muscular defect) requires inspection of the muscular coat of the rectum at surgery.

When there are clinical signs of urinary tract involvement with a perineal hernia, caudal abdominal radiography including the perineum are performed. The contents of the perineal hernia and the location of the urinary bladder is identified. If the urinary bladder cannot be visualized on routine radiography, retrograde urethrography and/or cystography can be done.[3,16] Alternately, ultrasonography can be used to identify the location of the urinary bladder (either within the hernia or abdomen) and can be used to assist decompression via syringe and needle.

Conservative Therapy

Conservative management of perineal hernia includes the use of stool softeners, periodic enemas, and digital evacuation of the feces from the rectum as needed.[3,17] Dogs considered for conservative medical and dietary management include dogs that are poor anesthetic/surgical candidates because of known organ disease and dogs with owners who refuse to have surgery performed.[3,20] Dogs with straining as the primary clinical complaint during the initial presentation are reported to have a poor response to medical management over an extended period of time.[20]

Hormonal therapy either by castration, low-dose estrogen therapy, or progestins can decrease the size of the prostate and alleviate clinical signs associated with prostatic hyperplasia. However, there are no reported studies that have evaluated the efficacy of hormonal therapy on controlling the long-term clinical signs associated with prostatomegaly and a concomitant perineal hernia.[17] Castration is recommended by the authors because of its beneficial effects regarding prostatic disease prophylaxis despite its questionable role in perineal hernia recurrence prevention. The authors caution against other forms of hormonal therapy for prostatic disease since severe and fatal complications such as bone marrow aplasia may result.

Surgical Anatomy

The structures involved in surgical repair of perineal hernia include the pelvic diaphragm, the perineal fasciae, and the nerves and vessels in the proximity of these structures (Figures 38-5 and 38-6). Additionally, extraperineal muscle flaps can be transposed for perineal herniorrhaphy (i.e., the semitendinosus muscle flap).[21]

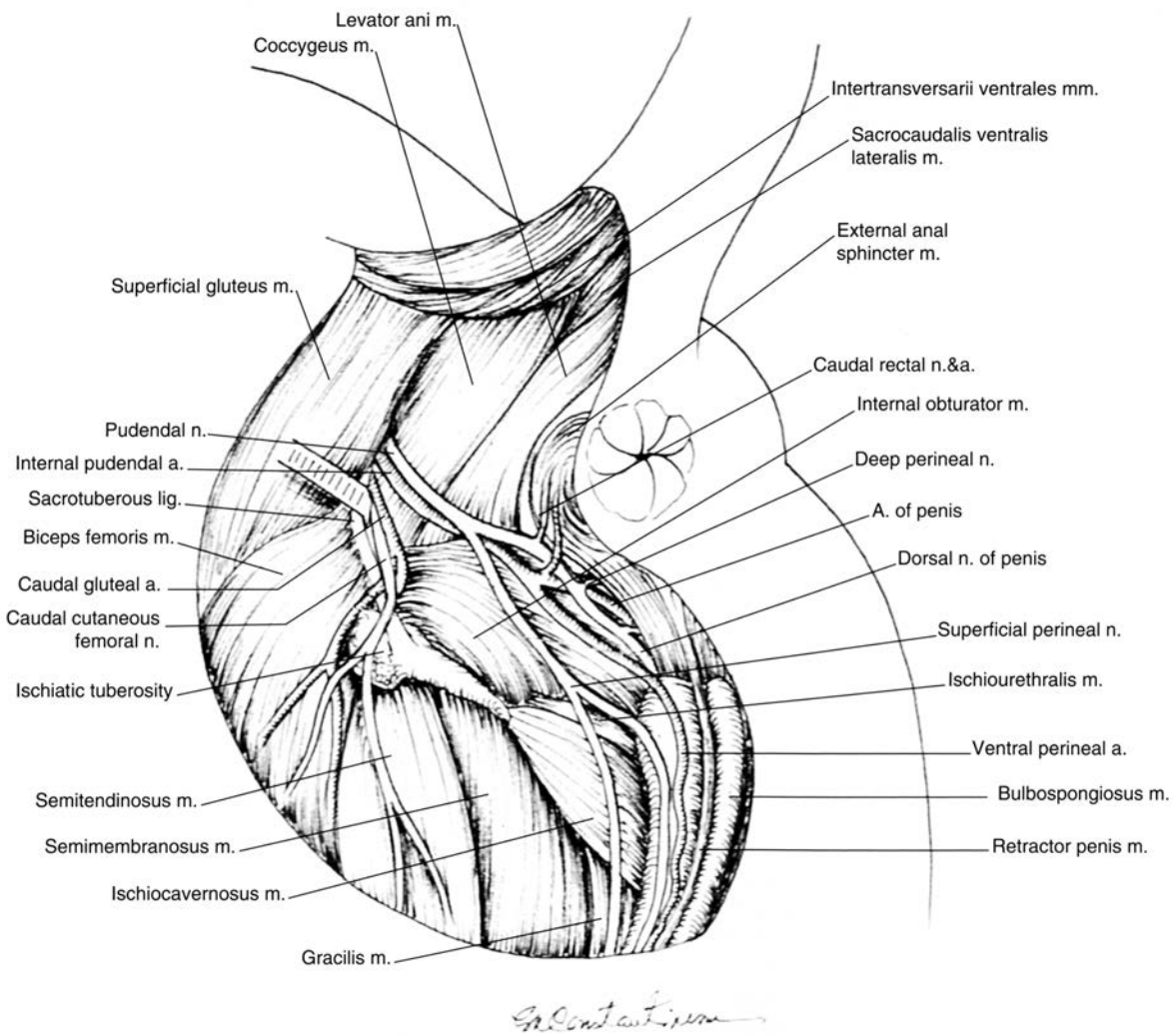


Figure 38-5. Surgical anatomy of the canine left perineum, caudal aspect.

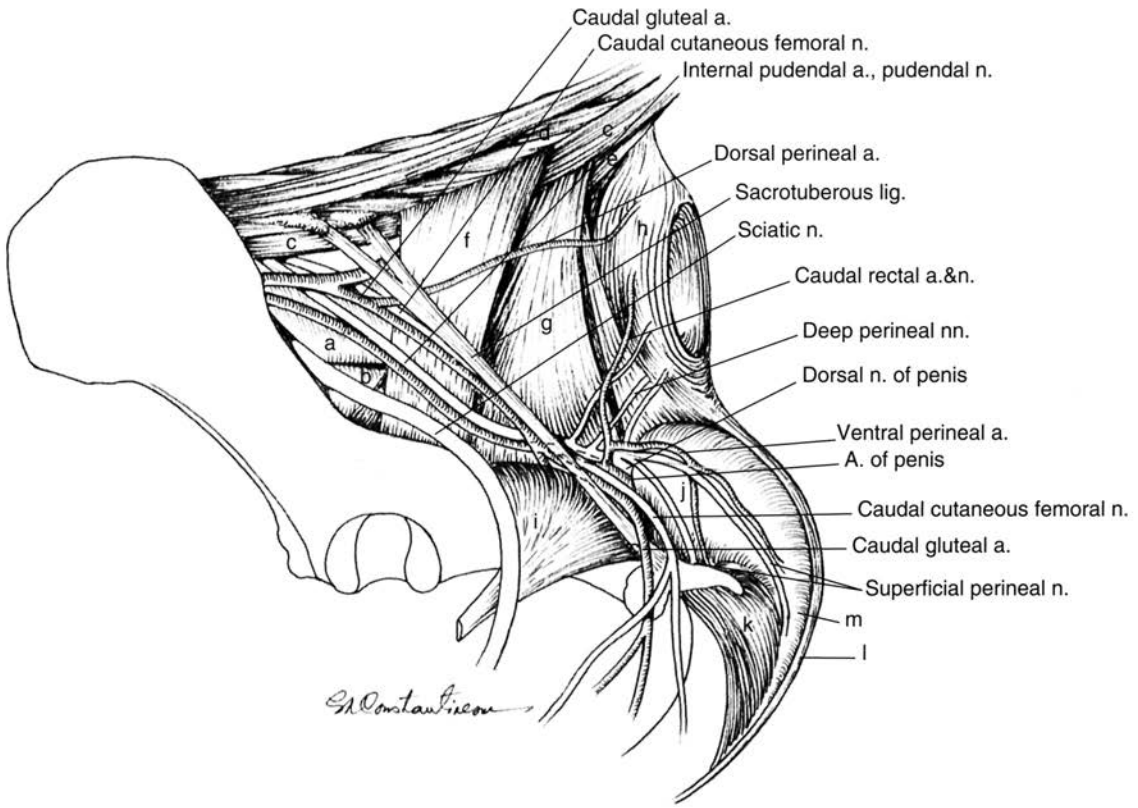


Figure 38-6. Surgical anatomy of the canine left perineum, lateral aspect. *a*- Rectum, *b*- Pelvic urethra, *c*- Sacrocaudalis lateralis ventralis m. (labeled twice), *d*- Intertransversarii dorsales caudae mm., *e*- Rectococcygeus m., *f*- Coccygeus m., *g*- Levator ani m., *h*- External anal sphincter m.–superficial part, *i*- Internal obturator m., *j*- Root of the penis, *k*- Ischiocavernosus m., *l*- Retractor penis m., *m*- Bulbospongiosus m.

The levator ani and coccygeus muscles originate from the medial side of the ischial spine and medial side of the body of the ilium/dorsal surface of the pubis cranial to the obturator foramen, respectively. The levator ani and coccygeus muscles insert on the third through seventh caudal vertebrae, and the first through the fourth caudal vertebrae, respectively. These two muscles form the lateral boundary for the rectum or the medial boundary of the pelvic diaphragm.[2,20]

The sacrotuberous ligament and the superficial gluteal muscle form the lateral aspect of the pelvic diaphragm. The sacrotuberous ligament originates from the ischiatic tuberosity and inserts on the sacrum and first caudal vertebra. The superficial gluteal muscle originates on the lateral aspect of the sacrum, first caudal vertebra, and the cranial half of the sacrotuberous ligament. The superficial gluteal muscle forms a tendon lateral to the perineal region and runs over the dorsal aspect of the greater trochanter to insert on the third trochanter.[2,20]

The ventral aspect of the perineal region is bounded by the internal obturator muscle, which can be transposed for perineal herniorrhaphy. The internal obturator muscle originates on the cranial and medial border of the obturator foramen and the internal surface of the ischium (ischiatic table), and inserts as a flat tendon embedded in the bellies of the gemelli muscles in the trochanteric fossa of the femur.[2,20]

The external anal sphincter muscle is a striated muscle that surrounds the anal canal. This muscle is divided into three parts: the cutaneous part, the superficial part, and the deep part. The cutaneous part lies directly under the skin in the subcutaneous fascia. The superficial part attaches to the third and fourth caudal vertebrae and passes around the lateral aspect of the anus and anal sacs to insert on the bulbocavernosus muscle (male) or the constrictor muscle of the vulva (female). The deep part surrounds the anal canal, passing medial to the anal sacs. The superficial and deep parts can interchange with each other.[2,17]

The semitendinosus muscle is a striated muscle that originates from the ischiatic tuberosity and inserts on the tibia and on the tuber calcanei.[1] Although it does not directly bound the perineal region, the semitendinosus muscle has been used to reconstruct perineal hernia defects.[21]

The internal pudendal artery and vein, and the pudendal nerve are bound together by loose connective tissue, and this neurovascular bundle passes ventrolaterally to the coccygeus muscle and continues caudomedially across the dorsal surface of the internal obturator muscle. At the caudal border of the ventral aspect of the external anal sphincter muscle, the pudendal nerve gives off the caudal rectal nerve. This branch of the pudendal nerve provides motor innervation to the external anal sphincter muscle.[2]

The perineal fascia is the connective tissue covering of the perineal musculature and is divided into deep and superficial layers. The deep perineal fascia is the fascia that tightly covers the musculature. The superficial perineal fascia is the loose connective tissue that makes a thin hernial sac. The superficial

perineal fascia is not considered to be of adequate strength to suture as the primary layer for hernia repair.

Patient Preparation

A perineal hernia is not usually considered a surgical emergency unless the urinary bladder is retroflexed.[16] If the urinary bladder is retroflexed into the perineal hernia, the urinary bladder should be manually reduced. If the urinary bladder cannot be reduced, a urinary catheter should be placed or paracentesis must be performed. Removal of urine from the urinary bladder should assist in reduction. Serum biochemistries (serum urea nitrogen and creatinine) should be evaluated. Dogs with azotemia should be treated appropriately and surgery postponed until the patient is stable.[16]

If the perineal hernia does not contain the urinary bladder, the surgical repair is a nonmergent procedure. Since the majority of dogs with perineal hernias are geriatric, a minimum data base including a complete blood count, serum biochemistries, thoracic radiographs and a complete urinalysis should be performed.[3]

Some surgeons prepare the dog for surgery by having the rectum cleaned of all feces with several enemas the day before surgery, and by fasting the dog for 24 hours prior to surgery. Enemas run the risk of rectal trauma and make for fluid fecal material which is difficult to contain during surgery; therefore, the authors prefer to avoid enemas. Instead, gentle digital extraction of feces is performed after the dog is anesthetized immediately prior to surgery.

After the dog is anesthetized, the perineal region is liberally clipped. The anal sacs are evacuated, a lubricated gauze tampon is inserted into the rectum, and a purse-string suture is placed in the anus. A preliminary scrub is performed to remove gross contamination from the perineum. The dog is positioned in sternal recumbence at the end of the surgical table (Figure 38-7A and B). The pelvic limbs are placed off the end of the table and are gently pulled forward. The table can either be tilted forward, or the dog can be placed in a perineal stand. If a perineal stand or tilt table are not available, sand bags or other padding can be used to elevate the dog's perineum. When pulling the pelvic limbs over the end of the table, the front of the limb should be protected by padding to prevent femoral and fibular (peroneal) nerve injury. If a tilt table is used to help position the dog, excessive tilting of the table should be prevented because of the concern for respiratory compromise. Since the perineal position causes the dog's head to be placed downward, the abdominal contents encroach on the diaphragm and intermittent positive pressure ventilation is required.

After the patient is positioned, the tail can be wrapped and adhesive tape placed above the base of the tail and then directed towards the dog's head. This pulls the tail over the dog's back. After the tail has been positioned, a final scrub can be performed.

Perioperative antibiotics are used by some surgeons; however, the use of antibiotics should not preclude good aseptic surgical technique. If antibiotics are chosen, a broad spectrum antibiotic with activity against gram-negative enteric organisms should be used.

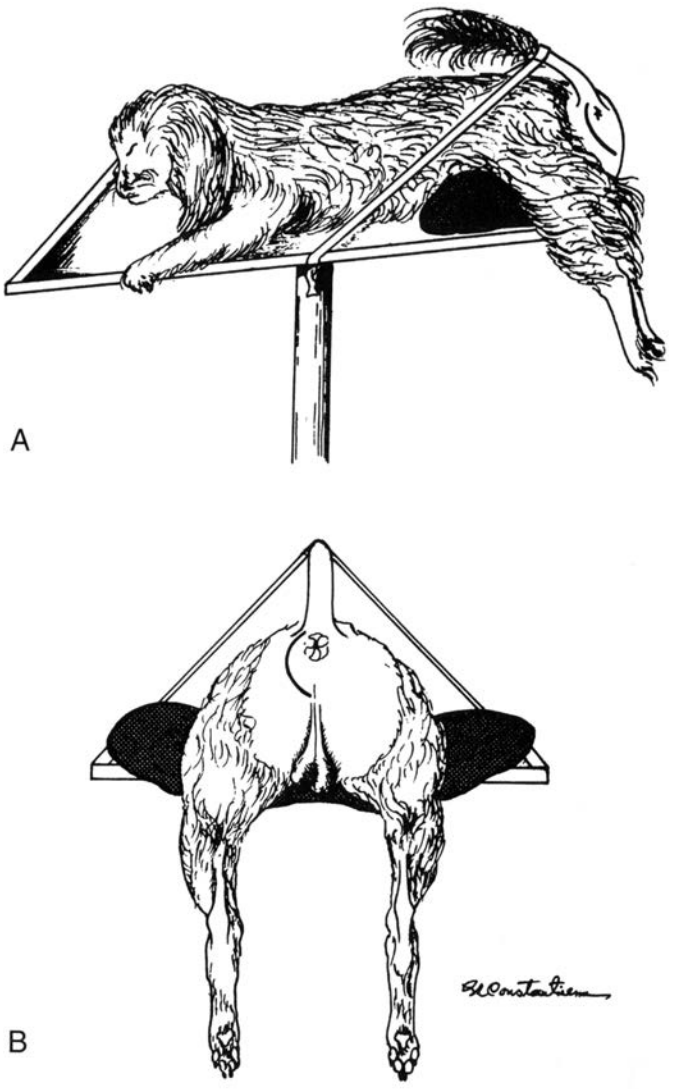


Figure 38-7A and **B.** Positioning for perineal herniorrhaphy. The sand bags provide padding. Tape secures the tail in a midline position over the back. Tape may also be used to secure the pelvic limbs in position, but care must be exercised to avoid excessive tension. The semicircular line to the left of the anus indicates the proposed incision. Surgical drapes are not pictured in order to allow anatomical reference.

Surgical Technique

Draping of the perineal region should be performed so that none of the anus is exposed after the skin incision is made, but accessible to visualization if necessary. Castration is performed on sexually intact male dogs prior to herniorrhaphy. Caudal castration[22] may be performed with the dog in the perineal position to decrease the overall length of the surgical procedure by avoiding the repositioning associated with standard prescrotal castration.

We prefer the internal obturator muscle transposition technique for perineal herniorrhapy. If there is questionable integrity of the internal obturator muscle, porcine small intestinal submuscosa (SIS) may be used in place of the obturator muscle.[23,24] Understanding the surgical anatomy and manipulations for the internal

obturator and SIS techniques is facilitated by an understanding of the traditional perineal herniorrhaphy procedure. Therefore, the traditional technique is discussed first below.

Traditional Perineal Herniorrhaphy

The incision is made over the hernia from just lateral of the tail base to just below the hernial mass (See Figure 38-7A and B). The incision is curved slightly laterally in a dorsoventral direction. Care must be taken to not incise too deeply and injure the hernial contents.

Blunt dissection is used to enter the hernial sac (superficial perineal fascia) and expose the hernial contents. Once the contents of the hernia are exposed, redundant fat can be excised and hernial fluid removed. If jejunum, prostate, colon, or urinary bladder are encountered, these structures can be reduced by digital manipulation in a cranial direction back to their pelvic or abdominal location and maintained with a gauze sponge. A suture can be tied to the gauze sponge to facilitate its removal prior to tying the herniorrhaphy sutures.

Following reduction of the hernia, the muscular defect and landmarks for surgical closure are identified (Figure 38-8). The medial side of the defect is bounded by the rectum, ending with the anal sphincter muscle caudally. The coccygeus muscle and, if present, the levator ani muscle are dorsolateral to the defect. The sacrotuberous ligament can be palpated as the lateral landmark of the repair. This ligament is a broad fibrous cord that extends from the sacrum and first caudal vertebra to the ischiatic tuberosity. The ventral boundary of the hernia is formed by the internal obturator muscle on the floor of the pelvis. Ventrolateral to the coccygeus and levator ani muscles and dorsal to the internal obturator muscle is the neurovascular bundle (internal pudendal artery and vein, and pudendal nerve) of this region. Identification of the neurovascular bundle is important because the pudendal nerve supplies motor function to the external anal sphincter muscle. Bilateral pudendal nerve injury may result in permanent fecal incontinence.[3] Unilateral pudendal nerve injury may lead to temporary incontinence until reinnervation or compensation from the opposite side occurs.

Before pelvic diaphragm repair the presence or absence of rectal disease must be ascertained.[4,8] Rectal deviation occurs as a result of a potential space created by the hernia. Perineal herniorrhaphy should alleviate rectal deviation and small sacculation. Large rectal sacculation and rectal diverticulum may cause straining to expel feces. Therefore, surgical excision of rectal diverticulum or large sacculation, followed by an inverting suture pattern, should be performed to prevent perineal hernia

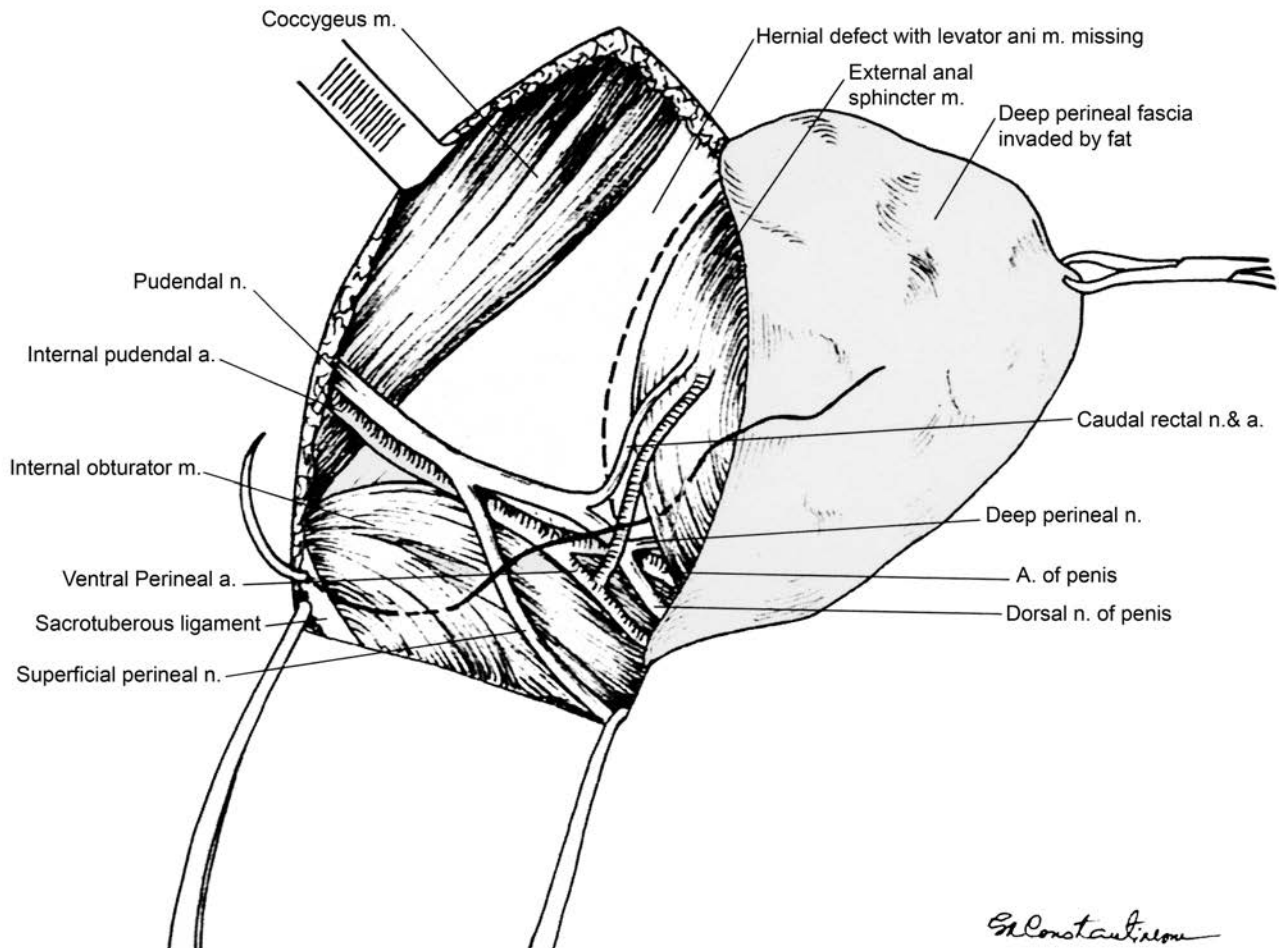


Figure 38-8. Operative view of left perineal hernia with placement of the first suture using the standard herniorrhaphy technique. The first suture is placed in the most ventral position, from the internal obturator muscle to the external anal sphincter. [Note: The levator ani muscle may be atrophied such that it is not recognizable.]

recurrence due to straining caused by impacted feces.[4]

All herniorrhaphy sutures should be preplaced before they are tied (Figure 38-9). The authors recommend synthetic nonabsorbable monofilament suture such as polypropylene for the primary closure of the hernial defect. Suture placement is begun from the most ventral aspect of the defect. The first suture is placed from the internal obturator muscle laterally to the external anal sphincter muscle medially, or vice versa, depending on the side of the hernia and the surgeon (right- versus left-handed). Care should be taken when passing sutures through the internal obturator muscle to not incorporate sutures into the neurovascular bundle in this region. Since the recurrence rate is high with the traditional suture technique, placement of an adequate number of sutures ventrally is important to success.[3] Additional sutures are placed dorsally to the internal obturator suture(s) incorporating bites from the external anal sphincter into the sacrotuberous ligament, the coccygeus muscle, and, when present, the levator ani muscle.[3] When placing sutures through the sacrotuberous ligament, care must be taken to not include the caudal gluteal artery/vein or the sciatic nerve which lie cranial to the ligament. Placing a finger medial and cranial to the sacrotuberous ligament may assist in determining the depth of suture placement by palpation of the caudal gluteal artery's pulse.[3] Furthermore, the suture should be placed through the fibers of the sacrotuberous ligament instead of encircling the entire structure. When placing sutures through the external anal sphincter muscle multiple fibers are gathered onto the needle. Care should be taken to avoid penetration of the rectum or anal sac(s). Once all sutures are preplaced they are tied from dorsal to ventral. As sutures are tied the anus may be visualized to ensure that it has not been grossly distorted.

Following closure of the hernial defect, the superficial perineal fascia is mobilized laterally from the skin. After mobilization, the perineal fascia can be used to reinforce the closure by suturing the fascia caudally to the external anal sphincter muscle using synthetic absorbable suture material. The subcutaneous tissue and skin are closed routinely. Strategic subcutaneous suture placement to minimize dead space eliminates the need for placement of drains. Drains are to be avoided in the perineal region because of postoperative contamination risks.

If bilateral hernia repair is considered, the hernias can be repaired at the same surgery; however, some surgeons will wait 4 to 6 weeks between repairs to decrease the stress and distortion of the external anal sphincter muscle associated with the traditional herniorrhaphy technique.[3]

We believe that castration should be performed for its benefits relative to treating prostatic disease. It is unlikely that castration prevents pelvic diaphragm muscle weakness.[12,13,25]

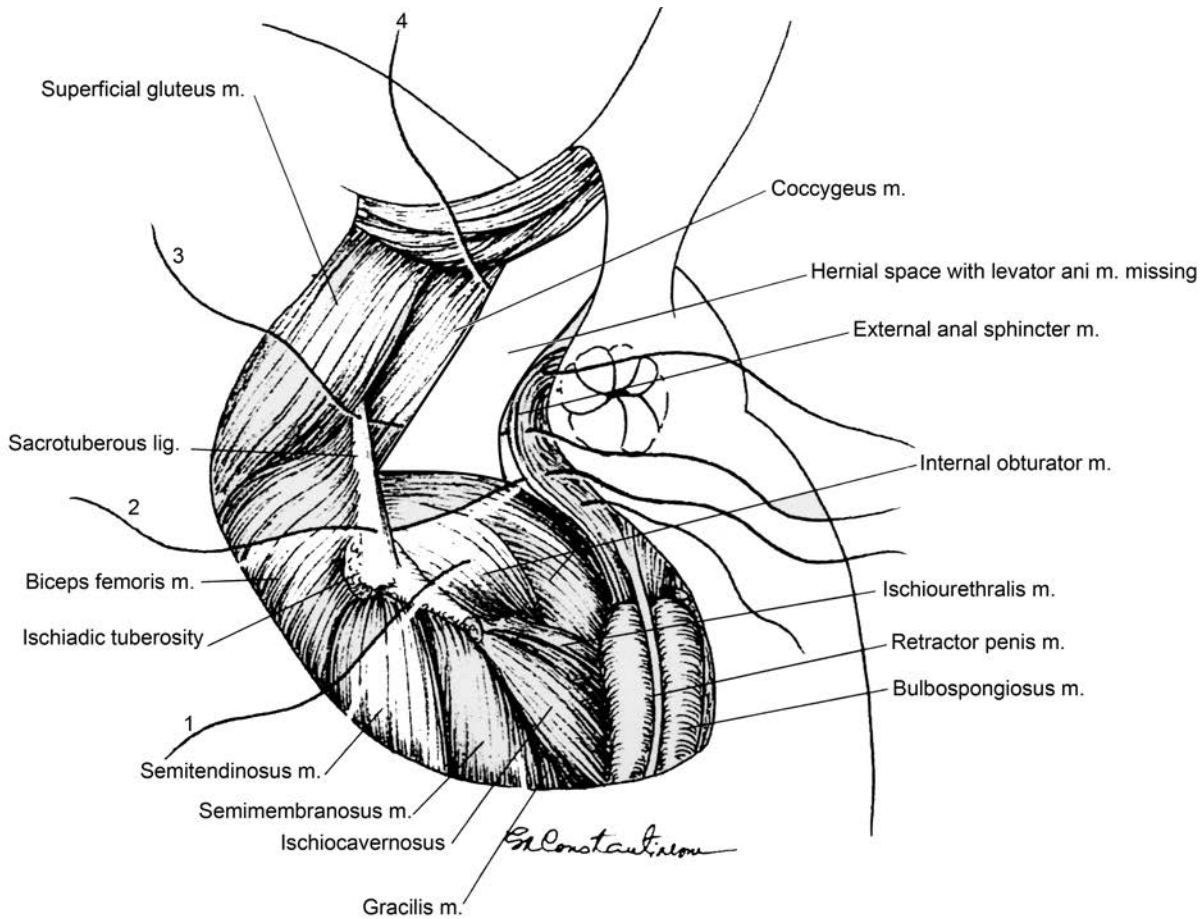


Figure 38-9. Placement of sutures in the standard perineal herniorrhaphy technique. Suture placement is from ventral to dorsal: *(1), (2), (3),* and *(4).* All sutures are preplaced and then tied. More than one suture may be placed in any of the four basic positions depending on the size of the dog. If the levator ani muscle is recognizable, it is engaged with suture along with the coccygeus muscle in positions *(3)* and *(4).*

After all procedures have been completed, the anal purse-string suture and rectal gauze tampon are removed. A thorough rectal examination should be performed to evaluate the integrity of the repair.

Internal Obturator Muscle Transposition

With the dog ventrally recumbent in the perineal position a semicircular skin incision similar to the one used for the traditional herniorrhaphy technique is made in the perineal skin from the tail base to the median raphe ventrally. The subcutaneous tissue is carefully incised and the skin edges are retracted to expose the perineal structures (Figure 38-10). After the hernial contents are isolated and reduced, the internal obturator muscle is subperiosteally elevated from the ischiatic table starting caudomedially and proceeding laterally and cranially. The internal obturator tendon is cut just before it disappears beneath the sacrotuberous ligament, and the muscle is lifted dorsally (Figure 38-11). Failure to completely incise the internal obturator tendon may result in inadequate coverage of the hernia by the muscle. The transposed internal obturator muscle is sutured medially to the external anal sphincter and laterally to the sacrotuberous ligament, the coccygeus muscle, and, if present, the levator ani muscle using polypropylene sutures (Figure 38-12). Any residual defect in the dorsal aspect of the repair is closed

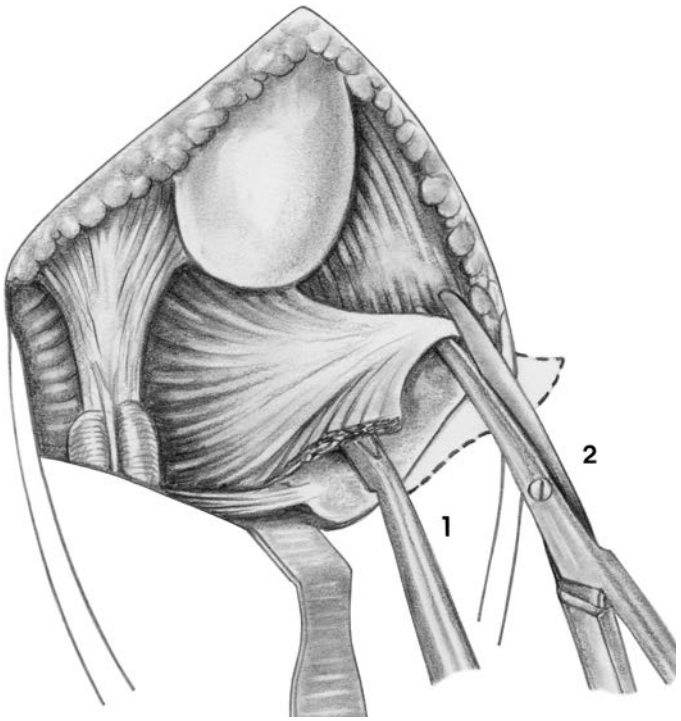


Figure 38-11. Elevation of the internal obturator muscle from the ischiatic table *(1)* and cutting of the internal obturator tendon *(2)*.

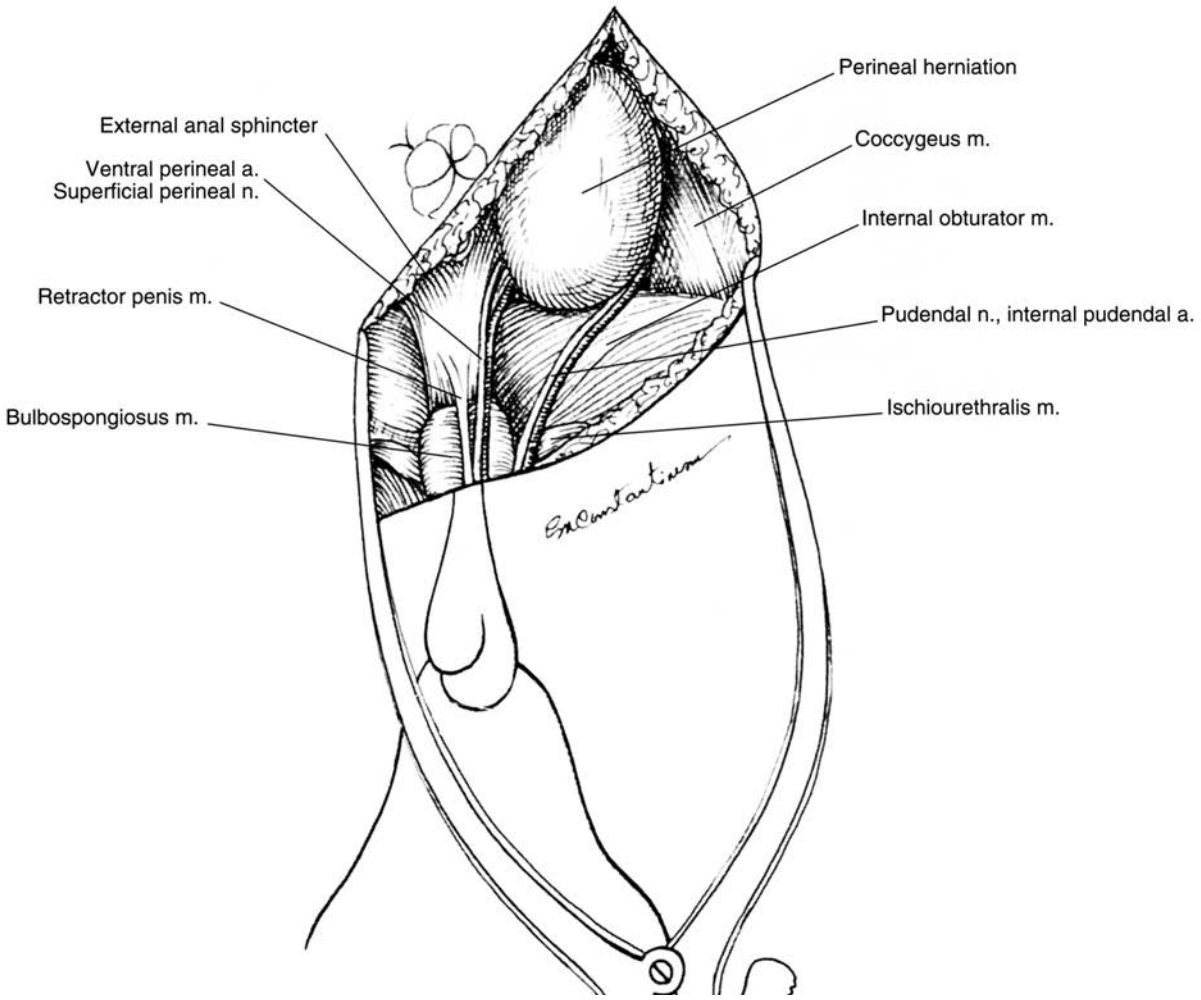


Figure 38-10. Exposure of the right perineum for perineal herniorrhaphy using the internal obturator muscle transposition technique.

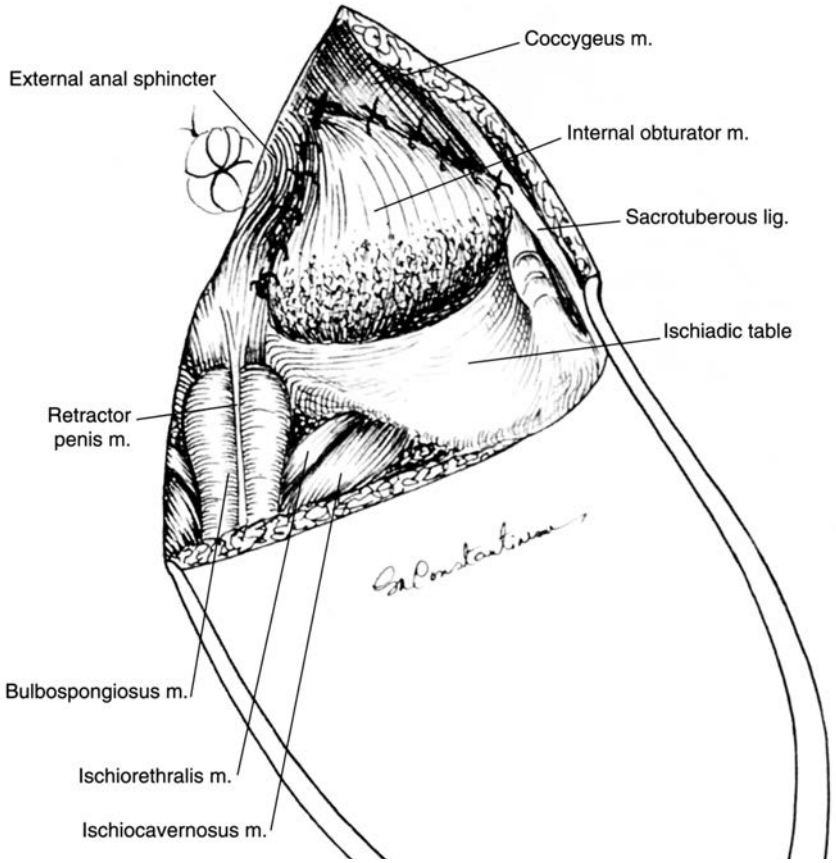


Figure 38-12. Right internal obturator muscle transposition. The transposed internal obturator muscle has been sutured to the external anal sphincter medially, and to the sacrotuberous ligament and coccygeus muscle laterally.

with additional interrupted sutures from the coccygeus muscle to the external anal sphincter. The perineal fascia, subcutaneous tissue, and skin are closed in similar fashion to the traditional perineal herniorrhaphy technique.

Failure of internal obturator muscle transposition most commonly occurs in the ventromedial aspect of the transposed muscle. To prevent failure care should be exercised during subperiosteal elevation to prevent excessive trauma to the muscle, and the ventromedial sutures from the internal obturator muscle to the external anal sphincter should be secure.

Perineal Herniorrhaphy using Porcine Small Intestinal Submucosa (SIS)

The skin incision and surgical approach are similar to the traditional and obturator muscle transposition techniques. Once the hernia is reduced, a 4-ply sheet of SIS is trimmed to dimensions slightly larger than the defect in the pelvic diaphragm. Horizontal mattress sutures (synthetic, absorbable or nonabsorbable, monofilament) are pre-placed from the external anal sphincter, coccygeus muscle, sacrotuberous ligament, and internal obturator muscle to the SIS, leaving a 5 to 10-mm edge on the SIS. After all mattress sutures are placed, they are tied, resulting in closure of the pelvic diaphragm defect (Figure 38-13). Any residual defect in the dorsal aspect of the repair is closed with additional interrupted sutures from the coccygeus muscle to the external anal sphincter. The perineal fascia, subcutaneous tissue, and skin are closed in similar fashion to the traditional perineal herniorrhaphy technique.

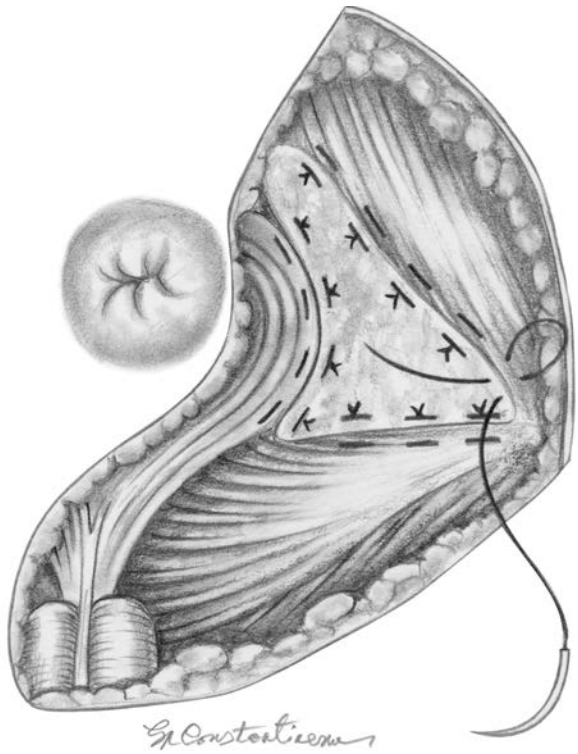


Figure 38-13. Porcine small intestinal submucosa sutured in place with horizontal mattress sutures to close the pelvic diaphragm defect. Medially, the mattress sutures engage the external anal sphincter muscle; laterally, the sutures engage the coccygeus muscle (dorsally) and the sacrotuberous ligament (not shown); and ventrally, the sutures engage the internal obturator muscle.

Postoperative Management

Efforts should be made to ensure a smooth recovery from anesthesia to prevent undo stress on the repaired perineum. To this end, light sedation is occasionally necessary in conjunction with routine analgesics in the early postoperative period.

Prophylactic use of antibiotics to lower the incidence of infection with perineal hernia repair is not straightforward. In a retrospective evaluation of 100 dogs, the authors recommended the use of perioperative antibiotics rather than administering antibiotics after surgery unless an infection has been documented.[15] Good aseptic surgical technique is more important than antibiotics to prevent infection. We select prophylactic antibiotics on an individual case basis.

A low-residue diet can be fed the first few days to help prevent straining during defecation which may lead to disruption of the perineal hernia repair. If straining to defecate does not resolve, digital palpation should be performed to rule out a suture placed in the rectal mucosa. If a suture is not the cause for straining, the pain usually resolves, but analgesics may be necessary in the interim.

If the dog chews or licks excessively at the incision, an Elizabethan collar or similar restraint device should be used to prevent the dog from chewing or licking the incision. Dogs should be returned in 10 to 14 days for skin suture removal.

Complications

Several potential postoperative complications can be associated with repair of perineal hernia. These complications include sciatic nerve injury; fecal incontinence; infection around the incision site; rectal prolapse associated with excessive straining; misplacement of sutures into the anal sac(s) or rectal lumen; urinary bladder necrosis; urinary incontinence; and recurrence of the perineal hernia.[25] Recognition, prevention and appropriate management of these postoperative complications are essential to a successful surgical outcome.

Sciatic nerve injury or entrapment can occur if the nerve becomes encircled or is penetrated by a suture passed around the sacrotuberous ligament. Entrapment of the sciatic nerve is identified immediately after recovering from surgery. The dog will show signs of extreme pain over the hip and perineal region. Furthermore, a sciatic nerve palsy may be detected on a neurologic examination. The treatment of sciatic nerve entrapment is removal of the suture through a caudolateral approach to the hip.[26] This surgical approach allows good visualization of the sciatic nerve and does not require disruption of the perineal hernia repair. Occasionally, epidural medicant administration is used for postoperative analgesia in patients having pelvic or perianal surgery. Because this analgesic technique can cause transient sciatic palsy, the authors recommend alternate means of controlling postoperative pain after perineal herniorrhaphy to avoid confusion with iatrogenic surgical injury to the sciatic nerve. Potentially, observation of sciatic palsy would subject the dog to unnecessary sciatic nerve exploration if the neurologic deficit was due to the epidural analgesic technique.

Fecal incontinence may be only temporary due to postoperative pain and inflammation associated with the surgery. Unilateral damage to either the pudendal nerve or the caudal rectal nerve may be associated with temporary incontinence that resolves after the contralateral caudal rectal nerve reinnervates the damaged nerve's side.[17,25] Return of full fecal continence may take several weeks after unilateral caudal rectal nerve damage. Permanent fecal incontinence is likely if bilateral caudal rectal or pudendal nerve damage occurs, or if damage to the external anal sphincter muscle or other pararectal tissue is excessive.[25] Permanent fecal incontinence is best avoided because the reported prosthetic implants and muscle transpositions used for treatment have demonstrated inconsistent success in reestablishing fecal continence.[21,27]

Incisional complications have been reported as a function of the surgical location.[15] Exposure of the incision to feces either during surgery or before a good fibrin seal has occurred can cause a wound infection. If an infection occurs surgical drainage of the site and administration of antibiotics based on culture and susceptibility is ideal. If antibiotics need to be instituted without knowledge of culture and susceptibility, a broad spectrum antibiotic with activity against Escherichia coli should be used.[25]

Rectal prolapse can sometimes occur immediately after surgery. Rectal prolapse can occur as a result of excessive straining postoperatively due to placement of suture(s) in the rectal lumen, or because of pain associated with bilateral hernia repair. Rectal disease and external anal sphincter nerve injury have been two other predisposing factors to rectal prolapse. The rectal prolapse should be reduced and a purse-string suture placed in the anus. If straining is excessive and unresponsive to narcotics, an epidural can be administered. The anal purse-string suture should be maintained until the straining has resolved. Generally, this may take several days. If the rectal prolapse recurs after multiple attempts at reduction, a colopexy should be performed.[25]

Misplaced suture(s) into the rectal mucosa can occur because of difficulty in identifying perineal structures due to excessive tissue inflammation and swelling. Misplaced sutures can lead to excessive straining, or, uncommonly, development of a rectocutaneous fistula. Misplacement of suture(s) into the anal sac can also lead to draining tracts. The treatment of chronic fistulas associated with misplaced sutures is by fistulectomy and anal sacculectomy, depending on the anatomic structure involved.[25]

Complications relative to retroflexion of the urinary bladder into the perineal hernia are seen infrequently. Retroflexion of the urinary bladder can stretch the nerves that supply the urinary bladder and urethral sphincter, stretch the detrusor muscle resulting in bladder atony, or interfere with the blood supply to the urinary bladder. Usually, clinical signs seen with this complication are temporary. Manual decompression of the urinary bladder or catheterization may be necessary to keep the urinary bladder empty until its muscle tone returns. Urinary bladder necrosis has been associated with long-standing cases secondary to urinary bladder obstruction and distention. The clinical signs secondary to urinary bladder necrosis are rupture and uroperitoneum. Exploratory celiotomy and resection of the

necrotic portion of the urinary bladder may be required; however, in some cases, excessive urinary bladder necrosis may prohibit a successful resection.[25]

Recurrence of a perineal hernia after repair has ranged from 5 to 46%.[8-11,28] Although some surgical procedures offer better results and less chance of recurrence, the accurate identification of all anatomic structures is paramount to the success of any procedure. Furthermore, understanding the limitations of each particular technique is important in the surgical decision-making process and may help in reducing the failure of any technique.

The association between castration and the recurrence of a perineal hernia after surgical repair has been reported to be 2.7 times greater in dogs that were not castrated versus those dogs that were castrated.[9] However, in a later study, no correlation was found between castration and perineal hernia recurrence. Failure of perineal hernia repair was thought to be more related to lack of experience with the surgical technique than any effect from castration.[15]

Salvage Techniques for Failed Perineal Herniorrhaphy

Recurrence of canine perineal herniation following traditional herniorrhaphy has been reported to be as high as 46%.[10] Recurrence rates as low as 5% have been reported for the internal obturator muscle transposition herniorrhaphy technique.[11] Nonetheless, until the ultimate cause of canine perineal hernia can be identified and controlled, a certain degree of recurrence can be expected regardless of refinements in surgical technique. When the traditional herniorrhaphy technique fails, the simplest and usually most effective means of salvage is to perform an internal obturator muscle transposition to reconstruct the pelvic diaphragm. Alternately, the SIS technique could be employed. When the internal obturator muscle transposition fails, SIS might be used to close the defect; however, absence of the internal obturator from its normal ischial location may make it difficult or impossible to anchor the SIS ventrally. When the internal obturator muscle transposition and SIS techniques are not options, the authors recommend choosing from one of the following two options: (1) semitendinosus muscle transposition[21,29] for perineal reconstruction or (2) colopexy/cystopexy[30-32] for preventing herniation of important structures.

Semitendinosus Muscle Transposition

The semitendinosus muscle transposition is particularly useful for reconstructions in which the ventral aspect of the perineum is severely affected as is the case with some bilateral perineal hernias. For unilateral perineal herniation the contralateral semitendinosus muscle is recommended for pelvic diaphragm reconstruction.

With the dog in the perineal position a skin incision is made in the perineal skin from the tail base to the median raphe ventrally just as is done for traditional, internal obturator muscle transposition, and SIS repairs, and the incision is continued across midline toward the ischiatic tuberosity where it curves and progresses distally on the caudal aspect of the pelvic limb to end at the caudomedial aspect of the transition between the stifle and the crus (Figure 38-14). The hernial contents are exposed and reduced in similar fashion to other herniorrhaphy techniques prior to isolation of the semitendinosus muscle. The subcutaneous tissues over the semitendinosus muscle are incised to expose the muscle (Figure 38-15). The semitendinosus muscle is bluntly isolated from surrounding structures taking care not to injure the proximal vascular pedicle (the caudal gluteal artery and vein). The semitendinosus muscle is transected as distally as possible near the stifle and is further isolated for mobilization to the perineal region. Incision of the lateral portion of the semitendinosus tendinous attachment to the ischium may be necessary for maximal mobilization, but care must be taken to avoid proximal vascular pedicle trauma or kinking that may occur with excessive mobilization. Using polypropylene or nylon suture, the transected portion of the semitendinosus muscle is sutured to the sacrotuberous ligament and the coccygeus muscle. The medial aspect of the semitendinosus muscle (now adjacent to the external anal sphincter muscle dorsally) is sutured to the external anal sphincter, and the lateral aspect of the semitendinosus muscle (now adjacent to the ventral aspect of the perineum) is sutured to the remnant of the internal obturator muscle, the ischiourethralis muscle, perineal fasciae, and/or the periosteum of the dorsal surface of the ischium (Figure 38-16). Synthetic absorbable sutures are used to obliterate dead space and close the subcutaneous tissues. The skin is closed with the routine closure of the surgeon's choice.

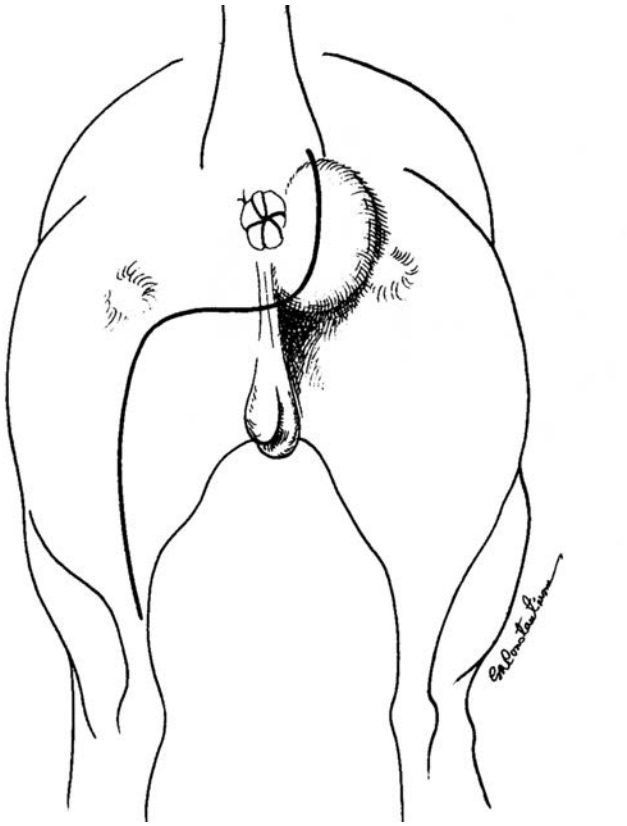


Figure 38-14. Skin incision for left semitendinosus muscle transposition to repair a failed right perineal herniorrhaphy.

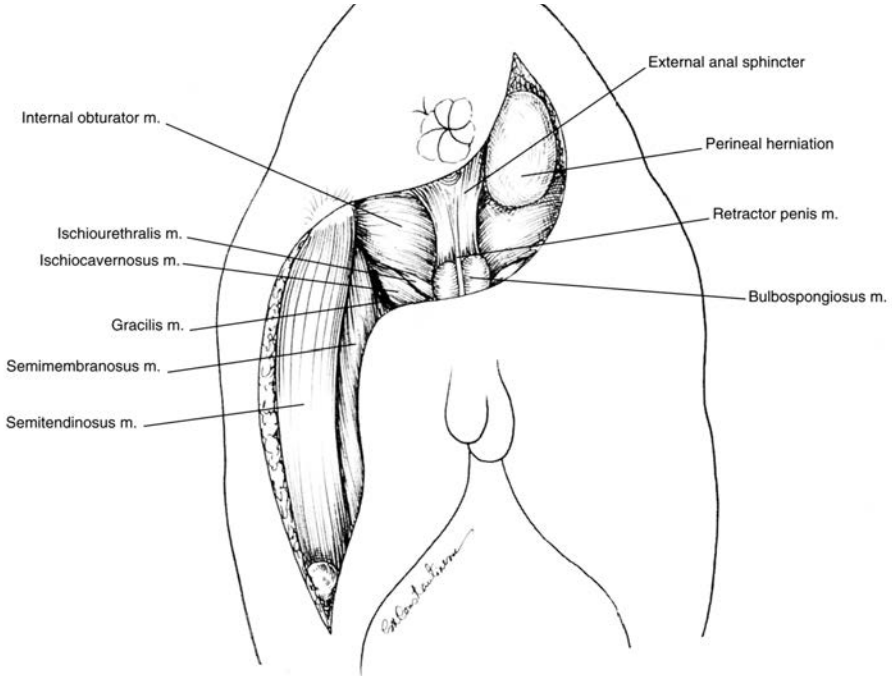


Figure 38-15. Left semitendinosus muscle exposed prior to isolation and mobilization to reconstruct a failed right perineal herniorrhaphy.

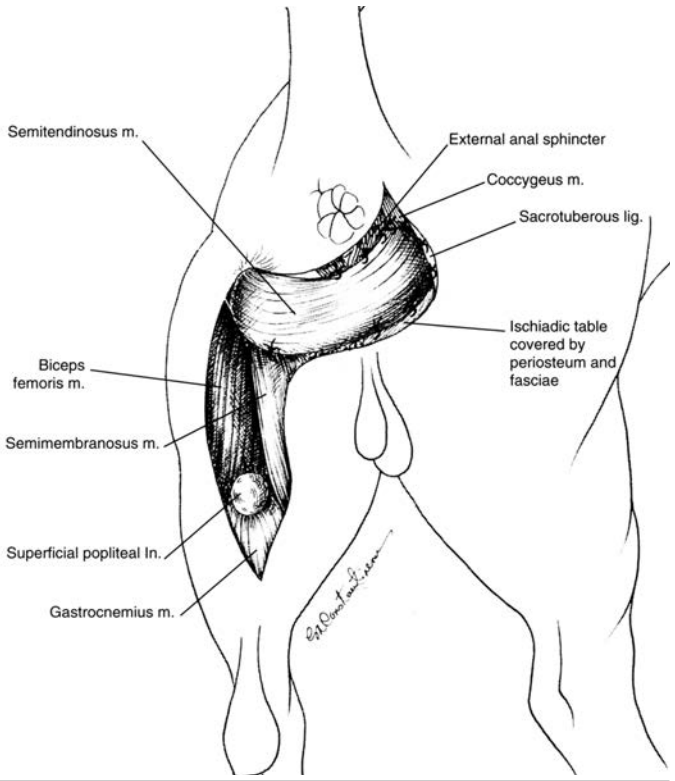


Figure 38-16. Transposed left semitendinosus muscle sutured dorsally to the external anal sphincter muscle, laterally to the right sacrotuberous ligament and coccygeus muscle, and ventrally to the internal obturator muscle fascia, the ischiourethralis muscle fascia, and the ischial periosteum.

Colopexy/Cystopexy for Failed Perineal Herniorrhaphy Salvage

Colopexy with cystopexy via deferent duct fixation is designed to prevent herniation of the most problematic organs (colon, prostate, urinary bladder) that may become entrapped in the perineal hernia space. This technique is typically reserved for cases where perineal reconstruction using muscle transpositions have failed or when the surgeon anticipates failure of muscle transposition.

The dog is positioned in dorsal recumbence for ventral midline celiotomy (Figure 38-17). If the dog is not castrated, standard prescrotal castration is performed prior to celiotomy. Once the abdomen is open, the colon and urinary bladder are exposed by packing the other abdominal organs cranially with moist laparotomy sponges (Figure 38-18). Cranial traction is applied to

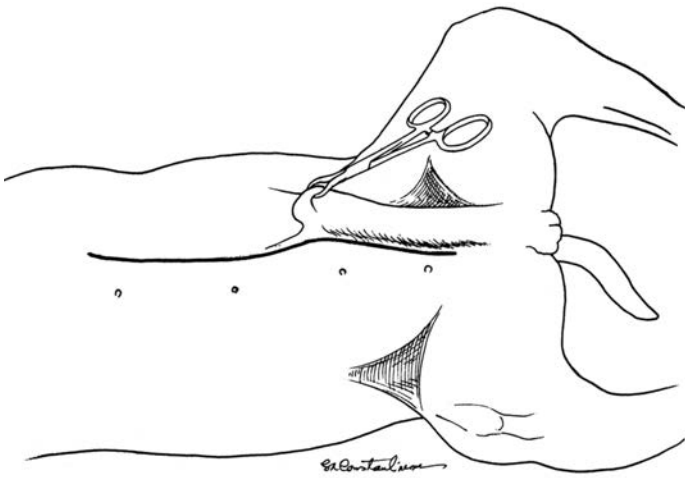


Figure 38-17. Skin incision for colopexy/cystopexy treatment of failed or complicated perineal herniorrhaphy.

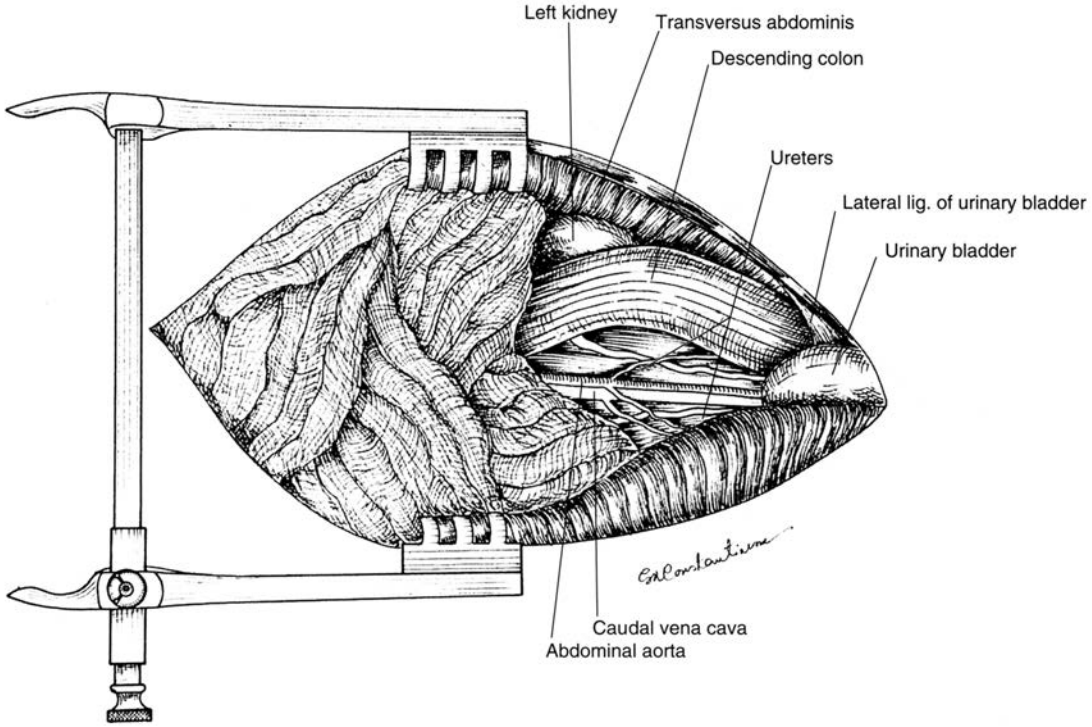


Figure 38-18. Exposure of caudal abdominal organs and positioning of the descending colon adjacent to the left dorsolateral body wall for colopexy. Abdominal organs are packed cranially with moist laparotomy sponges.

the colon to reduce herniated rectum and prevent the rectum from migrating into the perineal space. The colon is secured in this position to the dorsolateral body wall with two staggered rows of mattress sutures (three to four mattress sutures per row) of polypropylene placed in full-thickness fashion through the colon (Figure 38-19).

A stay suture is placed in the apex of the urinary bladder to aid in exteriorization and exposure of the deferent ducts. Both deferent ducts are gently pulled into the abdomen from the vaginal canals. A stay suture is placed at the severed end of the left deferent duct to assist manipulation. A 1 to 2 cm belt loop is created dorsolaterally in the left transversus abdominis muscle midway between the left kidney and urinary bladder. The belt loop is created by making two stab incisions parallel to the transversus abdominis muscle fibers and bluntly dissecting beneath the muscle between the stab incisions with hemostatic forceps. The stay suture in the deferent duct is grasped with hemostatic forceps and pulled from caudal to cranial through the belt loop to pull the deferent duct through the loop until it is taught. The deferent duct is then folded back (caudally) over the belt loop and is sutured to itself and to the belt loop with simple interrupted polypropylene sutures (Figure 38-20). The manipulated end of the deferent duct with the stay suture is excised. The right deferent duct is secured to the right body wall in the same fashion. After removal of the laparotomy sponges and urinary bladder stay suture, the celiotomy is closed routinely.

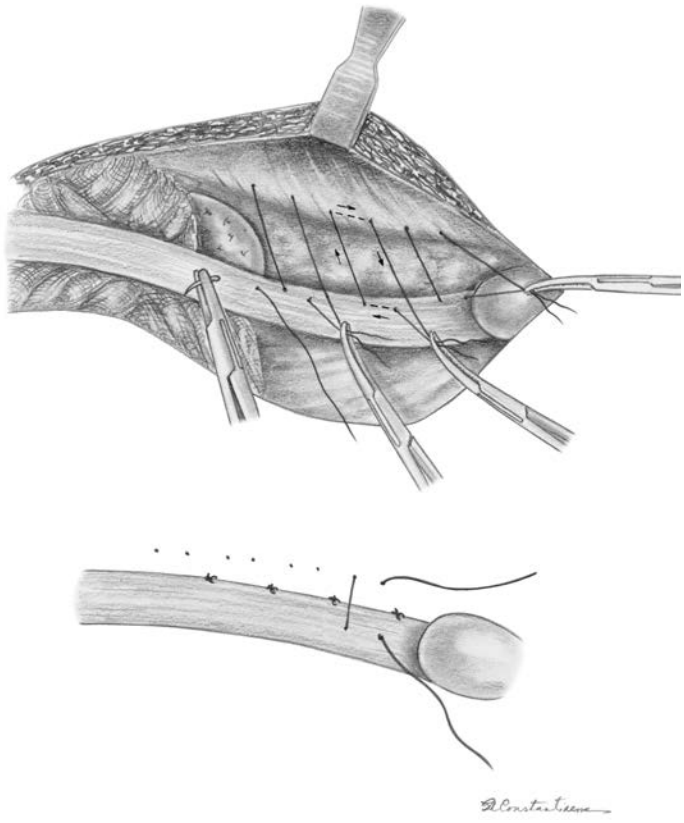


Figure 38-19. Colopexy. The mattress sutures in the first row are preplaced (top drawing) and tied (bottom drawing) before the second (staggered) row of sutures is completed.

Caudal Castration in the Dog

An alternative to standard prescrotal castration is desirable in dogs when castration is indicated in conjunction with perianal

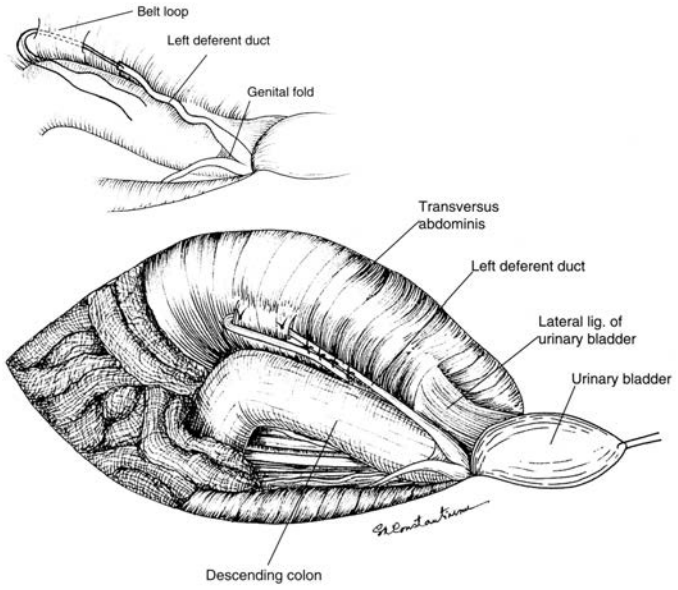


Figure 38-20. Cystopexy via deferent duct fixation. The left deferent duct is passed through a belt loop created in the left transversus abdominis muscle with the aid of a stay suture *(inset)* and is folded onto itself and sutured to itself and to the belt loop.

or perineal surgery. Although the role of castration in canine perineal hernia is debatable,[13] many surgeons continue to perform castration in conjunction with perineal herniorrhaphy. Whenever a dog is undergoing castration at the same time as a procedure that requires perineal positioning, caudal castration can decrease operative time by eliminating the need for intraoperative repositioning.[22]

Patient preparation: For caudal castration, the dog must be surgically prepared such that the scrotum is in the aseptic surgical field once the surgical drapes are in place. Therefore, gentle clipping of scrotal hair with a cool clipper blade is performed before clipping of the remainder of the surgical field. After clipping and hair removal are complete, the dog is placed in the perineal position (See Figure 38-7) for aseptic surgical preparation. We prefer to use chlorhexidine instead povidone iodine for scrotal disinfection, to minimize the chance of scrotal dermatitis. On completion of skin disinfection, surgical drapes are placed such that the scrotum is within the surgical field (Figure 38-21), and caudal castration is performed before the other scheduled surgical procedure (perineal herniorrhaphy, perianal adenoma excision). The anus and perianal region may be temporarily covered with drapes to minimize contamination of the castration procedure.

Surgical technique: The skin incision begins on the median raphe and extends ventrally onto the scrotum over the left testicle (Figure 38-22). Open castration is then performed. The left testicle is pushed toward the skin incision to allow incision of the internal spermatic fascia and parietal lamina of the vaginal tunic exposing the testicle. The excess internal spermatic fascia and parietal lamina of the vaginal tunic is excised, and the testicle is removed using a three clamp technique (Figure 38-23). The right testicle is approached through the same skin incision through the interdartoic septum and is removed in a fashion similar to that of the left testicle. A few subcutaneous subcuticular sutures of synthetic absorbable suture are used for closure. The perineal position is maintained for the subsequent surgical procedure, and the scrotum may be draped out of the surgical field to minimize contamination of the castration incision.

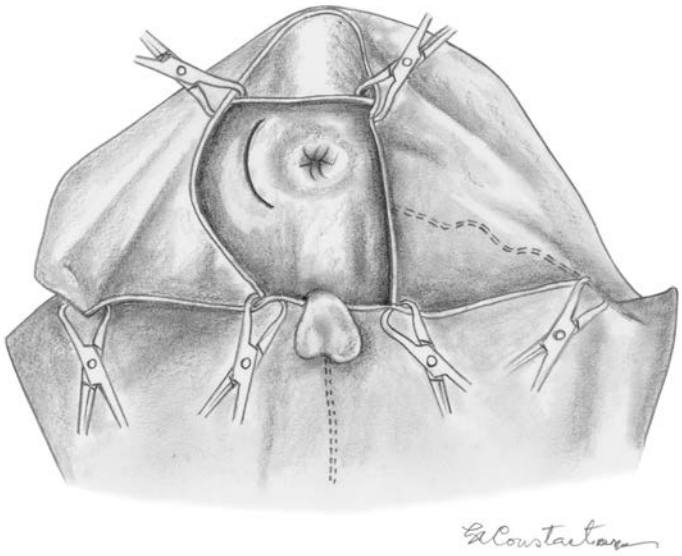


Figure 38-21. Aseptic draping for caudal castration and perineal herniorrhaphy. Castration is performed first, but the proposed herniorrhaphy incision is outlined to demonstrate draping of both sites in the surgical field. A rectal gauze tampon and anal purse-string suture (not shown) placed prior to the final skin preparation will prevent gross fecal contamination, but a temporary drape may be placed over the anus during the castration to further minimize contamination.

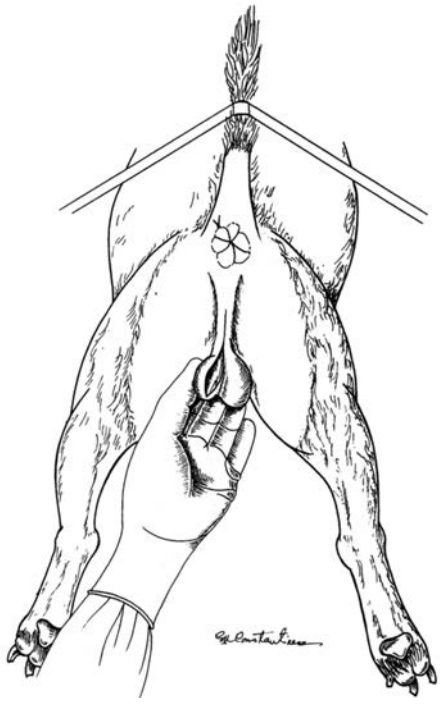


Figure 38-22. Caudal castration skin incision. Surgical drapes are not shown to allow anatomic reference. Both testicles are removed through the same skin incision.

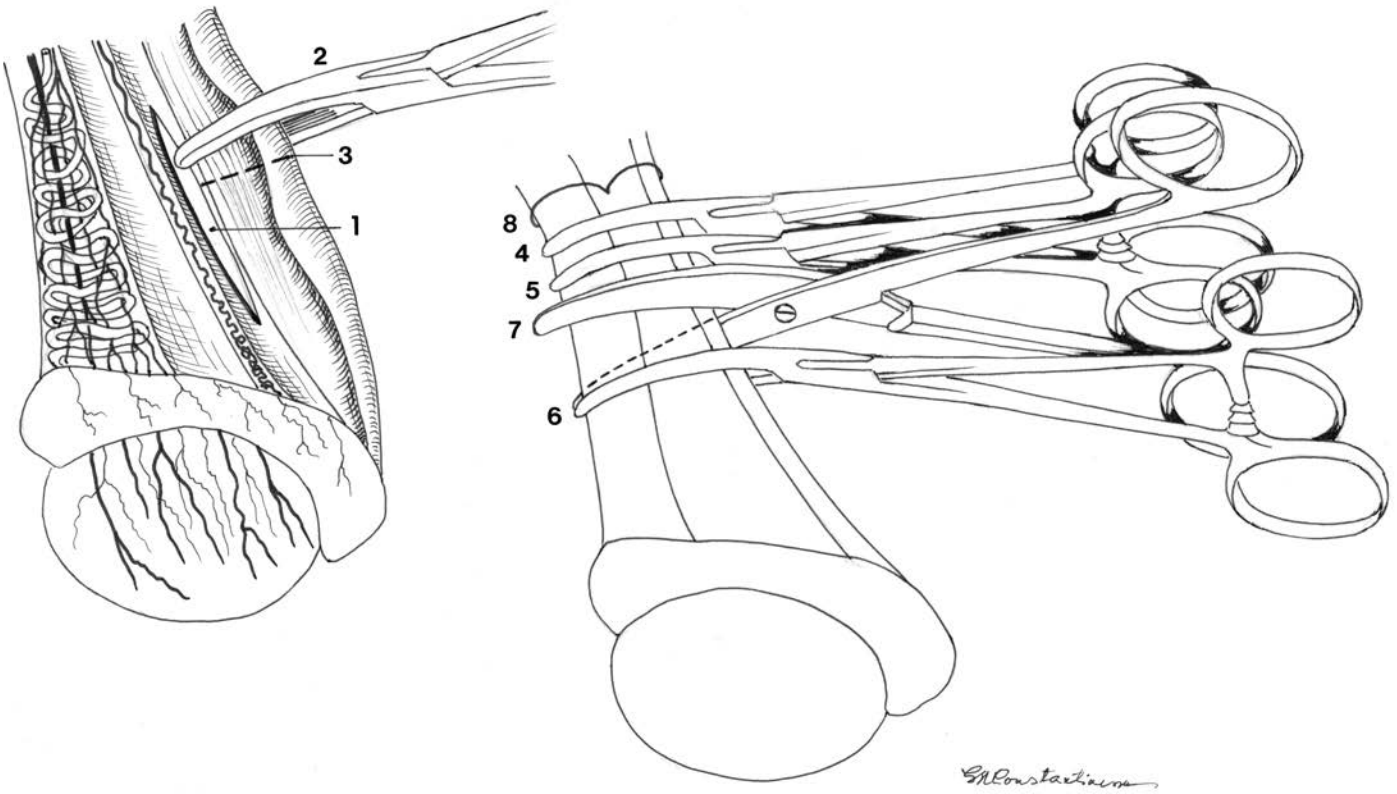


Figure 38-23. Three clamp technique for caudal castration (open technique) of the left testicle. A fenestration *(1)* is made in the mesofuniculus to allow a Carmalt forceps *(2)* to be placed across the tunic containing the cremaster muscle. An incision *(3)* is made distal to the Carmalt forceps. A transfixation ligature (not shown) is placed proximal to the Carmalt forceps and tied as the forceps is removed to control hemorrhage from the cremaster muscle. Three Carmalt forceps *(4, 5, and 6)* are placed across the spermatic cord, the proximal forceps applied first and the distal forceps applied last. The testicle is excised by cutting *(7)* between the two most distal forceps, and a ligature *(8)* is placed proximal to the most proximal Carmalt forceps and tightened as the most proximal forceps is removed. After the ligature is tied, the remaining forceps is removed. The numbers represent the steps of the procedure. (Alternately, the pampiniform plexus testicular artery complex and the deferent artery and ductus deferens may be excised and ligated using two separate three-clamp procedures.)

Perineal Herniorrhaphy in the Cat

The etiopathogenesis of perineal hernia in cats differs from that of dogs. In cats, perineal hernia may occur as a long-term complication of perineal urethrostomy or may be associated with megacolon. Feline perineal hernias that are not associated with either of these two situations are considered idiopathic; a hormonal influence has not been seriously considered because both genders are typically represented, most affected cats being spayed or castrated.[33-36] A left-sided perineal hernia in an 8-week-old cougar was thought to be congenital.[37] Most perineal hernias in cats are bilateral.[33]

The perineal herniorrhapy techniques used in dogs may be applied to cats, but attention should be paid to anatomical differences. Feline perineal muscles are smaller than like muscles in the dog, and the cat does not possess a sacrotuberous ligament (Figure 38-24).[38,39] Because feline perineal hernia is often bilateral, the internal obturator muscle transposition is preferred to the traditional technique to avoid excessive tension on the external anal sphincter. Although not yet reported in cats at the time of this writing, SIS repair could also be performed. The semintendiosus muscle transposition repair has been reported in a cat.[40]

Complications after perineal herniorrhaphy in cats seem to be less common than in dogs, but one should be vigilant for the same possible complications as described for dogs. Additionally, concurrent disease that might contribute to straining, such as megacolon, must be addressed for optimal success.

References

1. Constantinescu GM, Schaller O, Habel RE, Hillebrand A., Sack WO, Simoens P, deVos NR. Illustrated Veterinary Anatomical Nomenclature 2nd Edition. Enke F, Stuttgart, 2007, p. 222.

2. Constantinescu GM. The pelvis and genital organs. In: Constantinescu GM. Clinical Anatomy for Small Animal Practicioners. Ames, Iowa: Iowa State Press, 2002, pp. 267-301.

3. Bojrab MJ, Toomey A. Perineal herniorrhaphy. Comp Cont Ed Pract Vet 1981;8:8-15.

4. Krahwinkel DJ. Rectal diseases and their role in perineal hernia. Vet Surg 1983;12:160-165.

5. Spruell JSA, Frankland AL. Transplanting the superficial gluteal muscle in the treatment of perineal hernia and flexure of the rectum in dogs. J Small Anim Pract 1980;21:265-278.

6. Holmes JR. Perineal hernia in the dog. Vet Rec 1964;76:1250-1251.

7. Walker RG. Perineal hernia in the dog. Vet Rec 1965;77:93-94.

8. Pettit GD. Perineal hernia in the dog. Cornell Vet 1962;52:261-279.

9. Hayes HW, Wilson GP, Tarone RE. The epidemiologic features of perineal hernia in 771 dogs. J Am Anim Hosp Assoc 1978;14:703-707.

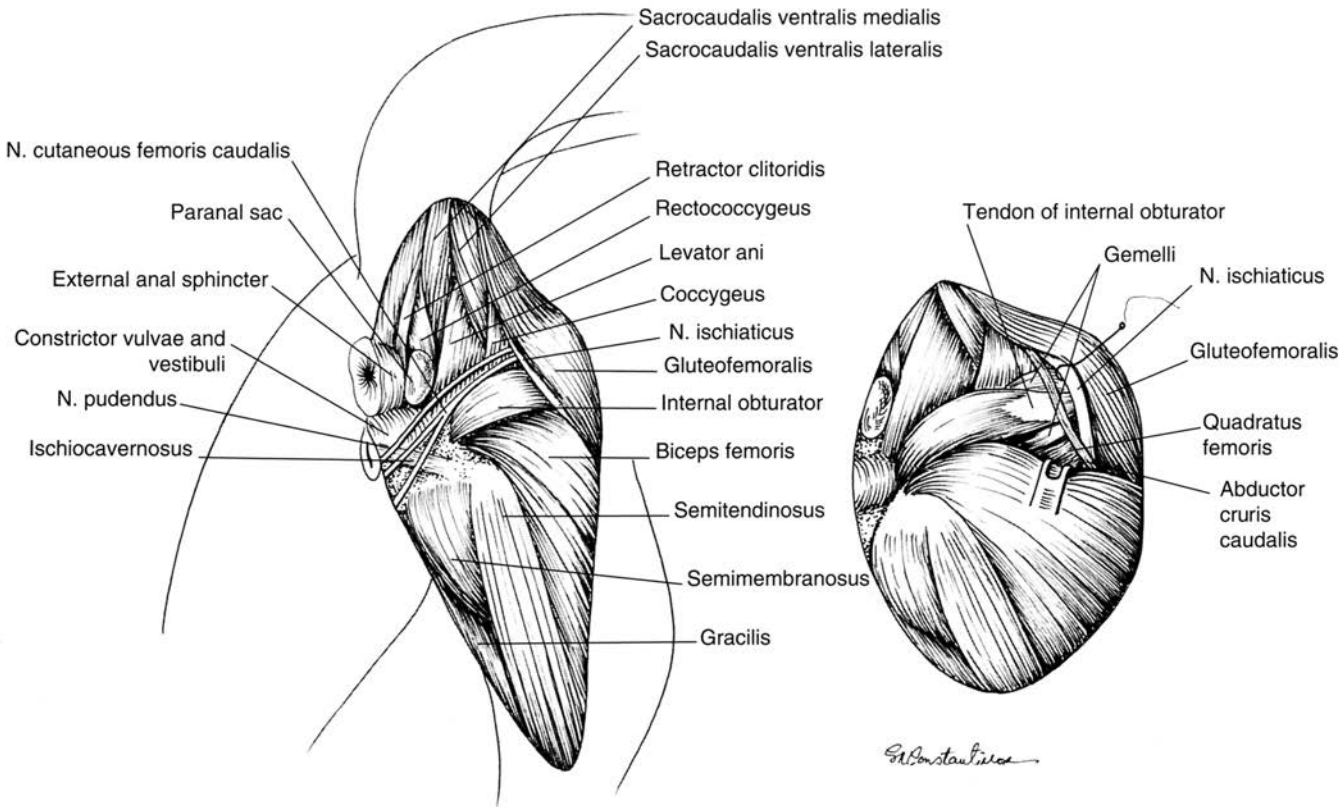


Figure 38-24. Feline perineal anatomy.

10. Burrows CF, Harvey CE. Perineal hernia in the dog. J Sm Anim Pract 1973;14:315-332.

11. Sjollema BE, Venker-van Haagen, van Sluijs FJ, et al. Electromyography of the pelvic diaphragm and anal sphincter in dogs with perineal hernia. Am J Vet Res 1993;54:185-190.

12. Mann FA, Boothe HW, Amoss MS, et al. Serum testosterone and estradiol 17-beta concentration in 15 dogs with perineal hernia. J Am Vet Med Assoc 1989;194:1578-1580.

13. Mann FA, Nonneman DJ, Pope ER, et al. Androgen receptors in the pelvic diaphragm muscles of dogs with and without perineal hernia. Am J Vet Res 1995;56:134-139.

14. Niebauer GW, Shibly S, Seltenhammer M, et al. Relaxin of prostatic origin might be linked to perineal hernia formation in dogs. Ann N Y Acad Sci 2005;1041:415-422.

15. Hosgood G, Hedlund CS, Pechman RD, et al. Perineal herniorrhaphy: perioperative data from 100 dogs. J Am Anim Hosp Assoc 1995;31:331-342.

16. White RAS, Herrtage ME. Bladder retroflexion in the dog. J Sm Anim Pract 1986;27:735-746.

17. Bellenger CR, Canfield RB. Perineal hernia. In: Slatter DH, ed. Textbook of Small Animal Surgery. 3rd ed. Philadelphia: Saunders, 2003, pp. 487-498.

18. Weaver AD, Omamegbe JO. Surgical treatment of perineal hernia in the dog. J Sm Anim Pract 1981; 22:749-758.

19. Dieterich HF. Perineal hernia repair in the canine. Vet Clin N Am 1975; 5:383-399.

20. Harvey CE. Treatment of perineal hernia in the dog- reassessment. J Sm Anim Pract 1977;18:505-511.

21. Chambers JN, Rawlings CA. Applications of a semitendinosus flap in two dogs. J Am Vet Med Assoc 1991;199:84-86.

22. Knecht CD. An alternate approach for castration of the dog. Vet Med/Small Anim Clin 1976;71:469-473.

23. Stoll MR, Cook JL, Pope ER, et al. The use of porcine small intestinal submucosa as a biomaterial for perineal herniorrhaphy in the dog. Vet Surg 2002;31:379-390.

24. Desai R. An anatomical study of the canine male and female pelvic diaphragm and effect of testosterone on the status of the levator ani of male dogs. J Am Anim Hosp Assoc 1982;18:195-202.

25. Matthiesen DT. Diagnosis and management of complications occurring after perineal herniorrhaphy in dogs. Comp Cont Ed Vet Pract 1989;11:797-823.

26. Piermattei DL, Johnson KA. Approach to the caudal aspect of the hip joint and body of ischium. In: Piermattei DL, Johnson KA, eds. An Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat. 4th ed. Philadelphia: Saunders, 2004, pp. 310-314.

27. Dean PW, O'Brien DP, Turk MA, et al. Silicone elastomer sling for fecal incontinence in dogs. Vet Surg 1988;17:304-310.

28. Orsher RJ. Clinical and surgical parameters in dogs with perineal hernia- analysis of results of internal obturator transposition. Vet Surg 1986;15:253-258.

29. Philibert D, Fowler JD. Use of muscle flaps in reconstructive surgery. Compend Cont Ed Pract Vet 1996;18:395-405.

30. Bilbrey SA, Smeak DD, DeHoff W. Fixation of the deferent ducts for retrodisplacement of the urinary bladder and prostate in canine perineal hernia.Vet Surg 1990;19:24-27.

31. Brissot HN, Dupré GP, Bouvy BM. Use of laparotomy in a staged approach for resolution of bilateral or complicated perineal hernia in 41 dogs. Vet Surg 2004;33:412-421.

32. Yoon H, Mann FA, Clinical evaluation of three different colopexy techniques in dogs. Indian Vet J 2009; 86:1129-1131.

33. Welches CD, Scavelli TD, Aronsohn MG, et al. Perineal hernia in the cat: a retrospective study of 40 cases. J Am Anim Hosp Assoc 1992;28:431-438.

34. Johnson MS, Gourley IM. Perineal hernia in a cat. Vet Med 1980;75:241-243.

35. Ashton DG. Perineal hernia in the cat: a description of two cases. J Small Anim Pract 1976;17:473-477.

36. Leighton RL. Perineal hernia in a cat. Feline Pract 1979;9:44.

37. Anderson M, Pope ER, Constantinescu GM. Perineal hernia in a cougar. J Am Vet Med Assoc 1992;201:1771-1772.

38. Martin WD, Fletcher TF, Bradley WE. Perineal musculature in the cat. Anat Rec 1974;180:3-14.

39. Constantinescu GM, Amann JF, Anderson MA, et al. Topography and surgery in the regio perinealis of the cat. Wien Tierarztl Monatsschr 1993;80:208-211.

40. Babic DV, Stejskal M, Capak D, et al. Application of a semitendinosus muscle flap in the treatment of perineal hernia in a cat. Vet Rec 2005;156:182-184.

Prepubic Hernia Repair

Daniel D. Smeak

Introduction

Prepubic hernia or cranial pubic ligament (CPL) rupture is the most common abdominal hernia caused by blunt trauma (particularly vehicular trauma) in small animals.[1,2] The lateral paralumbar (flank) region hernia is also seen with some frequency after blunt trauma presumably because it is another area that lacks elasticity, and it is not supported by the rectus abdominis muscle.[3] Because of their close anatomic relationship, many patients with prepubic hernias have coexisting inguinal ligament rupture and organs such as the bladder and/or intestines may be found within the hernia. These organs may extend into the inguinal canal or femoral vascular lacunae area causing swelling reaching from the caudal-ventral abdominal wall into the medial thigh and flank (Figure 38-25). One case report described a rare bladder incarceration within a chronic prepubic hernia in a dog with a vesicular-cutaneous fistula.[4]

The CPL attaches to the cranial aspect of the pubis and extends from one iliopectineal eminence and pectineus muscle to the other (See Figure 38-25). It serves as the principal attachment of the rectus abdominis muscle to the pelvis and is under constant tension. Blunt trauma causes avulsion of the cranial pubic ligament from its boney attachment or, less commonly, a tear occurs at the musculotendinous junction. In contrast, CPL rupture is spontaneous in large animals, and most often occurs during the last two months of gestation apparently due to increasing uterine weight.[5]

Blunt trauma severe enough to cause rupture of the abdominal wall may also cause widespread crush, rupture, or avulsion damage to surrounding structures and intra-abdominal organs. As many as 75% of small animals with traumatic abdominal hernias have other serious injuries, most are orthopedic in nature usually involving the pelvis. Other important common injuries are to soft tissues, including respiratory, gastrointestinal, and genitourinary systems.[2,3] Following patient stabilization, a thorough physical examination and diagnostic workup are indicated to evaluate for more insidious, often life-threatening, injuries.

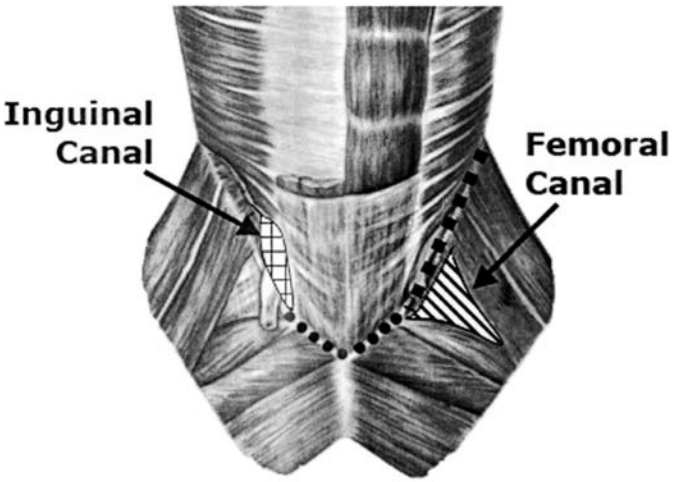


Figure 38-25. Caudoventral abdominal wall and inguinal anatomy. Dotted line indicates the rectus abdominis muscle attachment to the pelvis (the cranial pubic ligament). The dashed line marks the inguinal ligament separating the inguinal and femoral canals. (Modified from Robinette JD, Hernias. In Gourley IM, Vasseur PB eds. General Small Animal Surgery. Philadelphia, JB Lippincott, pp759, 1985.)

The diagnosis of prepubic hernia is often confirmed by palpating a defect in the caudal abdominal wall, by reduction of tissue back into the caudal abdomen, or by palpation of organs in the subcutaneous space near the pubic or thigh areas. Organs such as the intestine may not be confined to the local area and may migrate a considerable distance from the hernia, such as down the medial thigh or along the abdominal wall and thorax. Pain and swelling from trauma or hemorrhage may not allow detection of a hernial ring or herniated tissue during physical examination. In these instances, abdominal radiographs or ultrasound of the local area are indicated. Routine ventral-dorsal and lateral radiographs aid in identifying the abdominal stripe, or lack thereof, any malposition of the abdominal contents, and the presence of fluid in the abdomen. When radiographs or ultrasound are not conclusive, a positive contrast peritoneogram may help to delineate the abdominal wall defect. Patients should be thoroughly evaluated for concurrent injuries such as urinary tract rupture, abdominal hemorrhage, fractures, and thoracic trauma. Survey thoracic and abdominal films (including the pelvic area), and blood workup are usually indicated for all severely traumatized patients. If electrocardiography is available, a rhythm strip should be evaluated, otherwise, detection of an irregular rhythm or dropped beats while examining the pulse may indicate traumatic myocarditis. A complete blood count and serum chemistries should be evaluated to determine if significant blood loss or organ compromise has occurred.

Stabilization of the patient's condition takes precedence over hernia repair. Because these hernias are usually large, the risk of incarceration or strangulation of viscera is low. Therefore, if the patient is stable and serious intra-abdominal trauma has been ruled out, the hernia can be repaired several days later, after swelling and hemorrhage begins to subside and tissues reestablish their blood supply. If the patient does not stabilize with resuscitative measures, serious intra-abdominal injury or contamination should be suspected and further diagnostic tests and/or emergency exploratory laparotomy may be indicated.

Surgical Technique

Surgical correction is usually performed through a ventral midline approach. When an exploratory laparotomy is indicated, the entire abdomen should be prepared aseptically, and if the hernial sac extends to adjacent areas, these areas should be liberally prepared also. The way in which the patient is positioned on the operating table may be critical for successful closure of a prepubic hernia. Closure may be virtually impossible if the patient is placed in a routine dorsal recumbent position (limbs pulled caudally and abducted and trunk in slight dorsal flexion (Figure 38-26A). The rear limbs should be pulled cranially and the body ventroflexed to relieve tension during hernia repair (Figure 38-26B). If transposition of the cranial sartorius muscle is planned to augment the primary hernia repair, the adjacent hind limb is also prepared for aseptic surgery (Figure 38-27). Prophylactic antibiotics are administered during preparation of the surgical site.

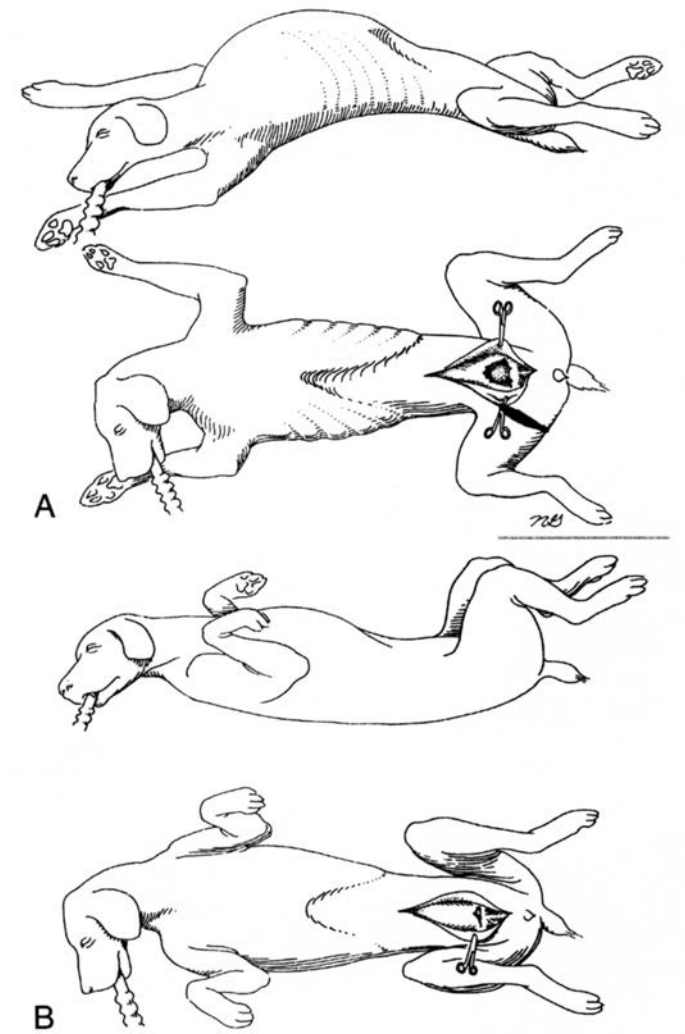


Figure 38-26A and **B.** Example after altering position to relieve tension on a prepubic hernia repair. **A.** Dorsal recumbency position for prepubic hernia repair; rear limbs are pulled caudally and are extended, causing undue tension. **B.** Modified dorsal recumbency position; rear limbs are flexed slightly and are pulled cranially. This creates truncal ventroflexion, reduces the size of the defect, and decreases tension during hernia repair. (Reprinted with permission from Smeak DD: Management and prevention of surgical complications associated with small animal abdominal herniorrhaphy. Prob Vet Med 1:259, 1989.)

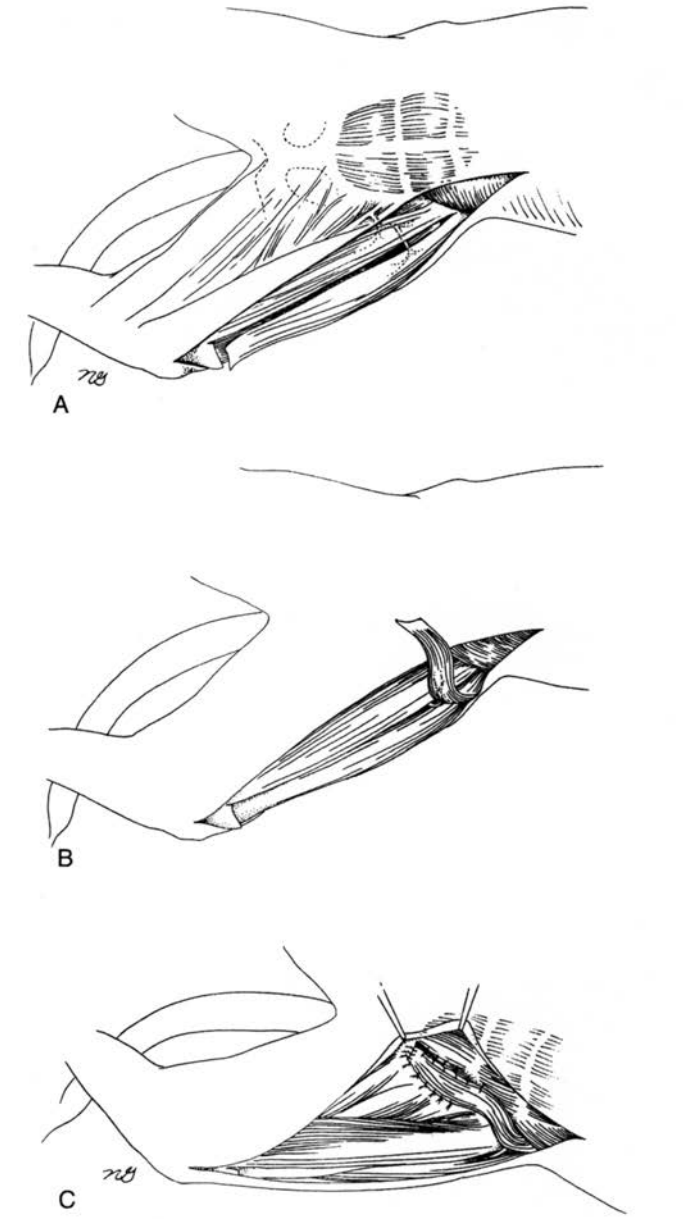


Figure 38-27. Illustration of a cranial sartorius muscle flap used to repair an inguinal hernia. **A.** The cranial sartorius muscle is elevated from its distal insertion. **B.** Mobilization of the muscle to the level of the vascular pedicle. **C.** Transposition of the cranial sartorius muscle to the caudal abdominal wall region so that its external surface is in contact with the external abdominal oblique muscle. (Reprinted with permission from Smeak DD. Abdominal Hernias. In Slatter D ed. Textbook of Small Animal Surgery. Philadelphia, Saunders, 463, 2003.)

Due to serious concurrent soft tissue injuries related to acute traumatic abdominal hernias, the abdomen should be aseptically prepared for thorough exploration before efforts are made at hernia repair.[3] In dogs surviving the acute insult that develop a chronic prepubic hernia, the defect can be safely approached locally without abdominal exploration. When prepubic hernias become chronic, significant muscle contraction and loss of tissue elasticity occurs, exerting excessive tension on the repair. In some cases, it is impossible to appose tissues. If tension is difficult to overcome, muscle or tendon has been lost, or the defect is very large, the use of a mesh prosthesis is recommended.[6] Besides

hernia recurrence, wound infection, seroma, and skin slough are the most common complications after repair.[6] Traumatized skin and soft tissues are handled with utmost care, and excessive blunt dissection is avoided because the vascular supply may be tenuous and further insult could result in tissue loss or an increased risk of infection.[6] After abdominal exploration, and necessary organ repair is completed, the abdominal cavity is lavaged, and the linea alba is closed routinely.

The prepubic hernia is exposed by careful dissection and debridement of devitalized tissue (Figure 38-28). Excision of connective tissue surrounding the hernia is avoided unless it is devitalized or infected, and will not support sutures. The surgeon carefully inspects the lateral margins to determine whether the hernia extends into the inguinal and femoral areas. Important vascular and neural structures are isolated and protected, particularly if the femoral region requires reconstruction. If femoral or inguinal areas are involved, the regional anatomy is studied carefully before undertaking herniorrhapy. The prepubic hernia component is repaired first, to help align tissues correctly for anatomic reconstruction of the inguinal and femoral hernias, if present. The cranial public ligament is reattached with large 2-0 to 0 size monofilament (prolonged absorbable) suture or nonabsorbable suture. If enough healthy tendon is present, the surgeon anatomically repairs the hernia with preplaced interrupted sutures incorporating large bites of tissue. As adjacent preplaced sutures are pulled firmly, knot the individual sutures. This maneuver helps reduce the risk of suture cutout during repair. In most prepubic hernias, the ligament is avulsed from the pubic bone leaving scant soft tissue attached. In this case, holes are drilled in the cranial brim of the pubis to anchor sutures. When the hernia cannot be repaired without excess tension, a cuff mesh reinforcement of the prepubic tendon can be performed using polypropylene mesh (Figure 38-29). Concurrent femoral or inguinal hernias are repaired by carefully isolating the hernia edges and anatomic reconstruction. Often, the inguinal ligament is ruptured, and sutures are preplaced between the abdominal oblique fascia and the musculature of the proximal medial thigh. Extreme care is required to avoid damaging, incorporating or obstructing important vascular and neural structures of the inguinal or femoral canal. If mesh is used for reconstruction, I prefer to transpose the cranial sartorius muscle to provide a seal and bring additional blood supply over the repair to support rapid healing and incorporation of the mesh (See Figure 38-27).[7,8] I also consider using this muscle to augment inguinal or femoral defects when tissue edges are tenuous or when the wound will not support synthetic mesh (heavily contaminated wounds). The surgeon should recognize that this muscle is not covered by heavy fascia so the muscle alone should not be expected to maintain abdominal wall continuity under excessive tension.

Usually a large amount of dead space is present in the subcutaneous tissues after herniorrhaphy. Gravity dependent drains such as Penrose drains or, preferably, closed suction drain systems (Jackson-Pratt) should be used in most cases. Avoid placing open-drain systems directly against buried mesh to reduce the risk of ascending infection.

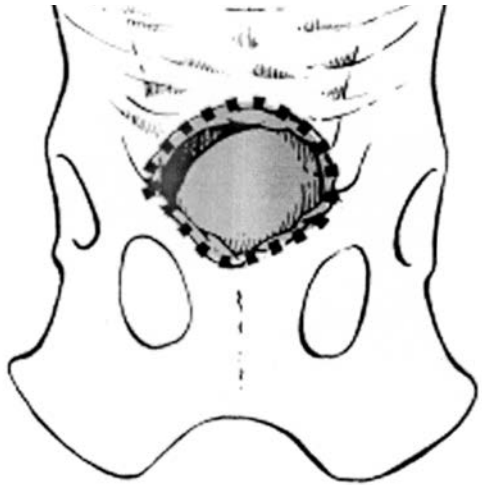


Figure 38-28. Ventral view of pelvis showing prepubic defect. Dashed line indicates hernia ring. (Modified from Robinette JD, Hernias. In Gourley IM, Vasseur PB eds. General Small Animal Surgery. Philadelphia, JB Lippincott, pp759, 1985.)

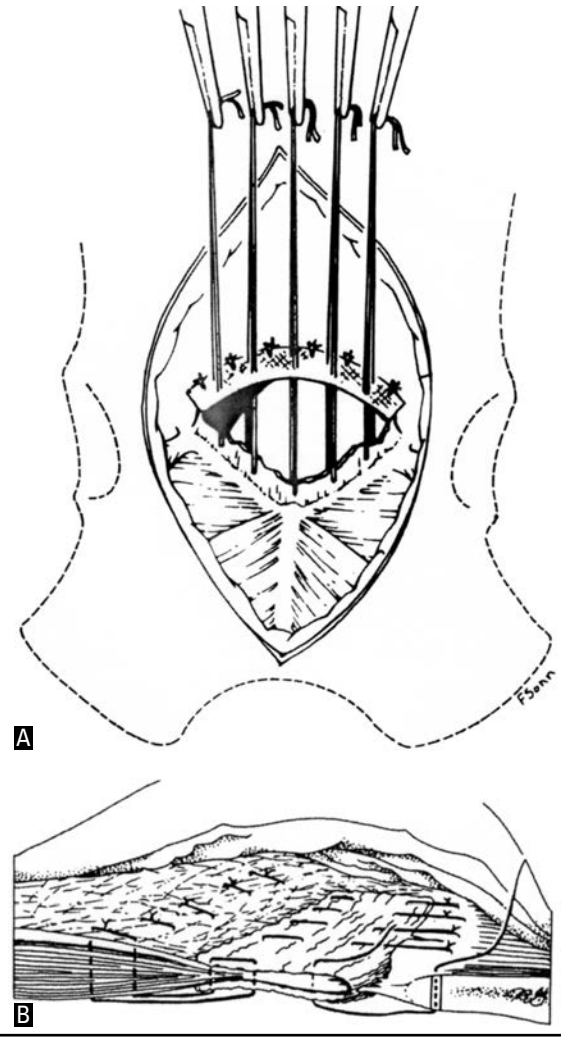


Figure 38-29. Cuff mesh reinforcement of a prepubic hernia. **A.** The prepubic defect is closed with preplaced sutures between holes drilled in the pubic bone, and a mesh reinforced edge of torn rectus abdominis muscle and prepubic tendon. **B.** Section through caudal abdominal wall showing cuffed mesh reinforcement of the rectus abdominis tendon, and fixation of the mesh to the pubis. (A, modified from Robinette JD, Hernias. In Gourley IM, Vasseur PB eds. General Small Animal Surgery. Philadelphia, JB Lippincott, pp755-776, 1985.)

Postoperative Care

Monitoring and postoperative care instructions are dictated by the nature and severity of the injury. The surgeon should continue to monitor the patient's vital signs and remains aware of possible problems related to occult visceral damage. Patients should be given analgesic agents for at least 24 hours after the surgical procedure. An epidural using narcotic analgesics is very effective to prevent postoperative pain. Unless contraindicated, nonsteroidal anti-inflammatory drugs are also administered to reduce postoperative wound edema and pain. Wounds and drains should be monitored for signs of infection or hernia recurrence. Drains should be bandaged, if possible, and removed when discharge has diminished. This is usually possible within 3 days. If infection occurs, wounds are opened, cultured, debrided, and secondarily closed. Strict exercise limitation is recommended for at least four to six weeks particularly if a prosthetic mesh was implanted. If the inguinal or femoral areas have been reconstructed along with the prepubic hernia, the surgeon should consider placing the patient's hind limbs in hobbles to prevent tension from excess limb abduction. An Elizabethan collar is used to guard against premature drain removal or wound mutilation.

Prognosis

Based on a report of a series of patients undergoing prepubic herniorrhaphy, approximately 80% will survive and have successful hernia repair. If a hernia recurs (about 15% do) the defect is usually evident by one month after surgery. Repair of these recurrent hernias is usually successful provided the repair is anatomic, is free of tension, and incorporates strong tissue. The remaining 20% have poor results because of the severity of accompanying injuries.[1,3]

References

1. Mann FA et al.: Cranial pubic ligament rupture in dogs and cats. J Am Anim Hosp Assoc 22:519, 1986.

2. Waldron DR et al.: Abdominal hernias in dogs and cats: A review of 24 cases. J Am Anim Hosp Assoc 22:818, 1986.

3. Shaw SP, Rozanski EA, Rush JE: Traumatic body wall herniation in 36 dogs and cats. J Am Anim Hosp Assoc 39:35-46, 2003.

4. Green RB, Quigg JA, Holt PE: Vesicocutaneous fistulation following prepubic tendon rupture in a bitch. J Small Anim Pract 30:315-317, 1989.

5. Hanson RR, Todhunter RJ. Herniation of the abdominal wall in pregnant mares. J Am Vet Med Assoc 189:790-3, 1986.

6. Smeak DD: Management and prevention of surgical complications associated with small animal abdominal herniorrhaphy. Prob Vet Med 1:254, 1989.

7. Weinstein MJ, Pavletic MM, Boudrieau RJ, Engler SJ: Cranial sartorius muscle flap in the dog. Vet Surg 184:286-291, 1989.

8. Philiber D, Fowler JD: Use of muscle flaps in reconstructive surgery. Comp Contin Ed Pract Vet 18:395-405, 1996.

Section H

Integument

Chapter 39

Feline Onychectomy

Jonathan M. Miller and Don R. Waldron

Introduction

Onychectomy is the surgical removal of the distal (third) digital phalanx (P3). This procedure is performed frequently in young cats as a primary surgery or at the time of gonadectomy. The forelimbs only (routinely) or all four paws (rarely) may be declawed however the latter requires the cat to be a totally indoors pet. Indications for onychectomy include destructive indoor scratching behavior, trauma, neoplasia, or infection. Onychectomy is estimated to be performed on at least 24% of all domestic cats in this country. The procedure has become controversial due to owner perceived postoperative pain, a relatively high rate of postoperative complications and anecdotal descriptions of negative behavioral side effects. Contrary to this belief, the scientific literature suggests that onychectomized cats ambulated normally by 9 days to 6 months postoperatively and declawing provided a protective effect against relinquishment to animal shelters which may result in euthanasia. Advances in perioperative analgesic protocols and refinement of surgical technique have improved the postoperative management of this procedure. Alternatives to declawing a cat with destructive scratching behaviors include repeated nail trimming, periodic application of plastic nail caps, behavioral training, or deep digital flexor tendonectomy.

Surgical Anatomy

The feline digit is composed of three phalanges. The third phalanx is comprised of an ungual crest which articulates with the second phalanx, and an ungual process which protrudes into the continually growing nail, also called the unguis. During onychectomy, the third phalanx is entirely or mostly removed. Paired dorsal elastic ligaments and axial and abaxial collateral ligaments span the joint space. Tendons of the common and lateral digital extensor muscles cross the dorsal surface of the 3rd to 5th digits. The deep digital flexor tendon attaches to the palmar flexor process portion of the ungual crest. Nail growth originates from the germinal epithelial tissue present in the ungual crest. This collection of dividing cells is located in the proximal and dorsal portion of the ungual crest, and if germinal epithelial tissue is incompletely removed claw regrowth can occur.

Anesthesia and Analgesia

Onychectomy requires general anesthesia. Adjunctive preoperative opioids and non-steroidal anti-inflammatory drugs have been shown to greatly improve postoperative comfort in cats. Buprenorphine (0.01 mg/kg intramuscularly) and application of a transdermal fentanyl patch (25 ug/hr) were shown to be the most effective opioids. Meloxicam (0.3 mg/kg subcutaneously) was proven more effective than butorphanol for pain control. Additionally, local anesthesia in the form of a ring block proximal to the paw is routinely performed. Bupivicaine (1 mg/kg) is distributed perineurally through a 25 gauge needle to selectively block nerve impulses in the sensory branches of the radial, median, and ulnar nerves (Figure 39-1). Bupivicaine has a 15 to 20 minute onset of action and lasts 6 to 8 hours.

Surgical Techniques

The most important component of any surgical technique for onychectomy is adequate removal of the third phalanx to avoid nail regrowth. Preparation of the paw aseptically is performed with surgical scrub and alcohol but without a need for clipping the hair. A tourniquet is applied for all but the laser technique to reduce intra-operative hemorrhage. Placement of the tourniquet distal to the elbow (proximal third of the antebrachium) is essential in preventing postoperative radial nerve dysfunction. For laser declaw, alcohol, due to its flammable nature, is avoided during surgical preparation and a tourniquet is not used.

Dissection Technique

With the cat in lateral recumbency, a #11 or 12 surgical blade is used to incise the skin along the distal ungual crest. Hemostatic forceps or Allis tissue forceps can be used to grasp the nail for manipulation. The third phalanx is extended and the skin overlying the P2-P3 articulation sharply incised. The ligamentous and tendonous attachments to the third phalanx are sharply transected using caution to not damage the digital pad (Figure 39-2). With proper technique, the smooth articular surface of the second phalanx should be easily visualized. Closure of the skin wound can be performed with small loosely tied absorbable suture or with tissue adhesive. When applying tissue adhesive (n-butyl cyanoacrylate), dried skin is compressed digitally in a medial to lateral direction and 1 to 3 drops are applied to the skin only. Subcutaneous application of adhesive will induce an inflammatory response that can be associated with postoperative draining tracts or persistent lameness.

Guillotine Technique

After tourniquet application and aseptic preparation, either a sterilized guillotine type (Resco) or scissors type (White) commercially available nail trimmer is used. The nail is grasped with forceps and the proximal cutting blade is placed between the ungual crest and the second phalanx. Care should be taken to avoid damage to the digital pad during cutting. A small portion of the palmar flexor process is often left with this method, but as long as the entire central and dorsal portions of the ungual crest are excised, nail regrowth rarely occurs. Skin closure is similar to the dissection technique.

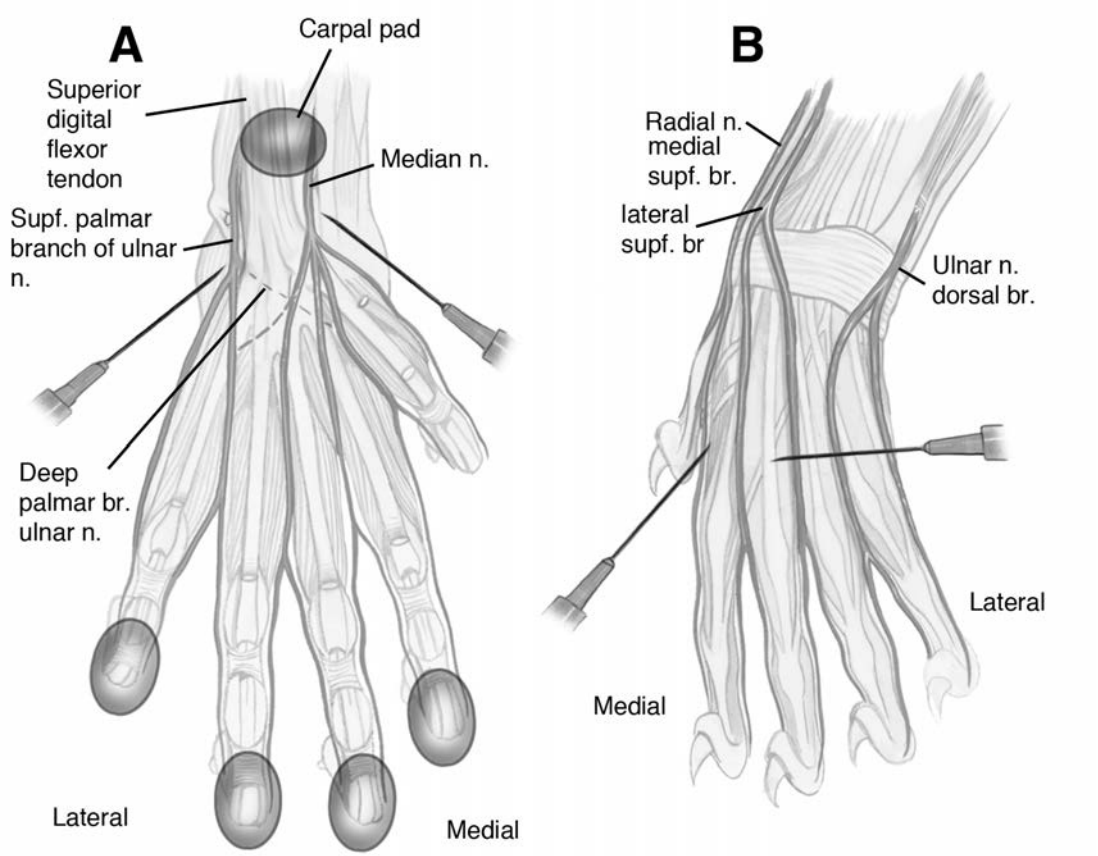


Figure 39-1. Note the anatomic location of needle placement for regional nerve block to the cat paw prior to forelimb declaw.

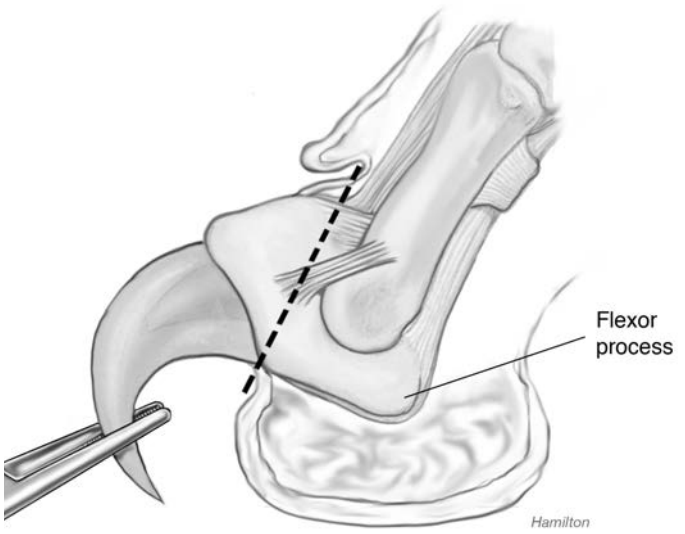


Figure 39-2. The anatomy of the feline digit is illustrated; note the flexor process of the third phalanx on the palmar surface extending proximally.

Laser Technique

Proposed benefits of laser onychectomy include reduced hemorrhage, decreased postoperative pain, and the reduced need for a tourniquet, skin closure, or postoperative bandaging. A CO_2 laser with a 0.4 to 0.8 mm tip set at 4 to 6 watts is used to perform onychectomy similar to the scalpel blade dissection technique. When performing laser surgery, appropriate planning and technique is required to prevent injury to the patient, surgeon, and other personnel. Protection of inspired oxygen in the endotracheal tube from combustion is accomplished by wrapping the tube with saline moistened gauze. Careful technique is required to protect the digital pad and the second phalanx from laser damage. The surgeon and any staff in the room should wear approved laser protective eyewear and facemasks, and a smoke evacuator should be utilized to minimize inhalation exposure of vapor. Any excessive char is wiped away before suture or tissue adhesive skin closure. Skin closure as with all declaw techniques is optional however less hemorrhage is seen postoperatively when closure is performed.

Postoperative Management and Complications

Following onychectomy, a light bandage is often applied for the first 12 to 24 hours during hospitalization. This consists of a dry 4x4 gauze sponge, kling, and self adhesive material placed to the proximal antebrachium. Hemorrhage following bandage removal is usually minimal, but may require longer term bandaging. Care must be taken when applying any bandage postoperatively to prevent ischemic injury to the foot. All bandages are removed prior to patient discharge from the hospital. Shredded paper or commercially available recycled newspaper litter is used for 7 to 10 days in the litter-box at home to minimize possible wound contamination. Pain should be managed by oral opioids (Buprenorphine), a fentanyl patch, and/or oral meloxicam or robenacoxib postoperatively. Lameness occurring postoperatively can be affected by the technique and pain management protocol selected but is usually self limiting and resolves in 1 to 2 weeks. One report of flexor tendon contracture lameness, occurring 6 to 12 weeks postoperatively, required tendon release and was thought to be

associated with excessive tissue trauma. Postoperative infections can be associated with subcutaneous tissue adhesive application and are best treated by opening the wound for drainage and allowing second intention healing with appropriate wound care. Nail regrowth, occurring in up to 10% of nail trimmer onychectomies, is often associated with draining tracts or fistula formation weeks to months after surgery. Radiographs will aid in the diagnosis, and treatment requires reoperation to remove the remaining ungual crest. Proper surgical technique and postoperative management will reduce the reported 24 to 50% complication rate associated with feline onychectomy.

Editor's Note: Management of postoperative pain is recommended for 7-10 days postoperatively. Repeated use of metacam in cats has been associated with acute renal failure and death. Metacam solution for injection is approved for one-time use in cats before surgery to control postoperative pain associated with orthopedic surgery, spays and neuters.

Selected Readings

Holmberg DL, Brisson BA. A prospective comparison of postoperative morbidity associated with the use of scalpel blades and lasers for onychectomy in cats. Can Vet J 2006;47:162-163.

Curcio K, Bidwell LA, Bohart GV, Hauptman JG. Evaluation of signs of postoperative pain and complications after forelimb onychectomy in cats receiving buprenorphine alone or with bupivacaine administered as a four-point regional nerve block. J Am Vet Med Assoc 2006;228:65-68.

Romans CW, Gordon WJ, Robinson DA, Evans R, Conzemius MG. Effect of postoperative analgesic protocol on limb function following onychectomy in cats. J Am Vet Med Assoc 2005;227:89-93.

Romans CW, Conzemius MG, Horstman CL, Gordon WJ, Evans RB. Use of pressure platform gait analysis in cats with and without bilateral onychectomy. Am J Vet Res 2004;65:1276-1278.

Young WP. Feline onychectomy and elective procedures. Vet Clin North Am Small Anim Pract 2002;32:601-619, vi-vii.

Mison MB, Bohart GH, Walshaw R, Winters CA, Hauptman JG. Use of carbon dioxide laser for onychectomy in cats. J Am Vet Med Assoc 2002;221:651-653.

Patronek GJ. Assessment of claims of short- and long-term complications associated with onychectomy in cats. J Am Vet Med Assoc 2001;219:932-937.

Tobias KS. Feline onychectomy at a teaching institution: a retrospective study of 163 cases. Vet Surg 1994;23:274-280.

Ringwood PB, Smith JA. Anesthesia case of the month. J Am Vet Med Assoc 2000;217:1633-1635.

Martinez S, Hauptman J, Walshaw R. Comparing two techniques for onychectomy in cats and two adhesives for wound closure. Vet Med 1993;88:516-525.

Carroll GL, Howe LB, Peterson KD. Analgesic efficacy of preoperative administration of meloxicam or butorphanol in onychectomized cats. J Am Vet Med Assoc 2005;226:913-919.

Gellasch KL, Kruse-Elliott KT, Osmond CS, Shih AN, Bjorling DE. Comparison of transdermal administration of fentanyl versus intramuscular administration of butorphanol for analgesia after onychectomy in cats. J Am Vet Med Assoc 2002;220:1020-1024.

Dobbins S, Brown NO, Shofer FS. Comparison of the effects of buprenorphine, oxymorphone hydrochloride, and ketoprofen for postoperative analgesia after onychectomy or onychectomy and sterilization in cats. J Am Anim Hosp Assoc 2002;38:507-514.

Cooper MA, Laverty PH, Soiderer EE. Bilateral flexor tendon contracture following onychectomy in 2 cats. Can Vet J 2005;46:244-246.

Chapter 40

Mammary Glands

Mastectomy

H. Jay Harvey and Jonathan M. Miller

Introduction

Mastectomy, the removal of varying amounts of mammary tissue, is the primary method for treating tumors of the mammary gland in dogs and cats. However, the amount of tissue to remove is a subject of some controversy. Cure rates for patients with malignant mammary disease are still low even after massive amounts of tissue have been removed. The biologic behavior of the tumor, not the extent of treatment, determines the eventual fate of the patient. Nonetheless, properly performed surgical treatment of mammary tumors can modify disease progression, prolong comfortable survival, and be curative in some instances.

Surgical Anatomy

Mammary glands in the dog and cat are modified sudoriferous skin glands with an apocrine compound lobuloalveolar structure. Mammary glands are arranged in two parallel paramedian rows from the axillary to the inguinal regions. The glands are surrounded by subcutaneous adipose tissue, which is scant in the thoracic region and abundant in the inguinal region.

Individual glands are discerned by the corresponding teat, although mammary tissue can be confluent between adjacent cranial and caudal glands. The midline separation between mammary chains is distinct. Glands are signified by name (cranial and caudal thoracic, cranial and caudal abdominal and inguinal) or by number (1 through 5 cranial to caudal). Dogs usually have five pairs of mammary glands, and cats have four, although the number can range from four to six in either species.

Thoracic glands adhere directly to the underlying pectoral muscles with little intervening fat or areolar connective tissue. Abdominal glands are loosely attached to the external fascia of the rectus abdominus muscle by connective tissue and fat. Inguinal glands are suspended from the body wall by an extension of the cutaneous trunci muscle. Blood is supplied to the thoracic glands by perforating branches of the internal thoracic artery, by cutaneous branches of intercostal arteries, and by the lateral thoracic artery. Cranial abdominal glands receive blood predominately from the cranial superficial epigastric artery. Caudal abdominal and inguinal glands are supplied by the caudal superficial epigastric artery and by perivulvar branches of the external pudendal artery. Veins parallel arteries, except for numerous veins that traverse the midline, which enlarge during lactation.

Lymphatic drainage of the mammary glands is subject to individual variation and also is influenced by the stage of lactation and by the presence of space-occupying masses.

Lymph generally flows from the cranial three pairs of mammary glands toward the axillary lymph nodes and from the caudal two pairs toward the inguinal lymph nodes. A lymphatic connection between the cranial and caudal abdominal glands is present in some bitches.

Mammary Gland Neoplasia: Incidence and Prognosis

Neoplasia is the major indication for mastectomy in dogs and cats. Mammary tumors are the most common type of neoplasia in dogs and the third most common type in cats. Mammary neoplasia affects middle-aged and older animals, with a median age of onset of 10 to 11 years.

Only about half of all canine mammary tumors are malignant, whereas most (86%) feline mammary tumors are malignant. Prognosis for both dogs and cats with malignant tumors is guarded to poor. Although length of survival is inversely correlated with the growth rate of the tumor, the extent of local infiltration, and the status of regional lymph nodes and lungs, the major statistically significant survival factor is tumor volume. Both dogs and cats with large (> 3 cm) malignant mammary tumors have significantly shorter survival times than those with small malignant tumors, emphasizing the importance of early diagnosis and treatment.

Treatment failure is represented by intractable local recurrence or, more commonly, by the development of metastatic disease. Because metastatic mammary cancer is found most frequently in the lungs, thoracic radiography is a common screening test before mastectomy. Dogs with mammary cancer affecting the caudal mammary glands, especially when the inguinal lymph nodes are palpably enlarged, should also be radiographically or ultrasonographically checked for enlarged sublumbar lymph nodes, because metastasis through sublumbar lymphatics is often detectable before the radiographic appearance of lung metastases. Enlarged lymph nodes should be excised at the time of surgery in dogs and the draining lymph nodes routinely removed in cats. Axillary lymph nodes are not routinely removed unless palpably enlarged while the inguinal lymph node is removed when the inguinal mammary gland (#5) is excised. Lymph node removal is regarded as a staging rather than therapeutic procedure in most dogs.

Mammary neoplasia can be prevented by ovariohysterectomy performed when the bitch or queen is young (i.e., before the first estrus). Ovariohysterectomy loses its protective effect after the 4th estrus in the canine. However, although estrogen, progesterone, and other receptors have been found in canine and feline mammary tumors, it is controversial as to whether ovariohysterectomy has any beneficial effect as a treatment for existing mammary neoplasia. The current recommendation is to spay the animal at the time of mammary tumor excision.

Selection of Surgical Procedure

The amount of mammary tissue to remove from a dog or cat with mammary neoplasia is influenced by several factors: the size, consistency, and location of the tumor; the size, age, and physiologic status of the patient; and the beliefs and prejudices of the surgeon. Unfortunately, subjective criteria still play a major role in the selection of a mastectomy procedure because objective data for choice are inconclusive.

The extent of tissue removal with various mastectomy procedures is illustrated in Figure 40-1. For the purposes of this chapter, these procedures are defined as follows:

Lumpectomy (nodulectomy): Removal of the tumor only with 1 to 2 cm of surrounding normal tissue. Generally, lumpectomy is used when a tumor is small, encapsulated, and noninvasive, thus requiring a minimum of surgical dissection for removal.

Partial mammectomy: Removal of the tumor and a surrounding margin of mammary tissue. This procedure usually is indicated for tumors that are small to moderate in size (up to 2 cm in diameter) and occupy only a portion of an individual gland. The tumor may be suspected to be invasive and may or may not have palpable distinct margins.

Simple mastectomy: Removal of the entire mammary gland containing the tumor.

Regional mastectomy (modified radical mastectomy): Removal of groups of mammary glands depending on which glands contain tumor. The rationale for regional mastectomy depends on the presumed anatomy of mammary gland lymphatic drainage and the assumption that mammary cancer spreads from one gland to another along lymphatic pathways, which are not altered by space-occupying masses.

Complete unilateral mastectomy (radical mastectomy): Removal of all ipsilateral mammary glands, intervening tissues, and regional lymphatics.

Complete bilateral mastectomy (bilateral radical mastectomy): Removal of both entire mammary chains, intervening tissues, and regional lymphatics. If performed, a 3 to 4 week interval between sides is recommended to reduce skin tension and postoperative complications.

Available data indicate that the extent of surgery had little influence on either the survival time or the rate of recurrence of mammary cancer in dogs. In other words, no evidence indicates that complete unilateral mastectomy (radical mastectomy) is any more beneficial for treating a 2 cm tumor in the fourth mammary gland of a dog than is a simple mastectomy. Until further data is available, selection of a surgical procedure in dogs is dictated by what is most efficient with the goal of attaining clean surgical margins by complete removal of the tumor. Good oncologic surgical principles still apply, however, regardless of the procedure used, invasive tumor should be widely resected with deep and centrifugal 2 cm en bloc margins of normal tissue with early ligation of blood vessels performed.

In cats, complete unilateral mastectomy is the surgical procedure of choice for all mammary tumors. This approach has been

recommended by veterinary oncologists because most feline mammary tumors are highly malignant. The 10 to 15% of cats with benign mammary nodules are overtreated by this philosophy.

Surgery is contraindicated for inflammatory carcinoma of the mammary gland. Inflammatory carcinoma of the mammary gland is a fulminant and aggressive malignant disease. Affected tissues are diffusely thickened, inflamed, painful, and frequently ulcerated. A space-occupying mammary mass may or may not be obvious. Commonly, the tissues are so diffusely thickened that discrete tumors are not apparent. The condition closely resembles severe mastitis and is frequently misdiagnosed as such. Surgery is unrewarding because it is virtually impossible to remove the affected tissues completely, and, more important, because most affected dogs also suffer from disseminated intravascular coagulation. Attempts at extensive surgical therapy often result in severe, intractable bleeding from the incision, deterioration of the patient over 12 to 24 hours, and death. Inflammatory mammary carcinoma is invariably fatal, usually within a month after clinical signs are obvious. Treatment is strictly palliative and consists of antiinflammatory drugs, analgesics, and antibiotics.

Surgical Techniques

Mastectomy procedures are performed similarly in cats and dogs, although the laxity of feline skin generally makes surgery easier in cats.

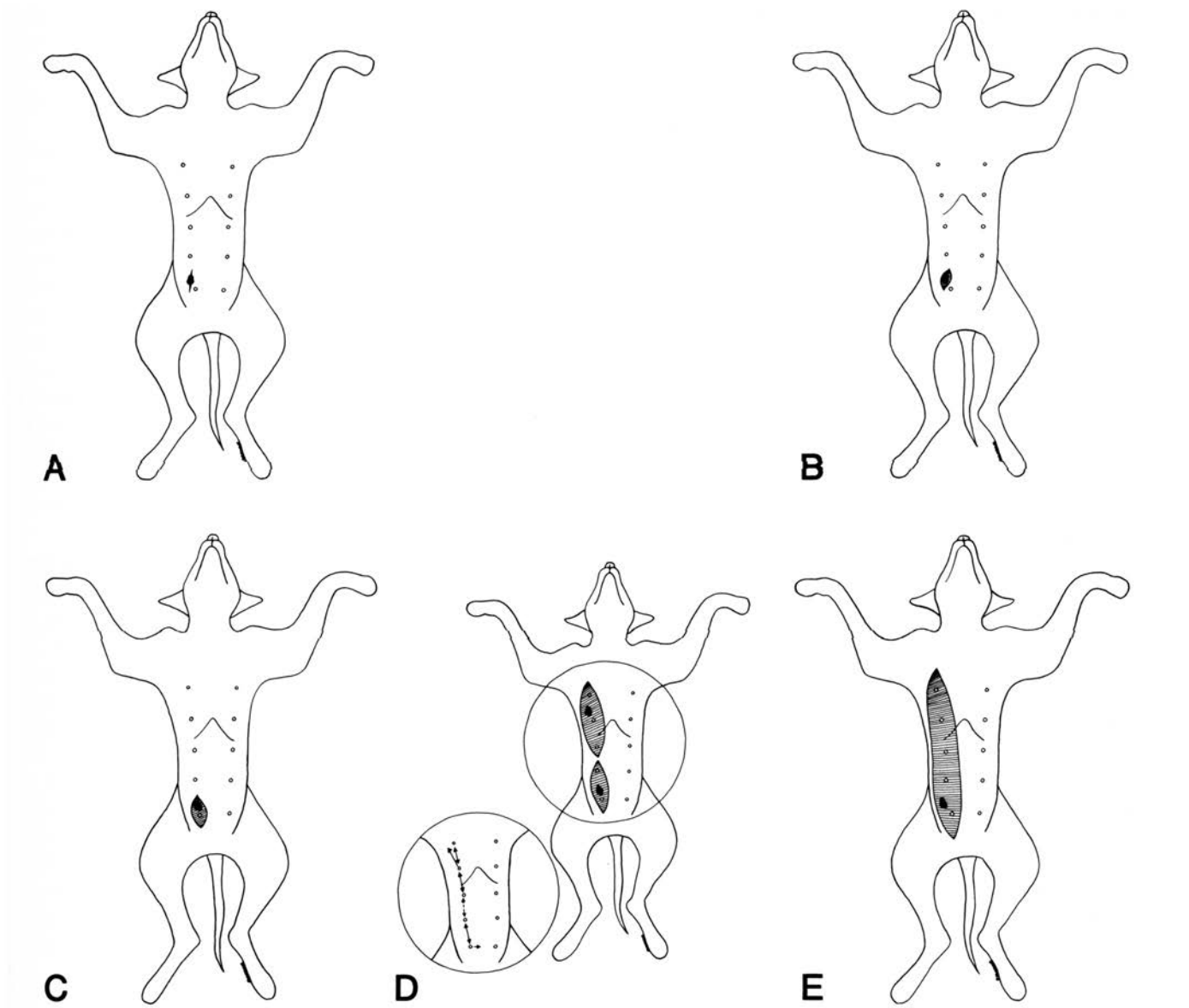


Figure 40-1. Comparison of extent of tissue removal with different mastectomy procedures. **A.** Lumpectomy. Skin incision is made directly over the tumor. **B.** Partial mastectomy. An elliptic skin incision is made, encompassing the tumor and a portion of the surrounding mammary tissue. **C.** An elliptic skin incision is made to encompass the gland that contains the tumor completely. **D.** Regional mastectomy. An elliptic skin incision is made to encompass the glands to be removed, as determined by the location of tumor and the presumed pathways of lymphatic drainage (inset). Generally, the first three glands are removed en bloc when tumor exists in any one of them; likewise, the last two glands are removed en bloc when tumor exists in either of them. Some authors recommend that the third gland be removed whenever the fourth and fifth are excised because of the "inconstant" lymphatic drainage between the third and fourth glands. **E.** Complete unilateral mastectomy. The skin incision encompasses all ipsilateral mammary glands. See the text for details of the dissection.

Lumpectomy

A lumpectomy is initiated by making a skin incision directly over the tumor. The mammary tissue overlying the tumor is bluntly separated. The periphery of the tumor is grasped with forceps, and the natural tissue planes adjacent to the isolated tumor are defined by blunt dissection with mosquito hemostats or by wiping the tissues away from the tumor with a sponge (sponge dissection). The tumor is removed, partially sectioned, and placed in 10% buffered formalin. After hemorrhage is controlled, the wound is closed by approximating mammary tissue with fine (4-0) absorbable suture. Skin is closed with suture of the surgeon's choice.

Partial Mammectomy

A liberal incision is made over the tumor. If the tumor contacts or is adherent to the skin or subcutaneous tissue (i.e., if the tumor is "fixed" to skin), an elliptic incision is made that encompasses both the tumor and the affected skin. An artificial plane of dissection is developed in normal mammary tissue surrounding the tumor. A liberal amount of tissue, often approaching one-third to one-half of the affected gland, is removed. Closure of the defect in the gland is by direct apposition of tissue if possible. Subcutaneous tissue apposition with 4-0 or 3-0 absorbable suture is performed to reduce tension on the skin closure. The skin is closed routinely.

Simple Mastectomy, Regional Mastectomy, and Complete Unilateral Mastectomy

The basic technique for simple mastectomy, regional mastectomy, and complete unilateral mastectomy is the same. All these procedures involve removal of the skin segment that encompasses the affected mammary gland or glands. Surgery is initiated by making an elliptic incision with 2 cm margins around the mammary gland or glands to be removed. The incision is extended sharply through the subcutaneous tissue to the body wall. In the thoracic region, the body wall is represented by the pectoral muscle and in the abdominal region by the external rectus fascia. A plane of dissection that allows the skin segment and associated mammary tissues to be cleanly stripped from the body wall is then established. The proper plane of dissection is deep to the adipose tissue and directly on the muscle fascia.

In the abdominal and inguinal regions, the glands are loosely adherent and can be stripped from the underlying fascia with a sponge (Figure 40-2A). In the thoracic region, the glands adhere to the underlying muscle, and the plane of dissection must be developed by a combination of sharp and blunt dissection with scissors (Figure 40-2B). The proper thoracic plane is represented by lacy but tough strands of fibrous connective tissue. Traction on the rostral portion of the skin segment facilitates dissection. Dissection proceeds from cranial to caudal without, in most cases, the need to damage underlying muscle. When removal of tissues is completed, intact muscle should be clearly visible in the thoracic region and rectus fascia should be seen in the abdominal region.

Invasion of underlying tissue by tumor, whether pectoral muscle in the thoracic region or rectus fascia in the abdominal region, requires en bloc resection of the affected body wall tissue with the tumor. In extreme cases, full-thickness resection of the body wall must be done to remove all visible tumor, even though body wall invasion by tumor is a grave prognostic sign, and even massive surgical resection is seldom curative.

Inguinal gland removal entails en bloc removal of the inguinal fat. Care must be taken to isolate and ligate the caudal superficial epigastric artery and vein, which emerge from the inguinal canal (Figure 40-3). The vaginal process, the finger-shaped protrusion of fat extending through the inguinal canal, along with the artery, vein, and vaginal ligament, may be bluntly separated from the inguinal fat and left behind or ligated and removed. Inguinal lymph nodes are removed along with the skin segment, mammae, and inguinal fat when the dissection is done correctly. Arteries and veins from the pudendal vessels enter the inguinal glands caudally from the tissues around the vulva and may require ligation or cauterization depending on their size.

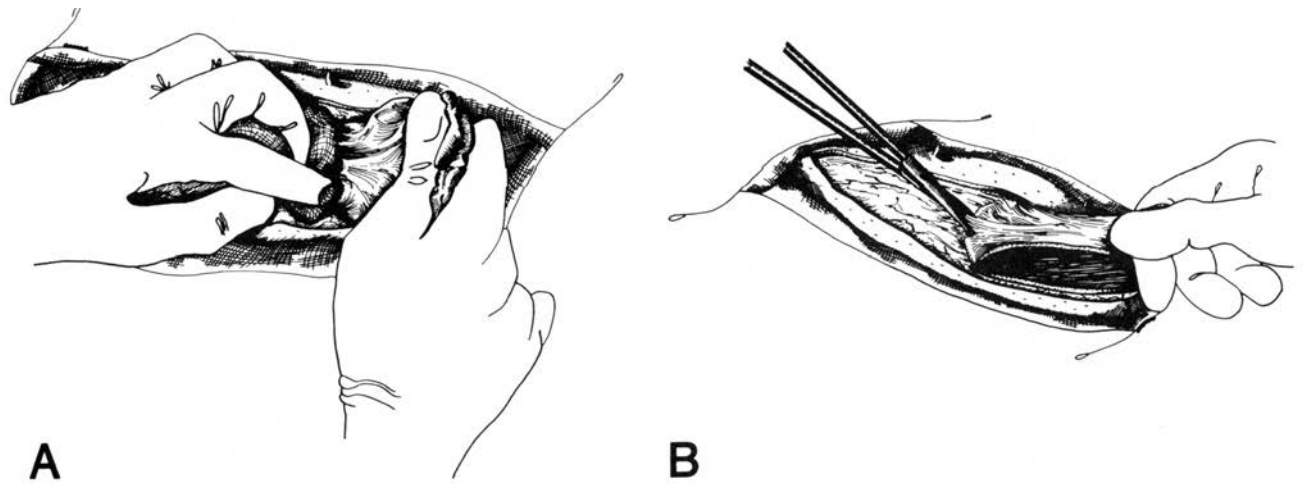


Figure 40-2. Developing a proper plane of dissection greatly facilitates simple, regional, and complete unilateral mastectomy procedures. **A.** In the abdominal and inguinal regions, the loosely adherent mammary glands can be stripped from the underlying fascia with a sponge. **B.** In the thoracic region, the glands adhere to the underlying muscle, so dissection with scissors is required.

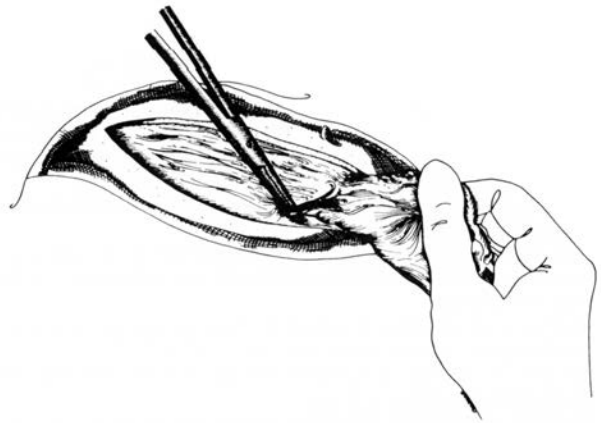


Figure 40-3. The superficial epigastric artery and vein emerge from the inguinal canal deep to the fifth mammary gland in the dog. When this gland is excised, these vessels must be isolated, clamped, divided, and ligated. The inguinal lymph node is contained with in the fat pad that is excised along with the gland.

Closure of the tissue defect left after a simple, regional, or complete unilateral mastectomy must account for the considerable dead space created. In most instances, drains, stents, bandages or reconstructive procedures are not necessary. Even large defects can be closed by initially apposing skin edges with subcutaneous absorbable suture. An interrupted pattern is preferred. The subcutaneous tissue may be tacked to the underlying body wall to reduce dead space. Skin is then closed according to the surgeon's preference. An interrupted cruciate suture pattern of 2-0 or 3-0 monofilament nylon can be placed quickly and distributes tension well (Figure 40-4). This pattern has the advantage of being an interrupted pattern, but one that spans a longer segment of incision per suture than a simple interrupted pattern. Regardless of the suture pattern used for skin closure, the ultimate success of skin apposition depends on placement of a proper subcutaneous suture line.

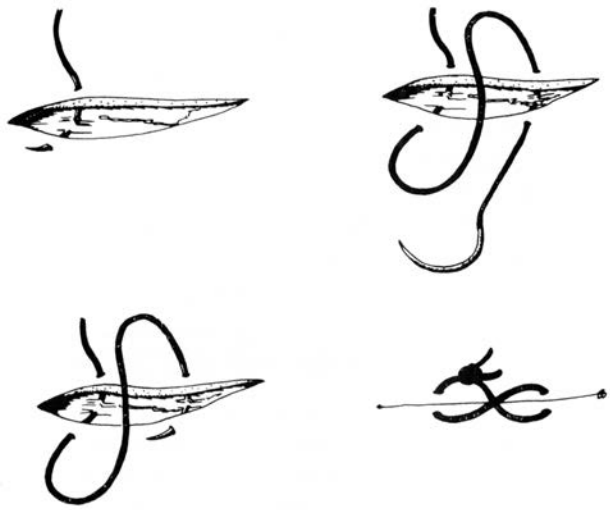


Figure 40-4. An interrupted cruciate suture pattern is recommended for closure of skin incisions with simple, regional, or complete unilateral mastectomies.

Postoperative Care and Complications

Postoperative complications associated with mastectomy include seroma formation, wound dehiscence, and edema of one or both rear limbs. Seroma formation is most common in the inguinal region and may be treated by the use of warm, moist compresses. Drainage by aspiration helps temporarily but increases the risk of infection. Wound dehiscences, if not extensive, are best left to heal by second intention. Extensive dehiscences may require debridement and delayed or secondary closure.

Rear limb edema may occur because of the surgical procedure or because of lymphatic invasion by the tumor. Removal of inguinal mammary tumors temporarily interrupts lymphatic drainage by removing lymphatic vessels and nodes. Moderate exercise, warm compresses, and time usually result in edema resolution. More ominous is the edema that results from tumor emboli in lymphatic vessels between the mammary glands and the sublumbar nodes and from tumor metastasis to sublumbar lymph nodes.

The latter situations are grave prognostic indications, and whereas edema may subside as potential lymphatic pathways become established, the chances for complete return to normal tissue fluid homeostasis are remote. Blockage of lymphatic vessels or nodes by tumor infiltration sometimes results in "retrograde metastasis." For example, inguinal tumor may extend distally in a string of nodules on the medial aspect of the hind leg.

Ovariohysterectomy, may improve survival time and may be desired at the time of mastectomy for other reasons. Spaying should performed before the mastectomy, taking care to not contaminate or introduce tumor cells into the abdomen. After the ovariohysterectomy and closure of the linea alba are completed, the skin incision forms part of the medial border of the mastectomy incision and is extended as needed to encompass the mammary gland or glands to be removed. Mammary tumors that extend across the midline should be removed before the ovariohysterectomy.

Suggested Readings

Alenza MDP, Tabanera E, Pena L. Inflammatory mammary carcinoma in dogs: 33 cases (1995-1999). J Am Vet Assoc 2001;219:1110-1114.

Allen SW, Mahaffey EA. Canine mammary neoplasia: Prognostic indicators and response to surgical therapy. J Am Anim Hosp Assoc 1989;25:540-546.

Hayes AA, Mooney S. Feline mammary tumors. Vet Clin North Am 1985;15:513-520.

Kristiansen VM, et al. Effect of ovariohysterectomy at the time of tumor removal in dogs with benign mammary tumors and hyperplastic lesions: A randomized controlled clinical trial. J Vet Intern Med 2013;27:935-942.

Morris JS, et al. Effect of ovariohysterectomy in bitches with mammary neoplasms. Vet Rec 1998;142:656-658.

Overley B, et al. Case-control study of hormonal influences on the development of feline mammary gland carcinoma. Proc Vet Cancer Soc 2002:36.

Rutteman GR, Withrow SJ, MacEwen EG. Tumors of the mammary gland. In:Withrow SJ, MacEwen EG, eds. Small animal clinical oncology. 3rd

ed. Philadelphia: WB Saunders, 2001:455-477.

Philibert JC, et al. Influence of host factors on survival in dogs with malignant mammary gland tumors. J Vet Intern Med 2003;17:102-106.

Sorenmo KU. Canine mammary gland tumors. Vet Clin North Am 2003;33:573-596.

Sorenmo KU, Shofer FS, Goldschmidt MH. Effect of spaying and timing of spaying on survival of dogs with mammary carcinoma. J Vet Intern Med 2000;14:266-270.

Viste JR, et al. Feline mammary adenocarcinoma: tumor size as a prognostic indicator. Can Vet J 2002;43:33-37.

Waldron DR. Diagnosis and surgical management of mammary neoplasia in dogs and cats. Vet Med 2001:943-948.

Yamagami T, et al. Influence of ovariectomy at the time of mastectomy on the prognosis for canine malignant mammary tumours. J Small Anim Pract 1996;37:462-464.

Chapter 41

Skin Grafting and Reconstruction Techniques

Skin Grafting Techniques

Michael M. Pavletic

In general, the simplest closure techniques are considered for problematic skin wounds, provided that the closure provides the appropriate durability and restores reasonable function to the area. Primary closure by apposition of skin margins normally is the simplest skin closure technique. Tension relieving techniques can be used to facilitate primary closure. In some cases, healing by contraction and epithelization is a practical option for wound closure, provided that this physiologic process can achieve the desired results in a timely fashion. There are occasions where open wound management can be more expensive than other surgical closure options. Skin stretchers, simple skin flaps, skin grafts, and axial pattern flaps are additional options for closing more challenging skin defects.

Anatomic Considerations

Preserving circulation is key to skin survival in wound management and closure. Direct cutaneous vessels are the primary vascular channels to the interconnecting cutaneous vascular network: the deep or subdermal plexus; middle or cutaneous plexus; and the superficial or subpapillary plexus (Figure 41-1). The elastic direct cutaneous arteries travel parallel to the overlying skin surface: they arborize to supply blood to the major capillary network, the subdermal plexus.[1,2]

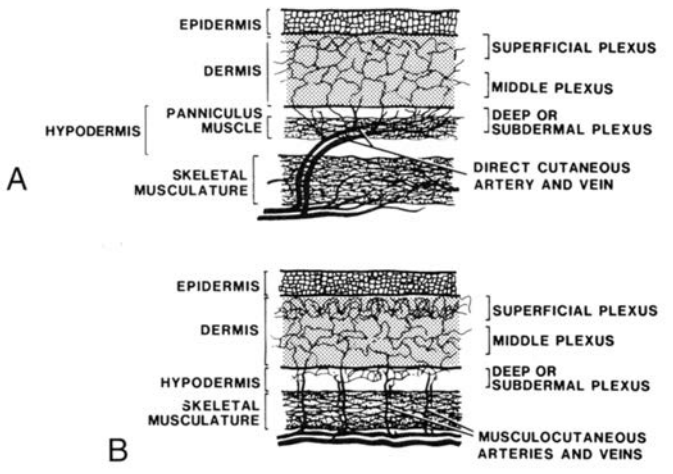


Figure 41-1. A. Cutaneous circulation in the dog and cat. **B.** Human cutaneous circulation. The subdermal plexus is formed and supplied by terminal branches of direct cutaneous vessels at the level of the panniculus muscle in the dog and cat. Note the parallel relationship of the direct cutaneous vessels to the overlying skin in the dog and cat, in contrast to the perpendicular orientation of musculocutaneous vessels in the human. (From Pavletic MM. The integument. In: Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1980.)

The direct cutaneous vessels and subdermal plexus reside in the hypodermal tissue layer beneath the dermis. Both are closely associated with the panniculus muscle layer, in areas where this cutaneous muscle layer exists. The major panniculus muscles include the cutaneous trunci, platysma, sphincter coli superficialis, and supramammarius muscles. This close relationship can be exploited to help preserve skin circulation during surgery.[1,2]

Undermining Skin

Undermining skin is normally performed to facilitate the mobilization of the skin for wound closure and skin flap elevation. The following points should be considered to help preserve circulation to the skin:

1. Undermine skin below the panniculus muscle layer when present, to preserve the subdermal plexus and associated direct cutaneous vessels supplying the overlying skin.
2. Undermine skin, lacking a panniculus muscle layer (eg. middle, distal portions of the extremities) in the loose areolar fascial plane below the dermis.
3. Preserve direct cutaneous vessels encountered during undermining of the skin, if possible.
4. Elevate skin closely associated with an underlying muscle by including a portion of the outer muscle fascia with the dermis to preserve the subdermal plexus.
5. If possible, avoid or minimize the surgical manipulation of skin recently traumatized until circulation improves, as noted by the resolution of contusions, edema, and infection.

Avoid direct injury to the subdermal plexus by using atraumatic surgical technique. Sharp scalpel blades should be used to incise skin; avoid cutting skin with scissors. Skin hooks, stay sutures, Brown Adson forceps and DeBakey forceps can be used to manipulate the skin; avoid crushing instruments, including the use of Allis tissue forceps.[2-5]

Technique Selection

Wound size and location usually dictates the technique(s) that should be considered for closure. The local availability of a loose, elastic skin will help determine if simpler closure techniques can be considered in a given case. Other potential sources of donor skin are then assessed. The primary goal is to restore function to the injured area, preferably with reasonable cosmetic results.[5]

Lower extremity wounds are particularly problematic due to the relative lack of circumferential skin. Wounds less than 90° circumference may close by second intention in some cases; the probability of contraction and epithelization decreases as the circumference of the defect increases.[5]

Clearly wounds approaching half or more of the limb's circumference require closure with a skin graft or flap. By contrast, the trunk has variable amounts of loose, elastic skin to facilitate wound closure by second intention, skin advancement, flaps, or simply by applying skin stretchers. In many cases, skin stretchers are simpler and more effective to use for closure of moderate to large skin defects.[5]

Although open wound management may be both practical and economical in managing many wounds, costs can add up especially in those cases where contraction and epithelization is slow. Bandages, dressings, topical agents, and recheck appointments cumulatively can approach or exceed surgical closure. Periodic reassessment of the wound, and clear communication can eliminate misunderstandings that occasionally occur with the pet owner. Flap and/or graft closure may be reserved for those wounds where 2nd intention healing fails to make significant gains in wound closure.[5]

Unlike humans, skin flaps generally are considered a more practical method to close problematic wounds in veterinary medicine; in human reconstructive surgery skin grafts are often preferred. Skin grafts are most useful for the more problematic lower extremity defects, and large surface area wounds where flaps and skin stretchers are not practical options.[5]

Skin Flaps (Pedicle Grafts)

A skin flap is an elevated portion of skin and subcutaneous tissue with a vascular attachment to the body. The base or pedicle of the flap may be a cutaneous attachment (with its intact capillary network), or an "island" segment of skin tethered by a single direct cutaneous artery or vein. Flaps also may be elevated with an underlying muscle which provides a source of circulation though interconnecting vascular channels: they are termed myocutaneous or musculocutaneous flaps.[3,5]

Skin flaps are particularly useful in small animals, allowing the veterinarian to utilize local or regional loose skin for closure of problematic wounds. They can be transplanted into areas devoid of circulation, unlike skin grafts which rely on revascularization from underlying healthy vascularized tissues for survival. Because the complete dermis and hypodermis are present, skin flaps have excellent durability and hair growth. Properly developed and transferred, skin flaps do not require the more elaborate bandage protection and immobilization needed for skin graft survival.[3,5]

Pedicle grafts can be classified according to their (1) type of circulation; (2) location in relation to the recipient (wound) bed; and (3) tissue composition (eg., myocutaneous flaps, compound/composite flaps). Most skin flaps are based on the subdermal plexus circulation *(subdermal plexus flap)* (Figure 41-2) incorporation of a direct cutaneous artery and vein results in the formation of an axial pattern flap (Figure 41-3). A variation of the axial pattern flap is the *island arterial flap*, in which the entire skin flap is detached from the body, but tethered by a paired direct cutaneous artery and vein (Figure 41-4). Because of their excellent blood supply, axial pattern flaps can be developed of greater dimensions for closing sizeable skin wounds.[3,5-7]

Flaps elevated immediately adjacent to the recipient bed are termed *local flaps*, whereas flaps elevated from a more remote location are termed *distant flaps*. Flaps made adjacent to a wound are technically easier to perform, provided that sufficient skin is available for their development. Distant flaps normally are more difficult to elevate and transfer. Historically distant flaps have been classified according to the method of transferring the skin to a given wound, including: delayed tube flap (indirect

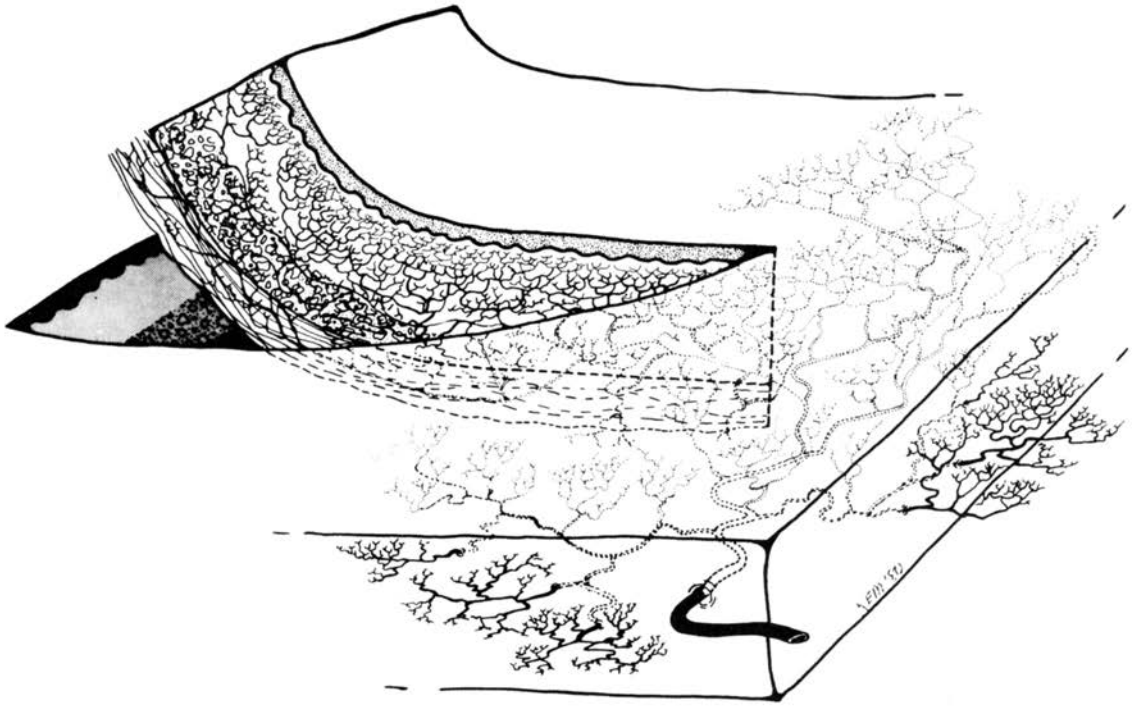


Figure 41-2. The subdermal plexus flap in the dog and cat. This flap is analogous to the random or cutaneous flap in human patients. The flap is nourished by the subdermal plexus and attenuated branches of the direct cutaneous vessels some distance away. (From Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res I98I;42:39I.)

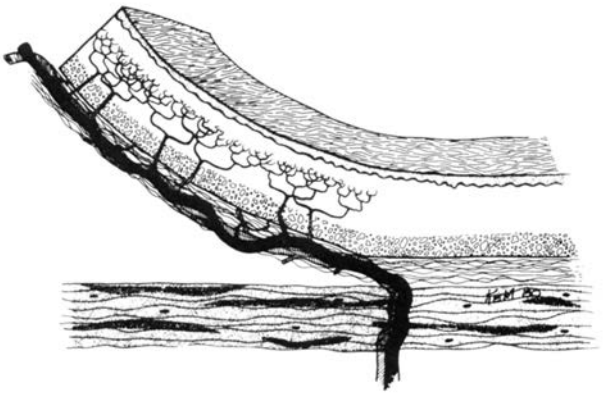


Figure 41-3. Axial pattern flap (arterial pedicle graft) in the dog and cat. A flap created over the direct cutaneous vessels has an intact blood supply capable of supporting a flap of considerable size. An axial pattern flap in humans is similar, with the exception of their poorly developed panniculus muscle. (From Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res I98I;42:39I.)

flap); elevation of the affected limb beneath a flap created on the trunk (direct flap). Axial pattern flaps have largely precluded the routine use of these more labor-intensive distant flap techniques. Similarly, most distal extremity wounds are better managed with skin grafts.[3,5-9]

Flaps need not be exclusively comprised of skin or mucosa alone. As noted above, skin flaps also can be elevated with an underlying muscle segment, creating a myocutaneous flap (Figure 41-5). Flaps comprised of two or more tissues are called *compound* or *composite flaps*. Muscle, bone and cartilage also may be included in these flaps.[3,5,10] For example, a full-thickness labial flap is comprised of mucosa, skin, and a central musculofascial layer. Oral composite flaps are useful for oral and nasal reconstructive surgery. However, these more specialized flap techniques are less commonly used compared to skin flaps and grafts for wound closure.[5]

General Principles of Flap Development

The wound size, location, shape, and condition dictate the technique(s) required to close the defect. In general, surgeons try to used the simplest, most direct technique to close the wound and restore function to the area.[3,5]

The elastic properties of the skin are assessed adjacent to the wound. Ideal donor areas have ample skin available to elevate a flap and close the donor bed under minimal tension. The scrotum also has been used to close adjacent wounds by flap advancement or rotation into the wound.[11] There are occasions where wound closure to protect an important anatomic structure may take precedent over creating a donor defect that cannot be closed after transposing the flap.[5]

The size of the wound will dictate the size of the skin flap required to close most, if not all of the defect. In some cases, partial wound closure with a skin flap may be sufficient to successfully close the recipient bed, with the assistance of 2nd intention healing for the remaining portion of the area. If there is insufficient healthy skin available for local flap development, axial pattern flaps, skin grafts, and skin stretching options are considered.[5]

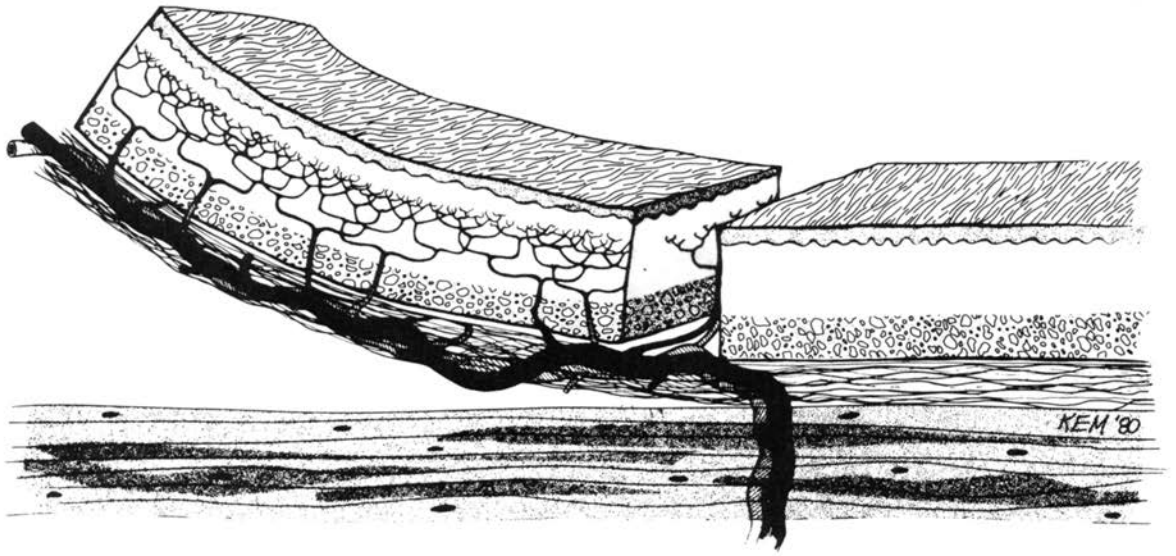


Figure 41-4. Island arterial flap (island axial pattern flap) in the dog. The graft is nourished solely by the direct cutaneous artery and vein. Island flaps have greater mobility than axial pattern flaps. Vessels have the potential to be severed and reanastomosed with microvascular surgery at a distant recipient site. (From Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res 1981;42:391.)

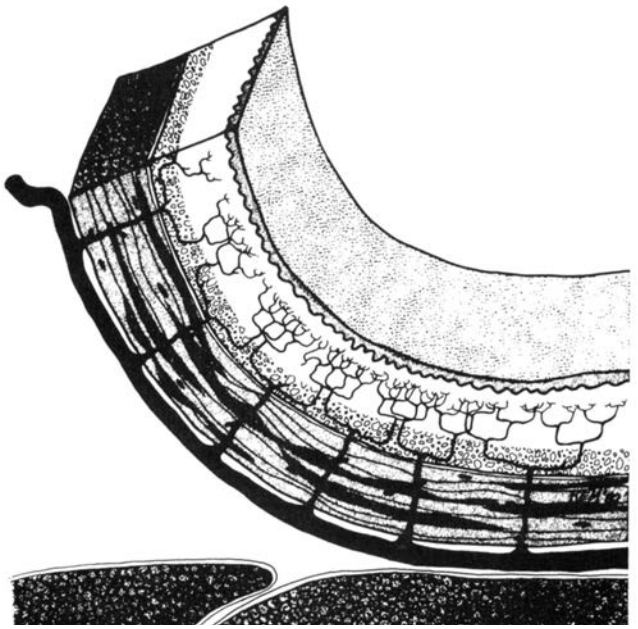


Figure 41-5. Myocutaneous flap in a human patient. The skin is nourished by musculocutaneous vessels, which receive circulation from the intact skeletal muscle vasculature. (From Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res 1981:42:391.)

Flap orientation is considered both for the relative ease of transference and the positioning of the pedicle for optimal circulation. Factors that help preserve circulation to a flap include: (1) the base of the flap should be equal to or slightly wider than the uniform width of the flap (island arterial flaps are an exception); (2) the flap length should be kept to the *minimum* required to close the wound without undue tension. However, simply increasing the width of a flap does not increase the total length of survival, unless direct cutaneous vessels are incorporated into the pedicle.

It is preferable to orient a subdermal plexus flap's base in the direction of a direct cutaneous artery/vein if possible. With few exceptions, necrosis associated with a skin flap is the result of insufficient circulation to sustain the tissue.[3,5]

Wound (Recipient Bed) Preparation

The recipient bed should be free of debris, necrotic tissue, and infection prior to closure. Unlike free grafts, skin flaps can survive over defects which have little or no circulation. Chronic granulation tissue can be resected at the time of flap closure. In some cases, the fibrotic and contaminated tissue can be removed, allowing for a healthy granulation bed to form within 3 to 5 days, thereby creating a more suitable wound surface for flap application. The epithelialized wound borders also are removed, thereby enabling the surgeon to close the defect completely with the skin flap.[3,5] Chronic radiation beds can be problematic to close, as a result of a dramatic decline in circulation over time. Skin flaps, muscle flaps, and myocutaneous flaps are options to close these wounds, provided that the vascular pedicle is preserved.[5]

Surgical Techniques

Local Flaps

Local flaps remain as one of the most simple and practical methods of closing small to moderate sized problematic wounds. Their effective use requires loose, elastic skin adjacent to the wound as a donor source for flap development. Local flaps normally are based on the subdermal plexus circulation. As noted, flaps must be kept as short as possible to help assure that perfusion can reach the terminal end of the flap. Local flaps are broadly classified as advancement flaps or rotating flaps. Local flaps can be developed in most body regions, although their use is somewhat limited in the lower extremity regions. The axillary and inguinal skin folds can be used in a similar fashion.[12,13] The following are the most useful local flaps to consider on a routine basis.[3,5]

Single-Pedicle Advancement Flap

The single-pedicle advancement flap (sliding flap) is simple in design and execution. The width of the flap approximates the width of the defect. Their effective use requires the flap to advance or stretch directly into the defect. The advanced flap simultaneously closes both the donor and recipient beds.[3,5]

To create a single-pedicle advancement flap, two skin incisions equal to the width of the wound are made in a staged or incremental fashion. In general, it is useful to have the two incisions slightly diverge to assure that the base of the flap is not inadvertently created too narrow thereby compromising circulation. The distant edge of the flap, bordering the wound is gently grasped, elevated, and the flap undermined. The process is continued until the flap stretches (advances) over the recipient bed. In most dogs and cats, 3-0 monofilament suture material is used to secure the flap (Figure 41-6).[5]

As noted, the length of the flap should be kept to the minimum in order to close the wound without excessive tension. Two shorter single-pedicle advancement flaps, on opposing sides of the wound, can be used to close longer defects. Termed "H-Plasty" two shorter flaps may close the wound without resorting to a single, longer advancement flap (Figure 41-7).[5]

The primary problem associated with advancement flaps is their reliance on stretching over the wound. There is a tendency for elastic retraction by the collagen fibers in the flap's dermis. This can contribute to postoperative distortion in some clinical situations. For example, advancement flaps, used to close problematic eyelid wounds, occasionally will distort the lid margin resulting in an unsatisfactory result both cosmetically and functionally. Under these circumstances, a 90° transposition flap should be considered, since this rotating flap closes wounds by "donating" additional skin to the immediate area.[3,5]

Bipedicle Advancement Flap

A bipedicle advancement flap is created by making two parallel incisions and undermining the skin segment: the flap is advanced at a right angle to its long axis. Bipedicle flaps are usually considered for closing adjacent elongated wounds. Although circulation is derived from two pedicles, long release incisions may result in a more centrally located "ischemic zone" with necrosis. If sufficient skin is present, the donor area can be closed (Figure 41-8).[3,5]

The release or relaxing incision in design and execution is a bipedicle advancement flap. Release incisions are used to reduce tension on an adjacent incision. Used in this fashion, the release incision is left open to heal by second intention. Release incisions may be little more than 1 or 2 centimeter "stab wounds" or extended several centimeters to close a problematic skin wound. As a general rule release incisions are no closer than 3 to 5 centimeters from incision.[5]

Transposition Flap

A transposition flap is a rectangular pedicle graft that pivots into position. Normally transposition flaps are rotated at a 45° to 90° angle in relation to the long axis of the skin defect. Flaps can be transposed at an angle greater than 90° although the flap length will shorten with this greater arc of rotation. One border of the flap generally contacts the wound border (Figure 41-9). Transposition flaps can be developed in most body regions, although their size is somewhat limited in the mid- to lower extremities.[5]

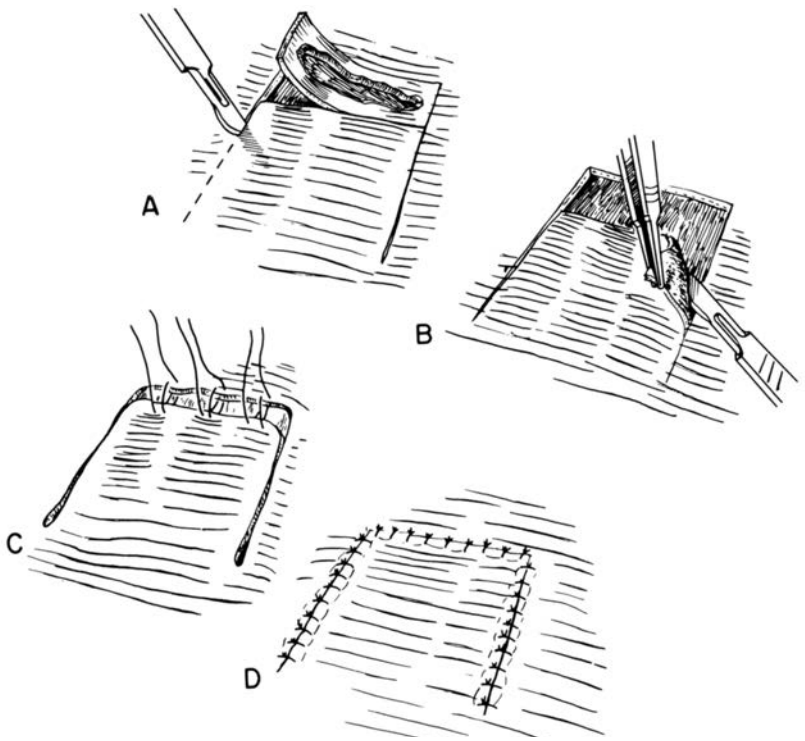


Figure 41-6. Single-pedicle advancement flap. **A.** Removal of skin lesions and outline of intended flap incisions. **B.** The flap is lengthened and undermined enough to allow for closure without excessive flap tension. **C.** Preplacement of tension sutures may aid in flap alignment. **D.** Closure.

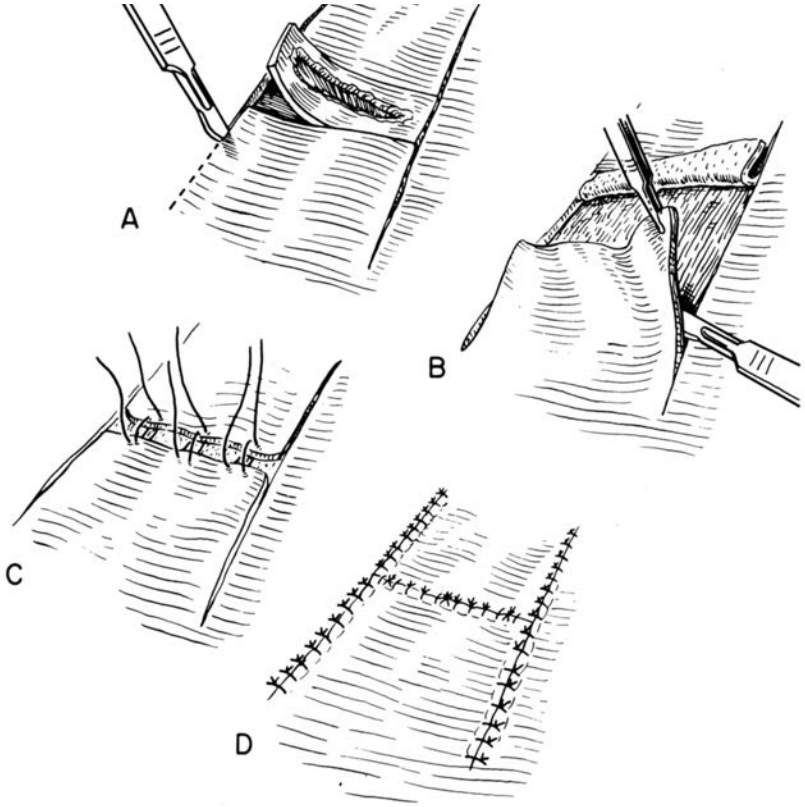


Figure 41-7. Sliding H-plasty. **A.** Removal of lesion and outline of the flaps on both sides of the defect. **B.** Undermining of both flaps. **C.** Alignment. **D**. Closure.



Figure 41-8. Bipedicle advancement flap. **A**. The flap width generally equals the width of the defect. **B.** The secondary defect (donor bed) is closed by direct apposition. (Redrawn from Grabb WC, Myers MB. Skin flaps. Boston: Little, Brown, 1975.)

Flap width approximates the width of the "rectangular" shaped defect; the flap length is measured from the *pivot point* of the flap base to the most distant point of the defect (Figure 41-10). To reduce tension, a stab or release incision may be created along the line of greatest tension. Alternatively, a release incision can be created in the skin adjacent to the defect, thereby eliminating the need to incise the flap. In practice, I will measure flaps with the above dimensions. In many cases, I will shorten the calculated length of the flap if possible, thereby improving the chance that reasonable perfusion can nourish the terminal flap border.[3,5]

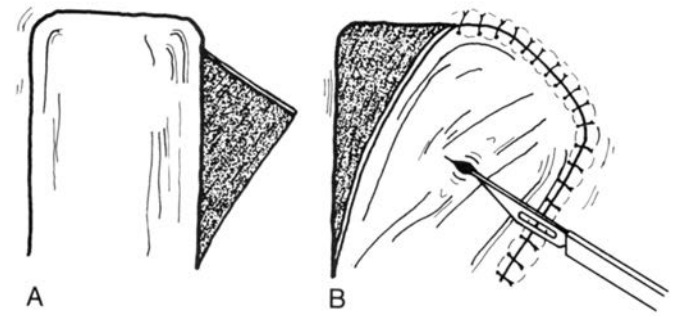


Figure 41-9. A and **B.** When creating a transposition flap, adjustment should be made to allow for the length loss caused by rotation of the flap. A stab incision made over the line of greatest tension can be used to relieve any excessive tension developed on transfer. The secondary defect can be closed by undermining and direct suture closure. (Redrawn from Grabb WC, Myers MB. Skin flaps. Boston: Little, Brown, 1975.)

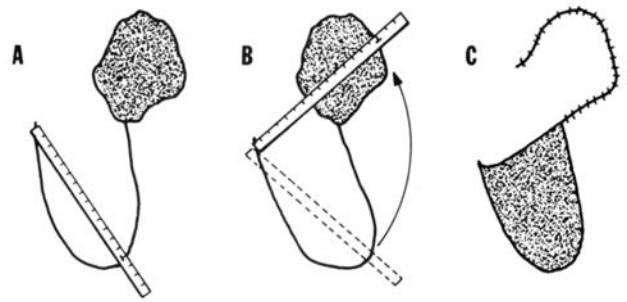


Figure 41-10. Transposition flap. **A.** Removal of defect and outline of the intended flap incision. **B.** Rotation and alignment of flap. **C.** Closure. The ruler measurement from the pivot point to the tip of the flap must equal the distance between the pivot point and the most distant point of the defect (recipient bed). The secondary defect is sutured closed after local undermining.

Z-Plasty

Z-plasty, by design, is a variation of the transposition skin flap. A "Z" shaped incision is created with the central limb of the "Z" placed parallel to, and overlying a problematic tension band. When each flap is transposed into their opposing donor beds, wound closure is achieved while modestly reducing tension in the immediate area. In veterinary medicine, Z-plasty is primarily used to reduce incisional tension or lengthen a restrictive scar band. In humans, Z-plasties (and its variation, W-Plasty) are used to cosmetically mask linear scars.[5] Use of multiple small z-plasties is not considered very effective for lengthening restrictive scars.

The basic design employed is creating a Z-shaped incision at 60° angles to the central limb of the "Z." Each incision is equal in length. The key to understanding Zplasty is the following: the central limb is aligned parallel to, and overlying the "line of tension." The net gain in length theoretically is 75% of the length of the central limb, after each triangular flap is transposed in opposite directions. In practice, the net gain is closer to 50%. In figure 41-11, z-plasty is employed to lengthen a restrictive scar.

Similarly, this Z-plasty technique can be used to lengthen a local area of skin tension to facilitate incisional closure (for example, a portion of a skin incision, after tumor removal, cannot be closed due to regional skin tension). The incisional gap is determined in centimeters. To lengthen this line of tension, a Z-plasty incision 5-10 centimeters from the incision with the central limb of the "Z" aligned over the tension "band." For example, to obtain a 3 centimeter gain, the Z-plasty central limb is aligned to this zone of tension with each incision 6 centimeters long. The Z-plasty is created, the problematic incision in closed, and each triangular flap is sutured into their transposed position}.[5]

The author prefers skin stretchers, the 90° transposition flap, and release incisions to relieve skin tension. However, some surgeons find the Z-plasty useful and effective for reducing incisional tension as described above.

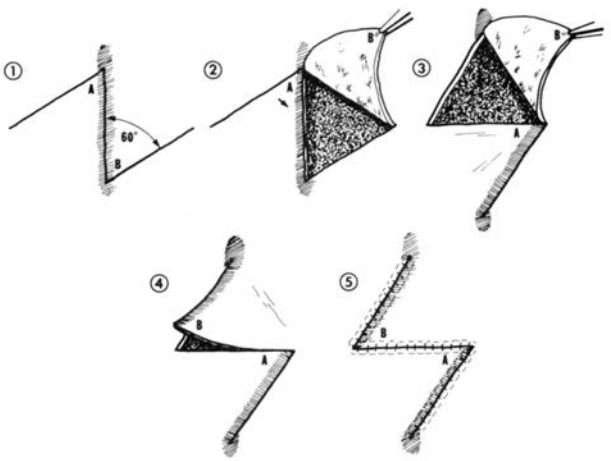


Figure 41-11. Z-plasty technique to lengthen a restrictive scar (shaded area): *(1)* a central incision is made over the scar, and two additional incisions equal in length to the central incision are created at a 60° angle forming a Z; *(2)* triangular flaps *A* and *B* are elevated and *(3, 4)* are transposed to their opposing bed; *(5)* the equilateral triangular flaps are sutured into place, resulting in a lengthening of the previously restricted area by 75%.

Axial Pattern Flaps

Axial pattern flaps receive a major source of their circulation by incorporating a direct cutaneous artery and vein into the flap's pedicle. As a result large skin flaps can be created with greater assurance of flap survival, provided the vessels are preserved.[3,5] There have been several papers describing the use of axial pattern flaps in the more recent veterinary literature describing the use of the lateral thoracic artery and superficial temporal artery in the dog and cat.[14-16] Other papers have described the use of various axial pattern flaps in wound closure with their clinical outcome.[17-20] Table 41-1, summarizes the major axial pattern flaps most commonly used in the dog and cat (Figures 41-12 and 41-13).[3,5,22-29]

Careful positioning of the patient is necessary for outlining each flap, using marking pens: skin distortion in relation to anatomic landmarks used for flap may result in failure to incorporate the vessels.[3,5] Axial pattern flaps can be rotated into a variety of wounds. On occasion the flap must cross over skin interposed between the donor and recipient sites. A "bridge incision" or partial tubing of the flap may be used to cross over this area. The flap may be shaped in the standard rectangular (peninsular design) shape or modified with a right angle (hockey-stick variation) for closure of wider or irregular problematic wounds.[5]

Axial pattern flaps may be converted to an island arterial flap, by cutting the cutanenous pedicle.[3,5] Tethered by the direct cutaneous artery and vein, the mobile island flap can be pivoted 180° into a defect. This technique is normally reserved to close large skin wounds that encroach on the normal base of the flap, thereby creating an island arterial flap by "default." Surprisingly, the survival area of island arterial flaps and axial pattern flaps is nearly identical.[24,30] A variation of this technique, the neovascular island flap has been reported in the dog for closure of small trophic ulcers of the paw.[31]

The thoracodorsal and caudal superficial epigastric axial pattern flaps are the most versatile in the dog and cat, based on their length and arc of rotation (See Figures 41-12 through 41-15). Nonetheless, the other axial pattern flaps provide a wide array of options for the veterinary surgeon to consider for closing wounds secondary to trauma or tumor removal.[5,26,32,33,34]

Compound and Composite Flaps

Although musculocutaneous (myocutaneous) flaps can be used to close skin defects, they may be better suited for closure of problematic wounds where muscle "padding" may be beneficial. The latissimus dorsi muscle, alone or as a myocutaneous flap, can be used for thoracic wall reconstruction. It also can be used to cover problematic elbow ulcers, providing padding over this bony prominence (Figures 41-14 and 41-15). The cutaneous trunci myocutaneous flap is better suited to exclusive wound closure, although the adjacent thoracodorsal axial pattern flap is better suited to closing the larger wounds within their respective arcs of rotation.[5]

Secondary or revascularized myocutaneous flaps can be created by grafting skin onto a muscle; once healed, the muscle is elevated

Table 41-1. Summary of Guidelines for Axial Pattern Flap Development

Artery	Anatomic Landmarks
Cervical cutaneous branch of the omocervical artery	Spine of the scapula Cranial edge of the scapula (cranial shoulder depression) Dogs in lateral recumbency, skin in natural position, thoracic limb placed in relaxed extension Vessel originates at location of the prescapular lymph node
Thoracodorsal artery	Spine of the scapula Caudal edge of the scapula (caudal shoulder depression) Dog in lateral recumbency, skin in natural position, thoracic limb in relaxed extension Vessel originates at caudal shoulder depression at a level parallel to the dorsal point of the acromion
Superficial brachial artery	Flexor surface of elbow Humeral shift Greater tubercle
Caudal superficial epigastric artery	Midline of abdomen Mammary teats Base of prepuce
Cranial epigastric artery	Hypogastric region Abdominal midline Mammary teats Base of prepuce
Deep circumflex iliac artery (dorsal branch)	Cranial edge of wing of ilium Great trochanter Dog in lateral recumbency, skin in natural position, pelvic limb in relaxed extension Vessel originates at a point cranioventral to wing of the ilium
Deep circumflex iliac artery (ventral branch)	Anatomic landmarks of flap base same as dorsal branch of deep circumflex iliac artery Shaft of femur
Genicular artery	Patella Tibial tuberosity Greater trochanter
Lateral caudal arteries (left and right)	Proximal third of tail length Transverse processes of vertebrae
Caudal auricular artery	Wing of atlas Spine of the scapula
Reverse saphenous conduit flap[b]	Inner thigh Tibial shaft

[a]**Major defects only.** [b]**Axial pattern flap variation.**

Reference Incisions	Potential Uses[a]
Caudal incision: Spine of the scapula in a dorsal direction *Cranial incision:* Parallel to the caudal incision equal to the distance between the scapular spine and cranial scapular edge (cranial shoulder depression) *Flap length:* Variable; contralateral scapulohumeral joint	Facial defects Ear reconstruction Cervical defect Shoulder defect Axillary defects
Cranial incision: Spine of the scapula in a dorsal direction *Caudal incision:* Parallel to the cranial incision equal to the distance between the scapular spine and caudal scapular edge (caudal shoulder depression) *Flap length:* Variable; can survive ventral to contralateral scapulohumeral joint	Thoracic defects Shoulder defects Forelimb defects Axillary defects
Incision lines: Flap base includes flexor surface of elbow, anterior third; lateral and medial incisions parallel humeral shaft; flap progressively tapered approaching greater tubercle *Flap length:* Variable, flap ends at level of greater tubercle	Antebrachial defects Elbow defects
Medial incision: Abdominal midline; in the male dog, the base of the prepuce included in the midline incision to preserve adjacent epigastric vasculature *Lateral incision:* Parallel to medial incision at an equal distance from the mammary teats *Flap length:* Variable: may include last four glands and adjacent skin	Flank defects Inner thigh defects Stifle area Perineal area Preputial area
Base of flap: Location in hypogastric region *Medial incision:* Abdominal midline *Lateral incision:* Parallel to midline incision at an equal distance from mammary teats *Flap length:* Glands 2, 3, 4; anterior to prepuce	Closure of wounds overlying sternal region
Caudal incision: Midway between edge of wing of ilium and greater trochanter *Cranial incision:* Parallel to caudal incision equal to the distance between caudal incision and cranial edge of iliac wing *Flap length:* Dorsal to contralateral flank fold	Thoracic defects Lateral abdominal wall defects Flank defects Lateromedial thigh defects Defects over the greater trochanter
Caudal incision: Extending distally, anterior to cranial border of femoral shaft *Cranial incision:* Parallel to caudal incision *Flap length:* Proximal to patella	Lateral abdominal wall defects Pelvic defects Sacral defects, as an island arterial flap
Base of the flap: 1 cm proximal to patella and 1.5 cm distal to tibial tuberosity (laterally) *Flap borders:* Extending caudodorsally parallel to the femoral shaft; flap terminates at base of greater trochanter	Lateral or medial aspect of the lower limb, from the stifle to the tibiotarsal joint
Incision: Dorsal or ventral midline skin incision, depending on intended flap usage; careful dissection along deep caudal fascia of the tail; vessels located lateral and slightly ventral to transverse processes, in proximal tail region; amputation of tail at third to fourth intervertebral space, preserving skin *Flap length:* Proximal third of tail length	Perineum, caudodorsal trunk
Base of flap: Palpable depression between lateral aspect of wing of atlas and vertical ear canal *Width of flap:* Central "third" of lateral cervical area over lateral aspect of wing of atlas *Flap length:* Up to spine of scapula (survival length variability)	Facial area Dorsum of head Ear
Proximal incision: Central third of inner thigh at level of patella; ligate saphenous artery and vein at level of femoral artery and vein *Cranial and caudal incisions:* Skin incisions extended distally in converging fashion, 0.5-1.0 cm cranial and caudal to cranial and caudal saphenous artery and medial saphenous vein; flap undermined beneath saphenous vasculature; ligate and divide peroneal artery and vein *Flap length:* Variable, base of flap at level of anastomosis of cranial branches of medial and lateral saphenous veins	Defects of tarsometatarsal regions Note: Use of flap requires intact collateral blood supply to lower extremity

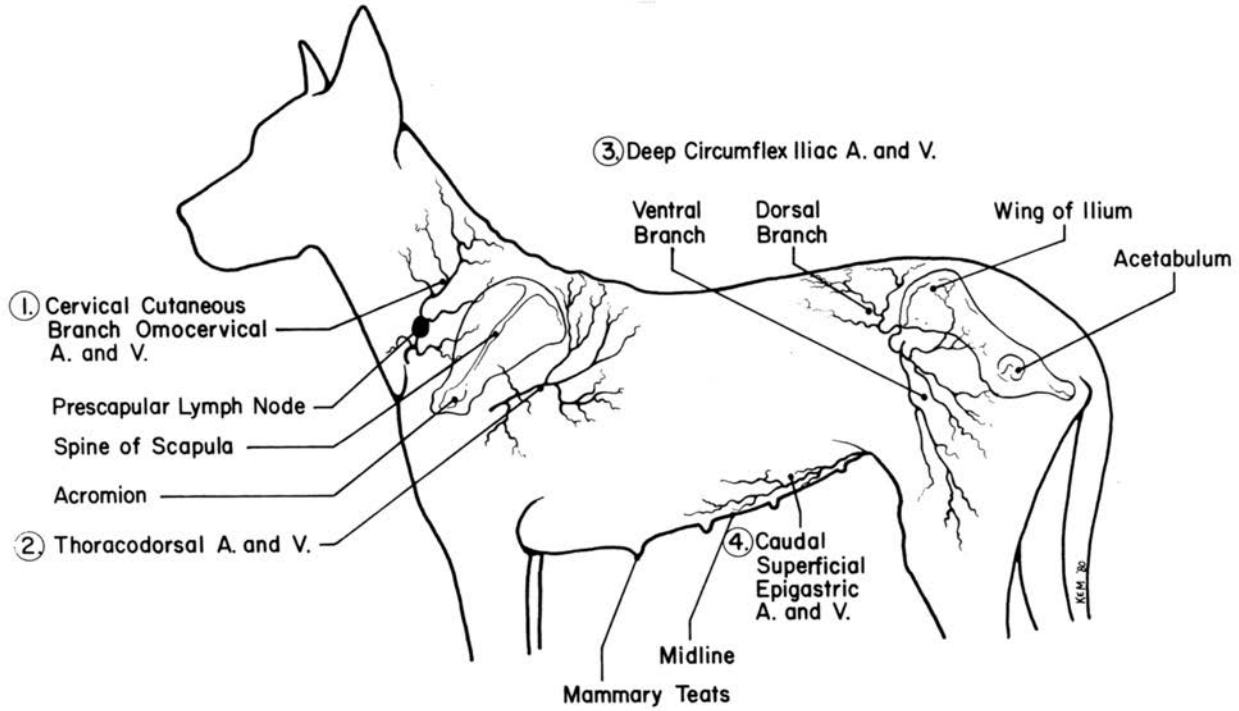


Figure 41-12. Four major cutaneous arteries are illustrated in relation to their anatomic landmarks *(1 to 4)*. (From Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res 1981 ;42:391.)

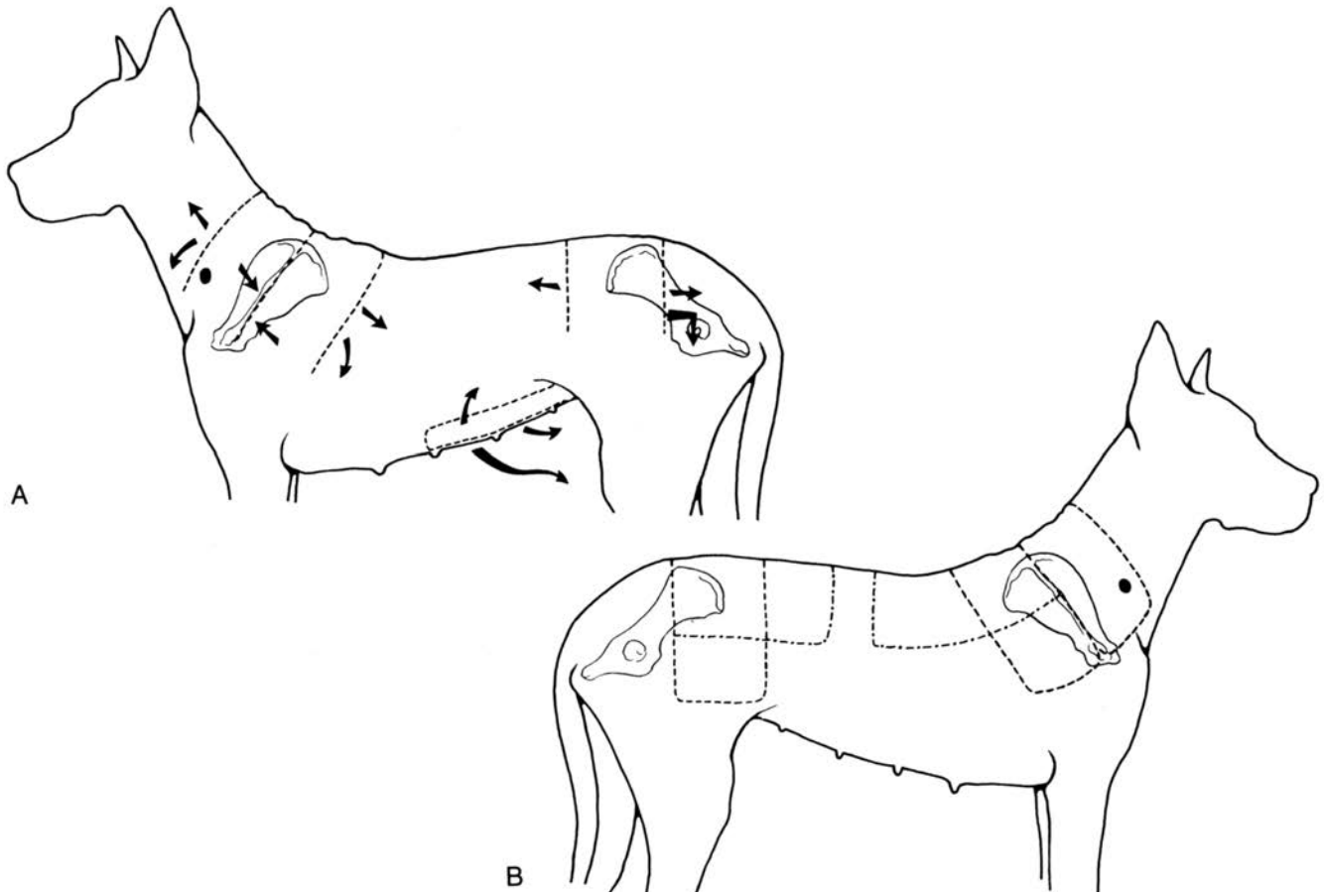


Figure 41-13. Reference lines for the omocervical, thoracodorsal, deep circumflex iliac, and caudal superficial epigastric axial pattern flaps. **A.** Standard peninsula flaps (dashed lines). **B.** L or hockey-stick (dashed and dotted lines) configuration. (From Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res 1981 ;42:391.)

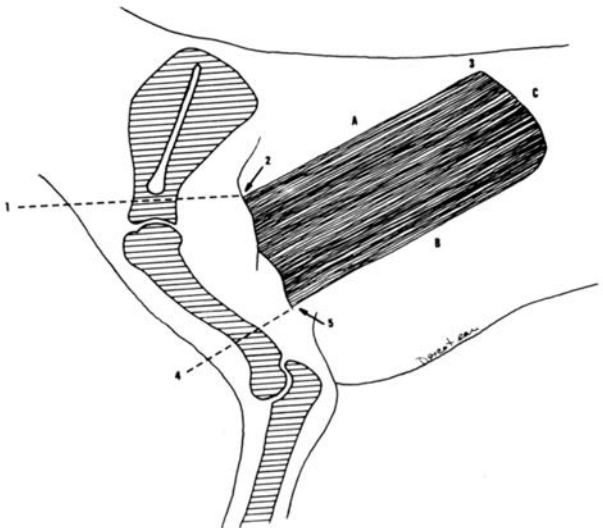


Figure 41-14. Anatomic landmarks for the latissimus dorsi and cutaneus trunci myocutaneous flaps: *(1)* ventral border of the acromion and *(2)* adjacent caudal border of the triceps muscle; *(3)* head of the last rib; *(4)* distal third of the humerus, which corresponds to the *(5)* axillary skin fold. The flap is drawn onto the skin with a marking pen by connecting landmarks *2* and *3* to form the dorsal flap border *(A)*. A second line is drawn from landmarks parallel to line A to the border of the last rib forming the lower flap border *(B)*. A third line *(C)* is drawn along the caudal border of the last rib, connecting lines *A* and *B*. (From Pavletic M, Kostolich M, Koblik P, et al. A comparison of the cutaneus trunci myocutaneous flap and latissimus dorsi myocutaneous flap in the dog. Vet Surg 1987; 16:283.)

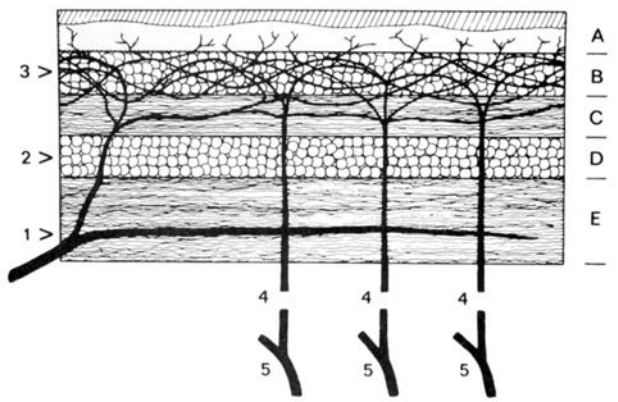


Figure 41-15. Vascular levels of the latissimus dorsi myocutaneous flap: (*A*) skin, (*B*) subcutaneous flap, (*C*) cutaneous trunci muscle, (*D*) fat, and (*E*) latissimus dorsi muscle. The vessels involved include: (*1*) the main branch of the thoracodorsal artery traveling within the latissimus dorsi muscle; (*2*) short perforating branches of the thoracodorsal artery to the cutaneus trunci muscle and overlying skin; (*3*) the subdermal (deep) plexus to the skin associated with the cutaneous trunci muscle; (*4*) the proximal lateral intercostal arteries divided during elevation of the latissimus dorsi muscle demonstrating anastomotic connections with the thoracodorsal artery intramuscularly; and (*5*) the intercostal arteries. (From Pavletic M, Kostolich M, Koblik P, et al. A comparison of the cutaneus trunci myocutaneous flap and latissimus dorsi myocutaneous flap in the dog. Vet Surg 1987; 16:283.)

and the composite flap transferred into a local defect as a flap or free flap [microvascular transfer].[35-40] Performed successfully under research conditions, they have limited clinical practicality over the flap and graft options already discussed.

Composite flaps have been successfully used for facial reconstruction, including the labial advancement flap, buccal rotation technique, labial lift-up bipedicled composite flap, and variations of these procedures.[5] In one case, a composite flap, using a damaged portion of the ear, was used to close a large adjacent defect.[41] A composite mucocutaneous subdermal plexus flap employing the upper lip ("lip to lid procedure") has been successfully used for full-thickness eyelid reconstruction in the dog and cat.[42,43] These compound or composite flaps are useful for specific body defects and are not routinely employed for skin defects alone.

Skin-Stretching Techniques

Skin is a nonhomogeneous viscoelastic tissue with the combined characteristics of a viscous fluid and elastic solid. Three factors account for skin extensibility as a stretching force is applied: (1) progressive straightening of dermal collagen convolutions; (2) Parallel alignment of dermal collagen fibers; (3) extension of fully aligned collagen fibers with increasing stretching force applied to the skin.[43]

Skin in various regions of the body has its own natural or "inherent extensibility". This is assessed by grasping and lifting the skin, a procedure **all** surgeons perform when assessing wound closure options. *Mechanical creep* is the biomechanical property that enables skin to extend or stretch beyond the limits of its inherent extensibility. As a stretching force is applied to the skin over time, collagen fibers align with the applied tension; collagen fibers compact and slowly displace interstitial fluid during the process. As the skin stretches beyond the limits of its natural extensibility over time, *stress relaxation* occurs. Stress relaxation refers to the progressive decrease in the force required to maintain the length of the stretched skin. For skin to stretch beyond the limits of its natural extensibility, the skin best deforms from the application of a constant load or force over time. Similarly intermittent application of force or "load cycling" also can assist in the process of skin stretching. A natural variation of this phenomenon is "biologic creep", or the progressive increase in cutaneous surface area noted as a result of expansile masses located beneath the skin.[44]

There are a few techniques that are currently used to stretch skin in humans and small animals, to facilitate wound closure. They include tissue expanders; presuturing; and an elastic cable system developed by the author, termed "skin stretchers."[5,44]

Skin Expanders

Skin expanders are inflatable devices composed of an expandable silicone elastomeric bag or reservoir; an attached silicone tube is connected to a self-sealing injection port. The entire device is placed beneath the skin. Controlled inflation of the device is accomplished by injecting sterile saline; a hypodermic

needle is inserted into the palpable injection port, through the overlying skin. The surface area of the overlying skin is gradually stretched, increasing its surface area by mechanical creep and stress relaxation. Once fully expanded, the skin is advanced or pivoted into a regional defect.[5,45-47]

Effective use of tissue expanders requires a reservoir of sufficient size to exert their stretching effect over on the overlying skin. However, they do require a degree of skin laxity for creating a pocket of sufficient size to accommodate the mass of the collapsed device. As a result, they are better suited for small to moderate sized problematic skin defects of the middle to distal aspects of the extremities. They may have limited use for closure of difficult wounds of the head. Many surgeons consider alternative means of closing extremity wounds, including skin grafts and select skin flap techniques. Veterinarians normally hesitate in purchasing a tissue expander for several hundred dollars with limited or no experience in their use. Properly handled, silicone tissue expanders can be autoclaved and reused.[5,45-47]

Implant size and shape is determined by the dimensions of the skin defect. Normally the surface area of the thick reservoir base corresponds to the surface area gain expected. Alternatively, slightly smaller reservoirs can be used, but hyperinflated 20- to 25% above the designated capacity of the device. Two smaller expanders also can be used in some situations. In one canine study, the rectangular 100 cc tissue expander appeared to be well suited for use in medium sized dogs.[5,45]

Variable rates of inflation have been used in human surgery. Although a somewhat slower rate of expansion may be reduce the risk of abrupt circulatory compromise to delicate skin, more rapid expansion rates may be preferable in other situations. Canine research demonstrated that 100 ml expanders can be inflated with minimal complications within 2 weeks, using an alternate-day injection schedule. A more cautious (3 week) rate may be advisable for delicate skin or tissues previously compromised by trauma. Use of expanders in previously irradiated tissues is best avoided.[5,45]

Outpatient visits enable the veterinarian to assess the skin during saline infusion. In human patients, the skin is assessed for color change (blanching, cyanosis) and patient discomfort. I have not noted these changes in the dog. During the later phase of expansion, skin tension can be pronounced immediately after the injection. When reassessed at the time of the following injection, skin tension has decreased. Viability of the skin is highlighted by the unimpeded growth of hair in the expanded skin.[5,45]

Upon completion of the expansion process, the expanded skin can be advanced or rotated into the recipient bed, usually in the form of a pedicle graft. This must be carefully planned in advance, since the initial access incision for implantation of the expander should not be incorporated into the base of the proposed flap (Figure 41-16).[5,45]

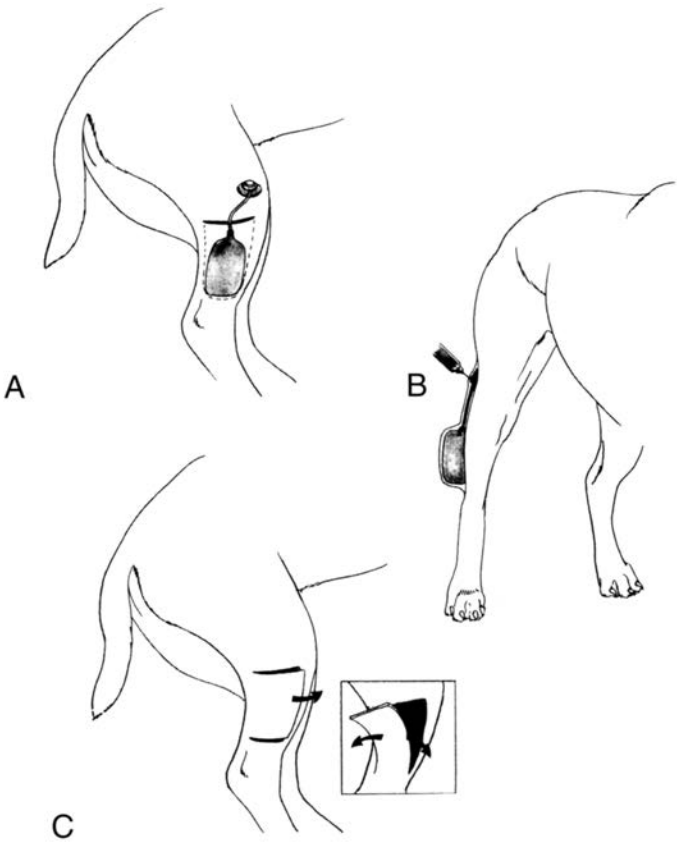


Figure 41-16. A-C. Tissue expander. In this illustration, a 100-ml tissue expander has been inserted into a subcutaneous pocket created by careful undermining of the skin. The access incision is closed with an intradermal suture pattern and skin sutures; 15 mL of saline is injected into the inflation reservoir, using a 23- to 25-gauge hypodermic needle, on alternate days after implant insertion. In approximately 2 weeks, the implant is deflated and removed; the expanded skin can be advanced or transposed into an adjacent detect. (From Pavletic MM. Atlas of small animal reconstructive surgery. Philadelphia: JB Lippincott, 1992.)

Skin Stretchers

Developed by the author, skin stretchers are an external device used to stretch skin rapidly, by the processes of mechanical creep and stress relaxation previously discussed. They are particularly effective for closing moderate to large wounds involving the trunk, neck and neighboring cranial area; they have limited use in the mid- to distal extremities. Skin stretchers enable the surgeon to close problematic wounds without the need for skin grafts or skin flaps.[5,34,44] They are my preferred method of choice to close most large skin wounds of the thoracic and abdominal areas.[5,44]

Skin stretchers have two components; skin pads to which elastic cables are affixed. The present design uses Velcro hook pads for the skin pads, and specially designed one inch elastic cable covered by Velcro "felt." Pads are placed on opposing sides of a wound and are secured to the skin with cyanoacrylate glue. Cables are applied to the opposing pads under moderate tension. Cable tension is gradually increased every 6 to 8 hours for 48 to 72 hours prior to surgical closure of the defect. At the time of surgery, pads can be pulled off the skin. Left in place, skin pads normally loosen within 7 to 10 days of application, as a result

of normal skin desquamation. Nail polish remover is a solvent for cyanoacrylate glue, although the author has not used it to facilitate skin pad removal (Figure 41-17).[5,44]

The primary complication is the occasional need to replace a skin pad that displaces as cable tension increases during their 48 to 72 hours of application. Pads are reglued or replaced until completion of the stretching procedure. Because the skin tension is applied over the wide footprint of the skin pads, patient comfort is maintained and allows for more forceful application of cable tension. The skin stretcher system can be used to prestretch skin prior to elective surgical procedures, including the surgical removal of problematic skin tumors. Skin stretchers are also very effective in minimizing incisional tension after wound closure; pads and cables can be used for 3 to 5 days to help prevent wound deshiscence.[5,44]

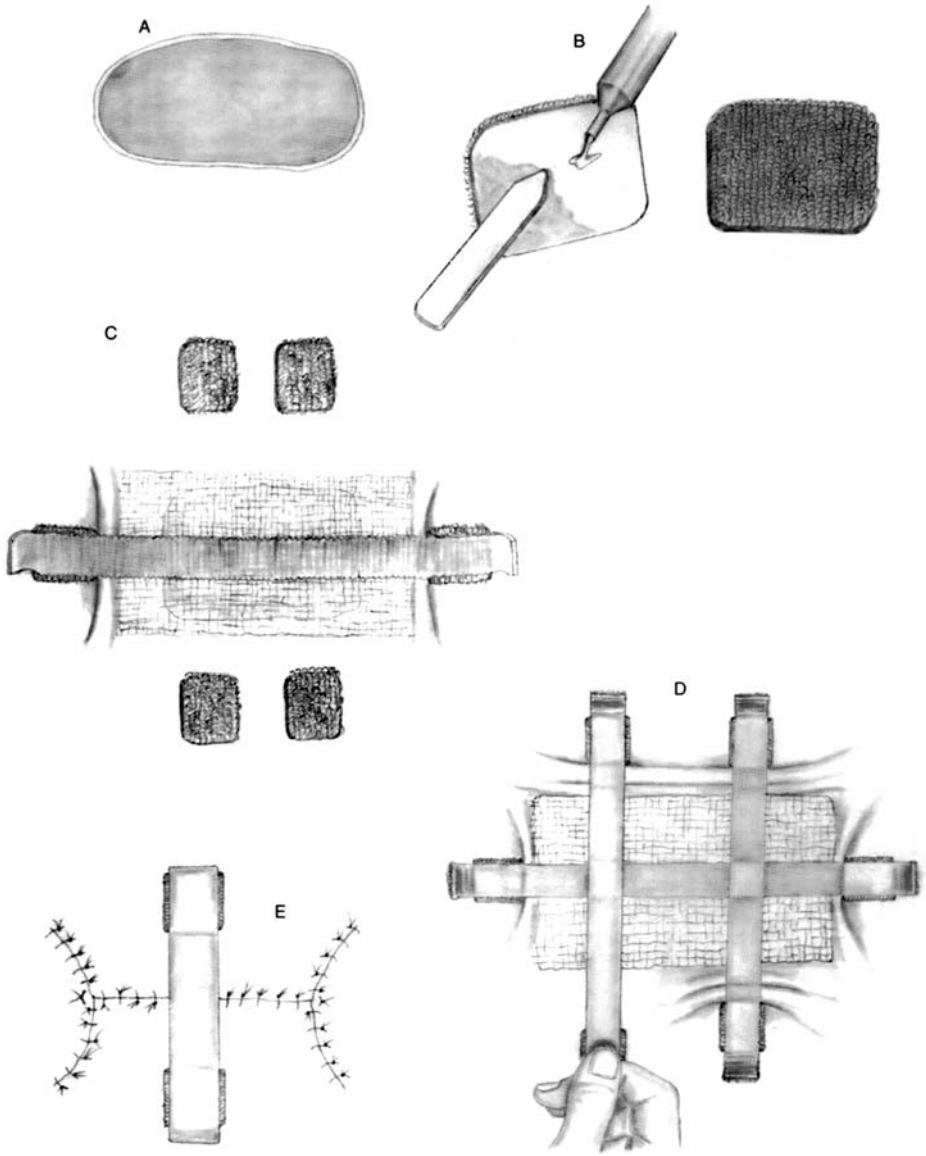


Figure 41-17. Illustration of a skin wound. The fur has been liberally clipped from around the area. Surgical soap and water are used to remove cutaneous oil and debris. Isopropyl alcohol swabs are then used to remove skin and residual skin oil. Excess alcohol is removed with gauze or towels and the skin allowed to completely dry before pad application. The hook pads can be applied to the skin after peeling off the protective tab or cover; cyanoacrylate glue is applied in a thin film to enhance pad adherence to the prepared skin surface. Note the long axes of the rectangular pads have been placed perpendicular to the wound borders, parallel to the tension cables to minimize the potential for pad displacement. Pads normally are placed 10-20 cm from the wound borders. An additional row (tier) of pads and cables can be applied outside this suggested zone, if further skin recruitment is required (and feasible) to recruit skin more distant to a large trunk defect. [Skin stretchers also can be effectively used to pre-stretch the skin prior to elective surgical removal of large tumors or diseased skin segments.] Completion of cable application. A mild amount of tension is initially applied to each cable. Cable tension is progressively increased every 6 hours as the skin stretches toward the defect. One end of the elastic cable is disengaged from a skin pad, stretched, and recoupled to the skin pad, as illustrated. **E.** In general skin is stretched for 48 to 96 hours prior to surgery. Pads are peeled off the anesthetized patient, the skin is prepared for surgery, and the recruited skin advanced over the wound. On occasion, the outer corneal layer will be stripped off during pad removal, but the surface rapidly reforms. [Nail polish remover can facilitate pad removal, but is unnecessary from the author's experience.] In this illustration, a second set of pads and a short cable segment are being used to offset postoperative wound tension upon completion of the surgery. Stretchers are very effective in reducing incisional tension; the author uses this device for 3-5 days.

Free Skin Grafts

Free skin grafts lack a vascular attachment on transfer to the recipient graft bed. As a result, their initial survival at the time of transplantation is by absorbing tissue fluid (plasmatic imbibition) from the recipient bed capillary circulation is established from the vascular wound bed. Initial reestablishment of circulation to the free graft is noted approximately 48 hours after application. During this period, capillaries from the recipient bed establish contact with the exposed vascular channels (exposed graft plexuses) to reestablish vital circulation. Termed "inosculation," reestablishment of vascular flow will give the skin graft a pink coloration. Grafts with a lavender color are the result of venous congestion; they assume a pink hue as circulation improves. The thickness of the graft will determine whether the superficial, middle or deep (subdermal) plexus is exposed to the underlying vascular bed. The finer vascular network of the superficial plexus has a greater chance at revascularization, a major reason why thin split-thickness skin grafts have a greater likelihood of vascularization. Similarly, a medium split-thickness skin graft has a greater likelihood of revascularization compared to a full-thickness graft. Despite these earlier research findings, properly prepared, full-thickness skin grafts have an excellent chance of surviving or "taking.[5,48]"

Once initial contact (inosculation) occurs between the capillary buds and exposed vascular channels of the skin graft, the capillaries grow into the graft and remodel the capillary network over the next several days. However, there are several factors that may delay or prevent revascularization of a skin graft, resulting in necrosis. Any accumulation of material between the graft and recipient bed can block inosculation, including pus, blood (hematoma), serum, or foreign material. Grafts techniques that provide effective drainage, can reduce the probability of graft loss from this potential complication.[5,48]

Subcutaneous fat must be removed from full-thickness skin grafts; presence of the fatty tissues will prevent revascularization of the free graft. The graft must conform to the contour of the wound bed: excessive stretching of the graft will create a "drum skin" over depressions in the recipent bed, preventing revascularization. Folds or wrinkles in the graft will have a similar effect. Lastly, grafts must be immobilized to prevent motion between the recipient bed and overlying graft: shearing forces will prevent revascularization.[5]

Skin staples or sutures are frequently used to secure skin grafts to the recipient area. Fibrin deposition between the graft and underlying recipient bed serves as a natural glue to help stabilize the graft. The fibrin serves as a scaffold for fibroblasts and subsequent collagen deposition. A protective bandage is required to prevent motion to the area during the healing process.[5]

As noted, a healthy vascular wound bed is required for graft survival. Healthy granulation tissue, viable muscle, and periosteum are capable of supporting a skin graft. Chronic granulation tissue is laden with collagen and has an unsatisfactory blood supply to support a graft. In many cases, this tissue may be excised, promoting reformation of a healthy granulation bed within 5 days. Chronic radiation ulcers lack the circulation to support a skin graft. In wounds lacking sufficient circulation to support a graft, a skin flap or muscle flap (covered with a skin graft) may be necessary.[5]

Skin Graft Classifications

Free grafts can be classified according to the source of the graft, its thickness, and its shape or design. Autogenous grafts are used exclusively for permanent coverage in dogs and cats. Allografts (homografts) and xenografts (heterografts) are rarely used in veterinary medicine as a temporary biologic dressing: left in place, these grafts are eventually rejected by the patient's immune system. Isografts, or the exchange of skin grafts between highly inbred strains of animals is usually limited to research rats and mice.[5,48]

Free grafts are commonly classified according to the thickness of the graft. Full- thickness skin grafts include the entire dermis, thereby retaining a large percentage of the compound hair follicles. Split-thickness skin grafts, harvested by a graft knife, razor blade, or dermatome include variable portions of the dermis. They are broadly classified as thin, medium, or thick split thickness skin grafts. Thinner grafts have relatively few hair follicles and are less cosmetic in fur-bearing animals, unlike the human. Although thin split thickness grafts reportedly survive or "take" more readily, they also lack the hair growth and overall durability of full-thickness skin grafts. Split-thickness grafts, harvested with a dermatome, normally are reserved for large wounds (especially large full-thickness bums) with more limited donor skin.[5,48,49]

Surgical Techniques

Free grafts are most commonly used for the more problematic defects involving the lower extremities. Most surgeons will use full thickness grafts when possible due to the superior hair growth, durability and relative ease of harvesting. Full thickness skin grafts can be harvested and applied as a "sheet" or cut into various shapes including punch-pinch grafts, strip grafts, stamp grafts, or mesh grafts (Figures 41-18 through 41-21).

Punch, pinch, strip, and stamp grafts afford partial coverage of a wound surface. The space between grafts provides drainage as their epithelial cells migrate over the exposed granulation tissue. Grafts that provide reasonable drainage are more likely to survive in the presence of a low-grade bacterial infection. Punch and pinch grafts are easy to perform and are used most commonly to promote epithelization of smaller, slow healing open wounds. However, depending on their numbers and spatial relationship, they do not provide a particularly durable epithelial surface for those body regions subject to periodic external trauma. Full-thickness mesh grafts are better suited for larger wounds.The techniques for punch, strip, and stamp grafts are described in (See Figures 41-18 through 41-21).[5]

Full-thickness mesh grafts are especially useful for coverage of larger wounds involving the distal extremities (See Figure 41-21). An impression template of the moist wound surface can be performed using gauze or absorbable paper [the paper packaging

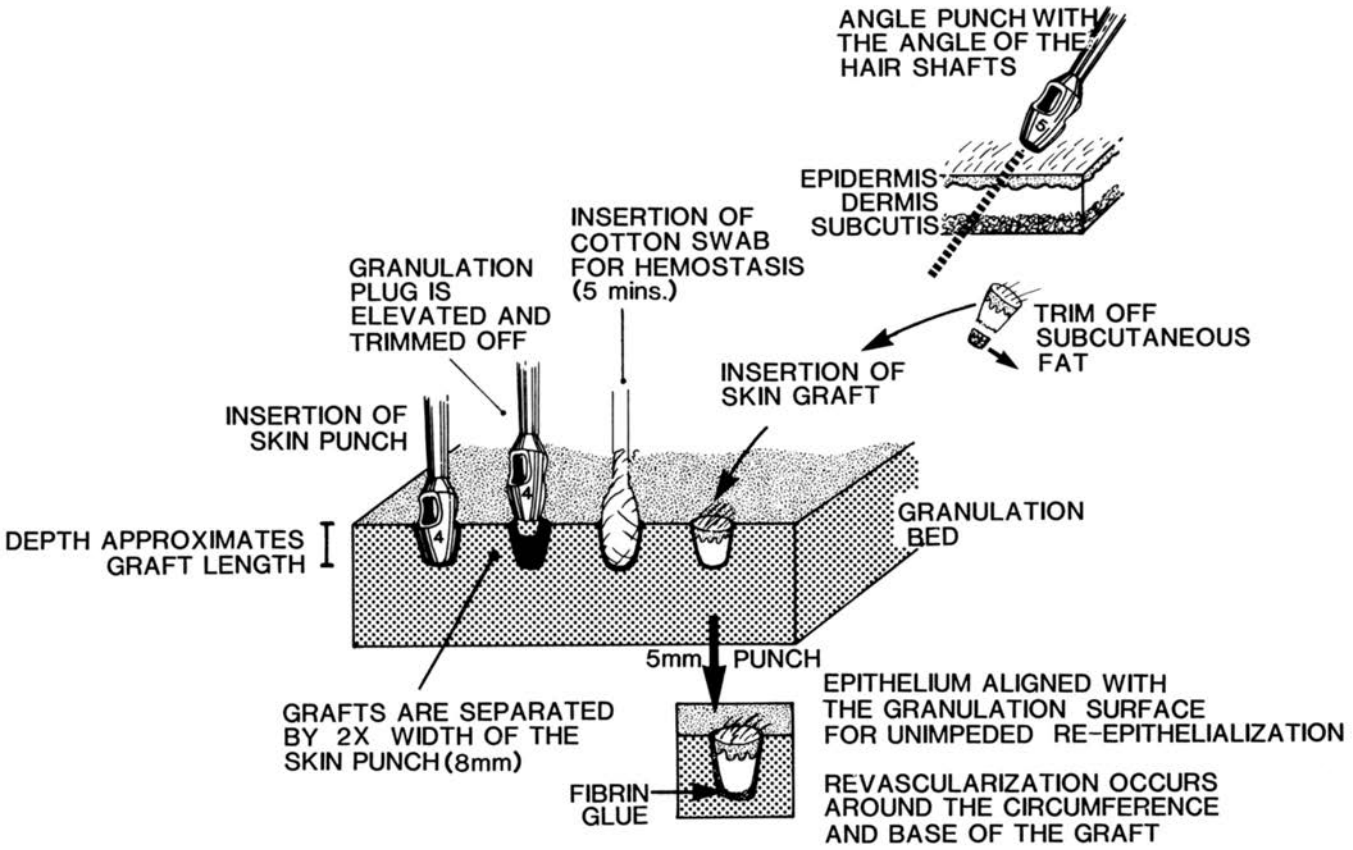


Figure 41-18. Punch graft technique (pinch grafts). A sharp 5- or 6-mm biopsy punch is used to harvest the graft plugs from a suitable donor site. The donor area is clipped, leaving the hair shafts exposed. Subcutaneous fat is trimmed off the graft base. A single stitch is used to close the donor bed. The grafts are placed between two moistened saline pads until needed. A 4-mm biopsy punch is used to remove cores of granulation tissue in the recipient bed. Holes are spaced 8 mm apart (twice the width of the biopsy punch). Fine scissors are required to remove the granulation core. A sterile cotton swab is inserted into each hole for 5 minutes. The graft plugs are then inserted in the direction of natural hair growth. A firm dressing is applied postsurgically to maintain the position of the grafts. This procedure has the following advantages: 1) 4-mm granulation holes compensate for graft shrinkage and allow the grafts to fit more snugly; 2) the epithelial surface of the graft is level with the granulation bed, and re-epithelialization is unimpeded; 3) as many hair follicles as possible are included into each graft to promote hair growth; 4) re-epithelialization is possible despite partial graft necrosis from surviving hair follicles and skin adnexa deep in the graft; and 5) graft revascularization occurs around the circumferences as well as through the base of the graft plug, a comparatively large surface area.

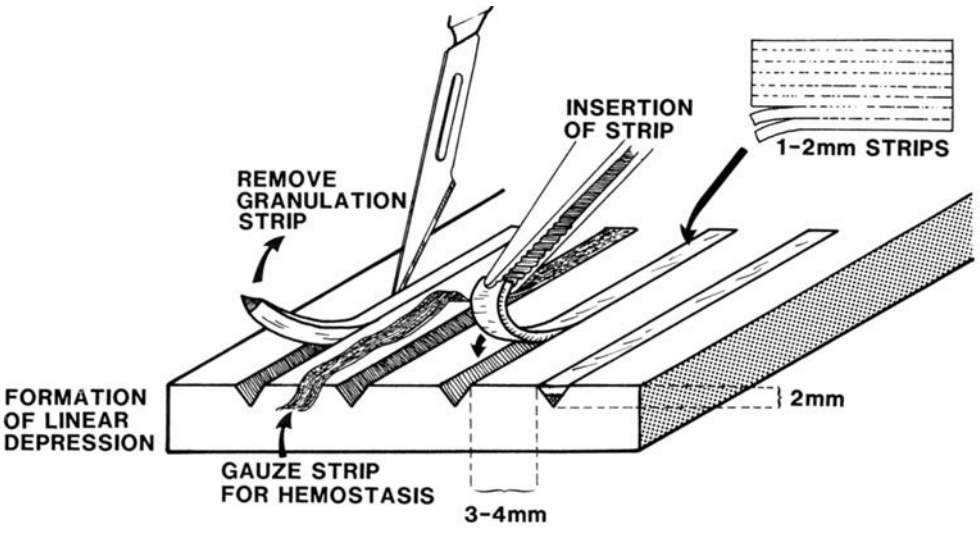


Figure 41-19. Strip grafts. Application of strip grafts is similar to that of punch grafts. Linear strips of skin are laid in granulation troughs cut with a special blade. Granulation tissue between the strips is eventually reepithelialized from the graft.

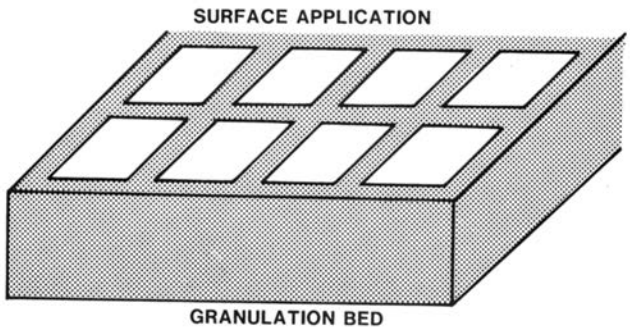


Figure 41-20. Stamp grafts. Full-thickness or split-thickness grafts are harvested and are divided into squares. Size can vary up to the size of postage stamps. Grafts are laid over the recipient bed a few to several millimeters apart. Square depressions may be cut into a granulation bed if necessary to improve graft immobilization.

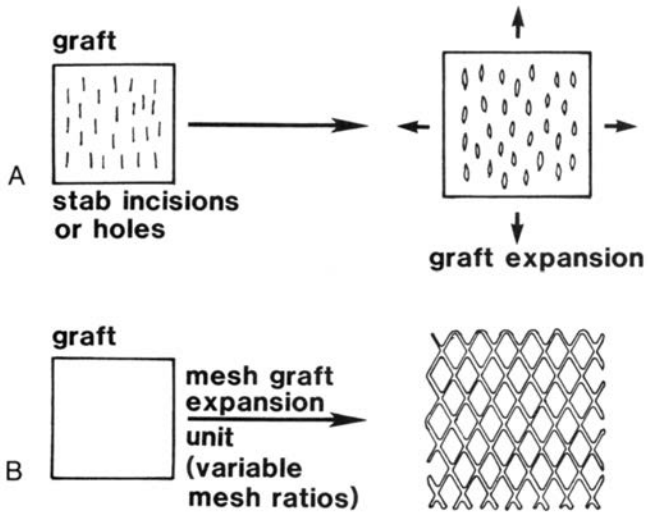


Figure 41-21. Mesh grafts. Both full-thickness and split-thickness grafts may be used. **A.** Multiple stab incisions or holes are cut into the graft to allow the graft to expand and to provide adequate drainage. The graft is sutured at the periphery. **B.** Mesh-graft expansion units have been developed to expand the graft into a uniform mesh. A graft can be expanded 1.5 to 9 times its original surface area to cover extensive skin defects.

for sterile gloves is an ideal material]. Using sterile materials, the template can be trimmed and directly applied to the donor area. In most cases, skin is simply harvested from the lateral thorax and abdomen. The template is placed on the donor area, ideally allowing for the graft to be harvested with the appropriate hair growth pattern of the recipient area. Normally, I will harvest an additional one centimeter around the circumference of the template. Harvesting of the graft as a simple geometric pattern that includes the footprint of the template [rectangular design is most commonly used] will facilitate closure of the donor area; the graft can be trimmed to the appropriate size at the time of application.[5]

A key step in full thickness graft preparation is the removal of all subcutaneous tissues (fat, panniculus muscle) down to the dermal surface of the graft. Unless removed, this layer of tissue will prevent revascularization of the graft. Properly "defatted", the dermal surface of the graft will have a "cobble stone" appearance: dermal collagen striations and the speckled appearance of compound hair follicles are identifiable on close inspection (Figure 41-22).[5]

Grafts can be directly abutted against the borders of the skin defect and sutured into position. Alternatively, the author prefers to slightly overlap the wound margins of the recipient bed with the graft. This facilitates securing the graft with sutures or skin staples while completely covering the wound. Skin staples facilitate graft application by rapidly securing the graft to the overlapped cutaneous borders. Graft tension is adjusted by stapling one side and slightly stretching the graft before stapling

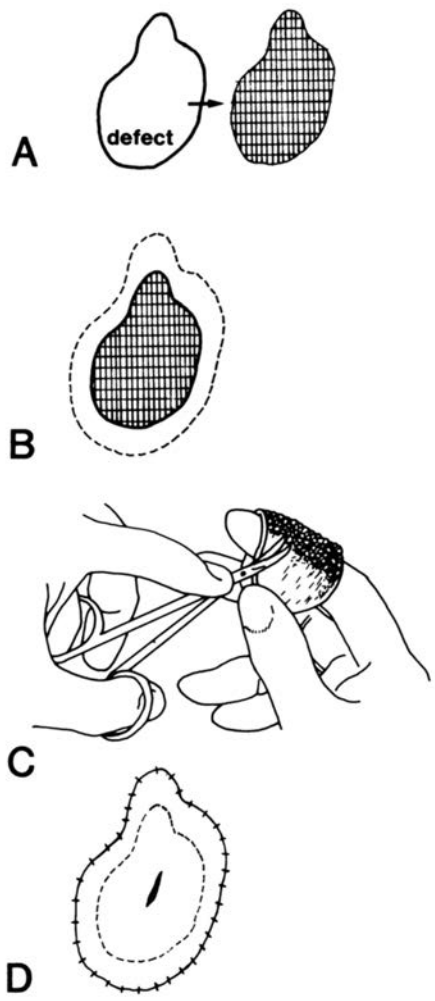


Figure 41-22. Free full-thickness graft. The recipient is prepared for operation, and any epithelialized areas are excised to accept full graft coverage (cross-hatching). **A.** A sterile gauze or paper template is made of the recipient bed. **B.** After the template is transferred to the prepared donor site, a sterile ink applicator is used to outline the template on the donor site I cm outside its border. **C.** The graft is removed, and the donor bed is closed. The graft is "defatted" by trimming away all subcutaneous tissue. The resultant graft appears opaque when held to a light source and must be kept moist at all times. **D.** The graft is laid over the wound. Stab incisions may be used to prevent fluid accumulation beneath the graft. The graft overlaps the recipient bed and is sutured into place with a simple interrupted or continuous pattern. The overlapped border eventually sloughs, leaving complete graft coverage over the recipient bed. The graft is dressed and bandaged postsurgically.

the opposing border. The process is repeated in the opposite plane. The graft is applied with sufficient tension to allow the graft to flatten and conform to all surface areas. Graft holes are stretched to allow a gap of a few to several millimeters to form, facilitating drainage. As a general rule, grafts are not sutured to the wound bed in order to avoid hemorrhage. If the graft is tenting over a depression, a fine suture can be used to assure proper graft to bed contact. Fibrin deposition occurs several hours after application, forming a natural glue to immobilize the graft. Skin sutures or staples can be removed in 7 to 10 days; the overlapped skin border will undergo necrosis and can be trimmed off at this time.[5]

Pad Grafting

There are several articles discussing the use of pad grafts to replace the loss of the metacarpal and metatarsal pads, with the simultaneous loss of the digital pads. With the presence of the adjacent toes, digital pad flaps can be used to reconstruct the metacarpal/metatarsal pads more effectively.[5,50-52]

Grafts: Postoperative Care

Proper protection and immobilization is essential to graft survival. It is preferable to confine the patient to a cage. Sedation may be advisable for hyperactive patients.

A nonadherent dressing covered with a thick layer of bland ointment [triple antibiotic ointment is economical to use] is applied to the grafted area.and stapled over the area to prevent displacement. This is followed by layers of sterile gauze pads, and self-adherent roll gauze alternated with cast padding. A firm, thick bandage is formed prior to application of an outer elastic wrap. To further immoblize the area, tongue depressors, aluminum bars, half casts, metasplints, slings, and Shroeder-Thomas splints may be employed. The Latter splint is especially useful for immobilizing the knee, elbow, and tibiotarsal joints. Spica splints/bandages are advisable to immobilize the upper extremity, especially in cats, whose reputation for extricating themselves from bandages is legendary.[5,48]

The author prefers to change the initial bandage 3 to 5 days postoperatively. Bandages can be changed 48 hours after surgery, but in this early period there is a risk of displacing the graft and damaging the fragile reestablished blood supply. Adherent dressings occasionally adhere to the grafted area. Saline can be applied to facilitate its removal, although it is more prudent to apply additional ointment to the area and rebandage the area. The exposed graft is inspected for viability and signs of infection. A culture can be taken if infection is suspected.[5]

Early signs of graft necrosis are discouraging but not always catastrophic: hair follicles in the deeper dermal layer of the graft may survive and serve as a source for epithelization. Subsequent bandage changes may be performed every 2 to 4 days, depending on the condition of the graft. This routine is continued for approximately 2 weeks or until epithelization is complete. This can be followed by application of a lighter bandage for an additional 10 to 14 days, if necessary. An Elizabethan collar is advisable to prevent self-mutilation of the graft site. Eventually, the owner can remove the collar temporarily with the pet under close supervision. If the patient does not rub or lick at the grafted area, the collar can be eliminated completely, usually within a month after the surgery.[5] Bandages can have adverse effects on the graft. Excessive bandage tension and pressure points from uneven bandage application can result in partial or complete graft failure. Bandages also can have an abrasive effect on the graft if immobilization of the affected area is inadequate.[5]

References

1. Pavletic MM. The Vascular supply to the skin of the dog; a review. Vet Surg 1980;9:77.

2. Pavletic MM. The integument. In: Slatter DH, ed. Textbook of small animal surgery, 3rd ed. Philadelphia: WB Saunders, 2003.

3. Pavletic MM. Pedicle grafts. In: Slatter DH, ed. Textbook of small animal surgery, 3rd ed. Philadelphia: WB Saunders 2003.

4. Pavletic MM. Underming the skin in the dog and cat. Mod vet Pract 1986;67:16.

5. Pavletic MM. Atlas of small animal reconstructive surgery, Philadelphia: WB Saunders, 1999.

6. Pavletic MM. Caudal superficial epigastric arterial pedicle grafts in the dog. Vet Surg 1980;9:103.

7. Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res 1981;42:391.

8. Alexander JW, Hoffer RE, MacDonald JM. The use of tubular flap grafts in the treatment of traumatic wounds on the extremity of the cat. Feline Pract 1976:6:2.

9. Yturraspe DJ, Creed JE, Schwach RP. Thoracic pedicle skin flap for repair of lower limb wounds in dogs and cats. J Am Anim Hosp Assoc 1976;12:581.

10. Pavletic MM, Kostolich M, Koblik P, et al. Comparison of the cutaneous trunci myocutaneous flap and latissimus dorsi myocutaneous flap in the dog. Vet Surg 1987:16:283.

11. Matera JM, Tatarunas AC, Fantori DT, asconcellos CNC. Use of scrotum as a transposition flap for closure of surgical wounds in three dogs. Vet Surg 2004;33:99.

12. Hunt GB, Tisdall PLC, Liptak JM, et al. Skin fold advancement flaps for closing large proximal limb and trunk defects in two dogs and cats. Vet Surg 2001:30:440.

13. Hunt GB. Skin fold advancement flips for closing large sternal and inguinal wounds in cats and dogs. Vet Surg 1995;24:172.

14. Anderson DM, Charlesworth TC, White RAS. A novel axial pattern flap based on the lateral thoracic artery in the dog; lateral thoracic skin flap. Vet Comp Orthop Traumatol 2004;17:57.

15. Fahie MA, Smith MM. Axial pattern flap based on the cutaneous branch of the superficial temporal artery in dogs: An experimental study and case report. Vet Surg 1999;28:141.

16. Fahie MA, Smith MM. Axial pattern flap based on superficial temporal artery in cats; an experimental study. 1997;26:86.

17. Aper R, Smeak D. Complications and outcome after thoracodorsal axial pattern flap reconstruction of forelimb skin defects in 10 dogs, 1989-2001. Vet Surg 2003;32:378.

18. Lidbetter DA, Williams FA, Krahwinkel OJ, et al. Radical lateral body-wall resection for fibrosarcoma with reconstruction using polypropylene mesh and a caudal superficial epigastric axial pattern flap: a prospective clinical study of the technique and results in six cats. Vet Surg 2002;31:57.

19. Lester S, Pratschke K. Certral hemimaxillectomy and reconstruction

using a superficial temporal artery axial pattern flap in a domestic short hair cat. Fel Med Surg 2003;5:241.

20. Stiles J, Townsend W, Willis M, et al. Use of a caudal auricular axial pattern flap in three cats and one dog following orbital exenteration. Vet ophthal 2003;6:121.

21. Smith MM; Carrig CB, Waldron DR, et al. Direct cutaneous arterial supply to the tail in dogs. Am J Vet Res 1992;53:145.

22. Kostolich M, Pavletic MM. Axial pattern flap based on the genicular branch of the saphenous artery in the dog. Vet Surg 1987;16:217.

23. Pavletic MM, Macintire D. Phycomycosis of the axilla and inner brachium in a dog: surgical excision and reconstruction with a thoracodorsal axial pattern flap. J Am Vet Med Assoc 1982;180;1197.

24. Henney LHS, Pavletic MM. Axial pattern flap based on the superficial brachial artery in the dog. Vet Surg 17:311, 1988.

25. Sardinas JC, Pavletic MM, Ross JT, et al. Comparative viability of penisular and island axial pattern flaps incorporation the cranial superficial epigastric artery in dogs. J Am Vet Med Assoc 1995;207:452.

26. Remedios AM, Bauer MS, Bowen CV. Thoracodorsal and caudal superficial epigastric axial pattern skin flaps in cats. Am J Vet Res 1992;53:145.

27. Smith MM, Payne JT, Moon ML, et al. Axial pattern flap based on the caudal auricular artery in dogs. Am JVet Res 1991;52:922.

28. Pavletic MM, Wafters J, Henry RW, et al. Reverse saphenous conduit flap in the dog. J Am Vet Med Assoc 1982;182:380.

29. Cornell K, Salisbury K, Jakovljevic S, et al. Reverse saphenous conduit flap in cats: an anatomic study. Vet Surg 1995;24:202.

30. Milton SH. Experimental studies of island flaps. I. The surviving length. Plast Reconstr Surg 1971;48:574.

31. Gourley IM. Neurovascular island flap for treatment of trophic metacarpal pad ulcer in the dog. J Am Anim Hosp Assoc 1978;14:119.

32. Pavletic MM. Surgery of the skin and management of wounds. In: Sherding R, ed. Diseases of the cat: diagnosis and management. New York: Churchill Livingstone, 1994.

33. Lascelles BDX, White RAS. Combined omental pedicle graft and thoracodorsal axial pattern flaps for the reconstruction of chronic nonhealing wounds in cat. Vet Surg 2001;30:380.

34. Mayhew PD, Holt DE. Simultaneous use of bilateral caudal superficial epigastiric axial pattern flaps for wound closure in a dog. Sm Anim Pract 2003;44:534.

35. Krizek TJTani T, Desprez JD, et al. Experimental transplantation of composite grafts by microsurical vascular anastomoes. Plast Reconstr Surg 1965;36:358.

36. Tsai TJ et al. The effect of hypothermia and tissue perfusion on extended myocutaneous flap viability. Plast Resconstr Surg 1982;70:444.

37. Harii K, Ohmori K, Sekiguchi J. The free musculocutaneous flap. Plast Reconstr Surg 1973;57:294.

38. Schlenker JD. Discussion: the effect of hypothermia and tissue perfusion on extended myocutaneous flap viability. Plast Reconstr Surg 1982;70:453.

39. Erol 00, Spira M. Secondary musculocutaneous flap: an experimental study. Plast Reconstr Surg 1980;65:277.

40. Schechter GL, Biller HF, Ogura JH. Revascularized skin flaps: a new concept in transfer of skin flaps. Laryngoscope 1969;79:1647.

41. Swanson SW, Goring RI, Dehann JJ, et al. Reconstruction of a facial defect using the ear pinna as a composite flap. J Am Animal Hosp Assoc 1998;34:399.

42. Pavletic MM, Nafe LA, Confer AW. Mucocutaneous subdermal plexus flap from the lip for lower eyelid restroration in the dog. J Am Vet Med Assoc 1982;180:921.

43. Hunt GB. Use of the lip to lid flap for replacement of the lower eyelid in cats. Vet Surg 2006;35:284.

44. Pavletic MM. An external skin-stretching device for wound closure in dogs and cats. J. Am Vet Med Assoc 2000; 217:350.

45. Spodnick G, Pavletic MM, Schelling S, et al. Controlled tissue expansion in the distal extremities of dogs. Vet Surg 1993;22:436.

46. Keller WG, Anon DN, Rarich PM, et al. Rapid tissue expansion for the development of rotational skin flaps in the distal portion of the hind limb of dogs: an experimental study. Vet Surg 1994;23:31.

47. Johnston DE. Tissue expanders. Vet Clin No Am. 1990;20:227.

48. Swaim SF, Henderson RA. Small animal wound management. Philadelphia Williams and Wilkins, 1997.

49. Bradley DM, Swaim SF, Alexander CM, et al. Autogenous pad grafts for reconstruction of a weight - bearing surface: a case report. J Am Anim Hosp Assoc 1994;30:533.

50. Aragon CL, Harvey SE, Allen SW, Stevenson MA. Partial thickness skin grafting for large thermal skin wounds in dogs. Compen Contin Edu 2004;26;2005.

51. Pavletic MM. Foot salvage by delayed reimplantation of severe metatarsal and digital pads using a bipedicle direct flap technique. J Am Anim Hosp Assoc 1994;30:539.

52. Bradley DM, Scardino MS, Swaim SF. Construction of a weight-bearing surface on a dog distal pelvic limb. J Am Anim Hosp Assoc 1998;34:387.

Mesh Skin Grafting

Eric R. Pope

Introduction

Skin grafting in dogs and cats is most commonly used for reconstructing degloving injuries on the extremities, but can also be used to cover skin defects on other areas of the body when simpler techniques may not be indicated or applicable. The use of both full-thickness and split-thickness grafts has been described but I have almost always used full-thickness grafts. Full-thickness grafts consist of the epidermis and entire dermis, whereas split-thickness grafts consist of the epidermis and variable portions of the dermis (Figure 41-23). Of the various types of skin grafts described in the literature, the mesh skin graft offers many advantages for the veterinary surgeon. A mesh graft is a full-thickness or split-thickness skin graft in which parallel rows of staggered slits have been cut either manually with a No. 11 scalpel blade or mechanically with a commercial mesh dermatome. Mesh grafts have the following advantages: 1) they can be expanded to cover large defects if donor sites are limited (e.g., burns); 2) they conform well to irregular surfaces; 3) the creation of numerous slits allows drainage from underneath the graft; and 4) they can be placed over areas that are difficult to immobilize. The primary disadvantage of mesh grafts is that when they are expanded and the interstices heal by epithelialization, resulting in islands of nonhaired epithelium throughout the graft. For this reason, a nonexpanded or minimally expanded graft is preferred.

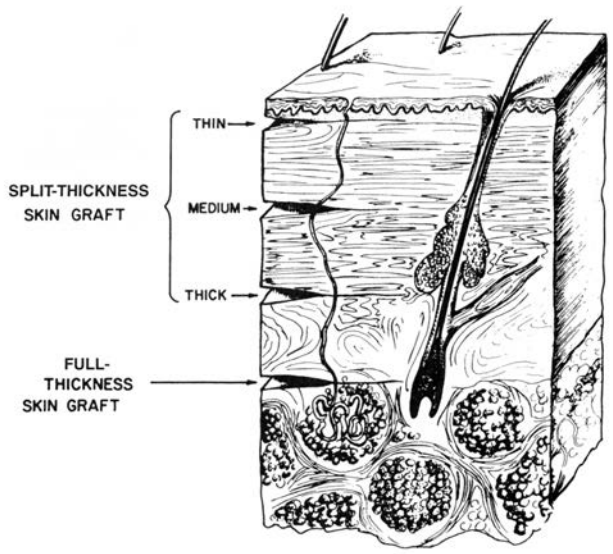


Figure 41-23. Full-thickness skin grafts consist of the epidermis and entire dermis. Split-thickness grafts consist of the epidermis and variable portions of the dermis. (Courtesy of Swaim SF, DVM, Auburn University, Auburn, AL.)

Preoperative Considerations

Recipient Bed

Skin grafts can be successfully placed on freshly created surgical wounds or on healthy granulation beds. A freshly created wound can be grafted immediately if the surface of the wound has a blood supply sufficient enough to produce granulation tissue if left ungrafted. Muscle and fascia generally support grafts well. Bone, cartilage, and tendon covered by their supporting structures also support grafts. Grafts placed over avascular areas less than 1cm in width (0.5cm from each margin) generally survive because of the extensive interconnection of blood vessels within the dermis; this is referred to as the bridging phenomenon.

Although fresh wounds can be successfully grafted, I prefer to allow a healthy granulation bed to form before grafting. A granulation bed should be sufficiently formed within 5 to 7 days. A healthy granulation bed is smooth and pink; the migration of epithelium from the wound margin is also a good indicator that the granulation tissue is healthy. Chronic granulation tissue is rough and dark red and may be infected. Chronic granulation tissue should be excised to its base and a fresh granulation bed allowed to form before any skin-grafting procedure is performed. Culture and sensitivity testing should be considered if infection is suspected. In most instances, traumatic wounds are best managed conservatively initially, followed by grafting after a healthy granulation bed has formed. Obviously, devitalized tissue should be debrided from the wound, and open wound management performed (e.g. moisture retentive wound dressings, wet-to-dry dressings, vacuum-assisted wound therapy) until a granulation bed forms. Once a granulation bed forms, the wound surface should be protected with nonadherent dressings until grafting is performed.

Donor Sites

Important criteria in selecting a donor site are the color and length of hair with respect to that surrounding the recipient site and also the ability to close the donor site after harvesting the graft. Because abundant skin generally is present on the thorax and neck, large grafts can be harvested from these areas, and primary closure of the donor site is possible.

Split-Thickness Versus Full-Thickness Graft

Split-thickness grafts can be classified as thin (less than 0.008-inch thick), intermediate (0.010 to 0.015-inch thick), or thick (0.015 to 0.025-inch thick), depending on the amount of dermis included. Thin and intermediate-thickness grafts generally do not grow hair well and may have a scaly appearance because of the lack of glandular structures. Thick split-thickness grafts approach full-thickness grafts in depth and therefore grow hair more successfully and result in a more normal appearance than thinner grafts. If thick grafts are harvested, the donor site should be excised and closed primarily, if possible, because healing is usually prolonged, and hair growth may be poor.

Full-thickness grafts have several advantages over split-thickness grafts. Because full-thickness grafts contain all the adnexal components, they are more likely to resemble normal skin than split-thickness grafts. They also generally grow hair well and are able to withstand trauma as well as the surrounding normal skin. In contrast to split-thickness grafts, no specialized equipment is required to harvest full-thickness grafts. Finally, the success rate with full-thickness grafts is at least as good as that obtained with split-thickness grafts. For these various reasons, I recommend using full-thickness grafts unless donor skin is limited (e.g., large burn wounds or multiple degloving injuries). Therefore, the remainder of this chapter describes a practical full-thickness mesh grafting technique that I use almost exclusively when grafting is indicated.

Surgical Technique

The mesh grafting procedure involves four basic steps: 1) preparing the donor and recipient sites; 2) harvesting and preparing the graft; 3) meshing the graft; and 4) applying the graft.

Preparing Donor and Recipient Site

The patient is anesthetized following a standard protocol, and the donor and recipient sites are prepared for aseptic surgery. The donor site should be widely clipped in case a plasty procedure is required for closure. The recipient bed is prepared first, so hemorrhage can be controlled before the graft is applied. Strong antiseptic solution should be avoided, but a dilute solution of chlorhexidine (0.05%) does not affect graft "take" and is used routinely.

Lightly scrape the surface of the granulation bed with a scalpel blade to remove any surface debris and to expose capillary ends. Hold the blade at a 90° angle to the surface to avoid removing too much tissue. At this point, a blood imprint of the recipient site can be made if a full-thickness nonexpanded graft is to be used (see next paragraph). Finally, saline-moistened sponges are applied

to the surface of the recipient bed, and digital pressure is used to control hemorrhage. Excessive use of cautery or ligatures should be avoided.

Donor sites for full-thickness grafts usually are abundant. Large grafts can be harvested by the technique described here, and the donor site can be closed primarily. The first step is to make a pattern of the defect if a nonexpanded technique is to be used, especially if the edges of the defect are very irregular. A pattern can be made by obtaining a blood imprint of the recipient site after it is prepared as described previously. After the pattern is made, it is placed on the donor site, with care taken not to reverse the pattern (i.e., turning the pattern over so the dermal side is up and a mirror image of the needed graft is harvested). The pattern should also be placed so the direction of hair growth of the graft matches that of the skin surrounding the wound. An arrow is drawn on the imprint indicating the direction of hair growth on the pattern before removing it from the defect. A skin scribe, sterile new methylene blue, or a scalpel blade can be used to transfer the pattern to the skin before cutting the graft. This is performed so the borders of the pattern can still be followed if the skin is distorted while the graft is being cut.

If the wound edges are fairly regular (e.g., rectangular) or if the graft will be expanded, an exact pattern is not necessary. For nonexpanded grafts, the length and width of the defect are measured at their widest point, and a segment of skin of those dimensions is harvested. Excess skin is trimmed from the edge after the graft is placed on the recipient site. When expanded grafts are needed, the graft should be cut longer in the direction parallel with the mesh incisions to account for the loss of length that occurs as the graft is expanded.

Harvest the graft at the level of the superficial subcutaneous tissue or just deep to the cutaneous trunci muscle if it is present. After the graft is dissected free from the donor site, the subcutaneous tissue (and cutaneous trunci muscle if present) must be removed from the graft. Removal of the subcutaneous tissue is enhanced by suturing the graft, dermal side up, to a piece of sterile cardboard with sutures or hypodermic needles (Figure 41-24). Sharp scissors are then used to cut the subcutaneous tissue from the graft. The base of the hair follicles is visible when the subcutaneous tissue is removed, giving the graft a cobblestone appearance. Because the hair follicles extend into the subcutaneous tissue in part of the hair growth cycle, the hair follicles may be damaged and hair growth reduced. Failure to remove all the subcutaneous tissue impairs revascularization of the graft and is an important cause of graft loss.

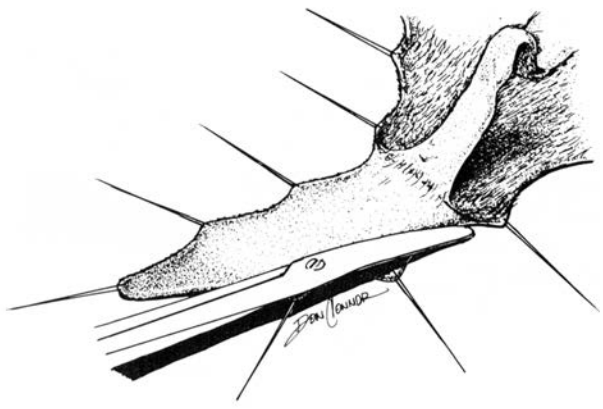


Figure 41-24. The graft is sutured, subcutaneous side up, to a piece of sterile cardboard, and the subcutaneous tissue is removed with sharp scissors. The base of the hair follicles should be visible in a properly prepared graft.

Meshing the Graft

Meshing can be accomplished with a No. 11 scalpel blade or a mesh dermatome but I typically use a scalpel blade because it is convenient and inexpensive. If a scalpel is used, the graft is left attached to the sterile cardboard, and staggered rows of parallel slits (approximately 0.5 to 1 cm in length) are cut in the graft (Figure 41-25). The degree of expansion achievable is influenced by the number of rows and length of the slits. Increasing the number of rows and the length of the slits increases the amount of expansion possible.

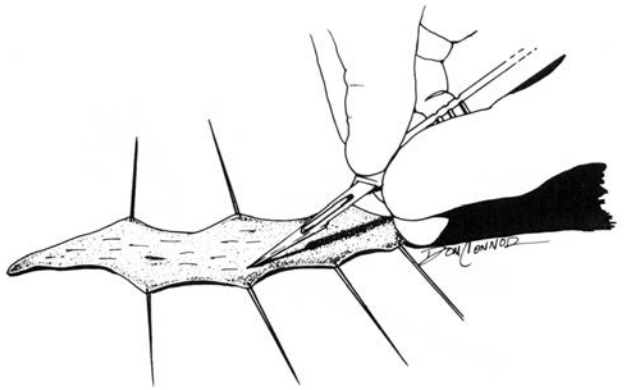


Figure 41-25. Meshing the graft with a number #11 scalpel blade. Increasing the number of rows and the length of the slits allows increased expansion of the graft and provides for more drainage of exudate from under the graft.

Application of the Graft

After the skin graft is harvested and prepared, it is placed on the recipient bed. To avoid disrupting the fibrin seal that begins to form soon after the graft is placed on the recipient bed, the graft should be manipulated as little as possible. The edge of the graft is sutured to the edge of the recipient bed using either nonabsorbable monofilament suture material or surgical staples. Alternatively, the graft is allowed to overlap the surrounding skin several millimeters and sutures are placed between the overlapped graft edge and skin below. The overlapped portion of graft will die and separate from the surviving graft, minimizing the risk of traumatizing the graft during suture removal. I have not noticed a significant difference using either technique but prefer suturing the graft to the skin edges of the recipient wound bed. Tacking sutures may be placed between the graft and graft bed on large grafts to help immobilize the graft.

Postoperative Care

Proper postoperative management is essential to successful skin grafting. Complete immobilization of a graft is necessary until a fibrous union occurs between the graft and recipient bed. Immediately after the surgical procedure, the graft is covered with a nonadherent pad. I apply an antibiotic ointment such as gentamycin ointment to the pad before placing it over the graft. A layer of absorbent material (e.g., Telfa WetPruf pads [Kendall Company Hospital Products] or cast padding is applied next and is covered with elastic gauze. Cast padding is easier to conform to the limb but is not as absorbent. If the graft crosses a joint, a splint is incorporated in the bandage to immobilize the limb. Finally, the entire bandage is covered with cohesive elastic bandage material or elastic tape. The bandage should provide moderate pressure. The dressing usually is changed in 48 hours but can be changed as early as 24 hours if drainage from the recipient bed soaks through the surface of the bandage. Care must be taken not to disturb the graft. Fractious animals should be sedated if necessary.

Because a moderate amount of drainage from the graft bed is common, waiting longer than 48 hours to change the bandage is not recommended. Bandages usually are changed every other day for the first 10 days and then as needed for 2 more weeks. Splinting usually can be discontinued after 10 days if the graft has healed normally. Healing grafts normally pass through a series of color changes during the healing process. Initially, many grafts appear pale because of the lack of blood supply. After 2 to 3 days, a graft normally develops a dark red or bruised appearance as the blood supply is reestablished. The graft may also appear edematous because of venous congestion. Graft areas that remain white or turn black will probably slough. Unless the entire graft is obviously nonviable, questionable areas are left until healing is complete. Attempts to remove small areas of nonviable graft may disrupt healing of surrounding areas. In some instances, partial thickness loss occurs leaving viable dermis in the deeper parts of the graft. The surface re-epithelializes from surrounding viable epidermal cells and from epidermal cells in the hair follicles.

Postoperative infection can have devastating results. Infection between the graft and the recipient bed may result in dissolution of the fibrin seal, or the graft may be physically elevated from the graft bed by the exudate produced. Care must be taken not to contaminate the graft when bandages are changed. Full-thickness skin grafts may develop a superficial infection, especially if revascularization is delayed. This generally is the result of the overgrowth of normal skin flora on abnormal skin and does not affect graft take. Infection usually is controlled by swabbing the graft lightly with an antiseptic solution when the bandages are changed and applying a topical antibiotic ointment. Sutures are removed 10 days postoperatively. The patient's owner should be cautioned to watch for developing paresthesia, as evidenced by constant licking and chewing at the graft. This problem is not common, but it is distressing if the patient chews off a successful graft. If this problem occurs, the graft should be protected with bandages for a longer period or a collar applied to prevent the animal from being able to traumatize the site.

Suggested Readings

Fowler D: Distal limb and paw injuries. Vet Clin Small Anim 2006; 36: 819-845.

Swaim SF, Henderson RA: Wounds on the limbs. In: Small animal wound management. Philadelphia: Lea & Febiger, 1990.

Macphail CM: Skin grafts. In: Fossum TW (ed). Small animal surgery 4th ed. St. Louis: Mosby-Elsevier, 2013.

Reconstructive Microsurgical Applications

J. David Fowler

Reconstructive microsurgery refers to the use of the operating microscope and microvascular technique in facilitating reconstruction of difficult or complex wounds. The premise of reconstructive microsurgery involves harvesting autogenous tissue from a body part distant to the wound, transferring that tissue into the wound bed for reconstruction, and reestablishing the transferred tissue's blood supply by microvascular anastomosis of vessels feeding the flap to vessels adjacent to the wound bed. Tissues transferred in this manner are most commonly termed "free flaps." Microvascular tissue transfer, free tissue transfer, and vascularized grafts are terms also used to refer to microsurgically transplanted tissue.

Free flaps are further described according to the tissue or tissues comprising the flap. Cutaneous free flaps refer to flaps incorporating skin and subcutaneous tissue. Free muscle flaps, omental flaps, jejunal flaps, and autogenous vascularized bone grafts are other examples of tissue transfers incorporating a single tissue type. Compound flaps incorporate more than one tissue type and are described accordingly. Myo-cutaneous flaps incorporate both muscle and skin; myo-osseous flaps incorporate muscle and bone; osteomusculocutaneous flaps incorporate bone, muscle, and skin.

Successful application of microvascular tissue transfer was first reported in human patients in the early 1960s. The development of instrumentation, suture, and needles appropriate to the repair of small vessels was a prerequisite. Throughout the 1970s and 1980s, a plethora of manuscripts detailing microvascular flaps and techniques in human patients appeared in the literature. Free tissue transfer is now strongly integrated into orthopedic and reconstructive surgery.

Veterinary reconstructive microsurgery is comparatively in its infancy. However, several microvascular flaps have been described experimentally and have been applied clinically to reconstructive problems in dogs. The purpose of this discussion is to detail the latest developments in veterinary reconstructive microsurgery and to provide the reader with some insight into future potential applications.

Recipient Site Requirements

Tissues used in free flaps vary according to the requirements of the recipient wound. A detailed assessment of the wound

bed should be performed to obtain an optimal outcome after reconstruction. One of the greatest advantages of microvascular tissue transfer is the ability to select from various tissues and donor sites to best suit the patient's specific reconstructive requirements. Timing of reconstruction may also vary according to the status of the wound or exposure of vital structures.

Vascular supply is paramount to successful wound healing. Complex and high-velocity impact wounds are often associated with extensive vascular disruption. Loss of blood supply delays wound healing and increases the incidence of complications, especially in instances of orthopedic injury with associated soft tissue disruption.[1] Adequate debridement of devitalized tissue, followed by vascular enhancement through early reconstruction, is beneficial in these patients. Muscle is most efficacious in the revascularization of ischemic wound beds.[2-6] Free microvascular transfer of muscle into the wound bed assists in neovascularization of the wound and provides a source of systemic factors reducing the incidence of wound sepsis.

Structural requirements of the recipient site must also be considered in selecting appropriate tissues for microvascular transfer. In the simplest of cases, the wound may simply require a volume of tissue to replace a tissue deficit. This may be accomplished using various tissues and flaps. The specific selection of donor site depends, in these instances, on ease of access and volume of tissue required. More complex wounds, such as segmental bone loss, may have specific structural requirements that are the major determining factors in selection of donor tissue.

Functional requirements of the recipient site frequently play a role in determining the optimal donor tissue. For example, little benefit results from reconstructing a wound with loss of a vital functional muscle group unless that function is restored. Functional muscle transfer has not been reported clinically in the dog, but is used in human patients for facial reanimation and restoration of flexor function after forearm trauma.[7,8] The functional requirements of weight-bearing surfaces are particularly problematic after extensive injury to the footpads. Reconstruction using "like tissue" is ideal in such circumstances. Sensory reinnervation, although not of certain necessity, may also be accomplished through the use of a neurovascular free flap that incorporates a sensory nerve as well as a vascular pedicle. Sensory nerve repair of the donor nerve to an appropriate recipient nerve may assist in the ultimate protection of the transferred tissue against ongoing weight-bearing stresses.

Donor Site Selection

Selection of an appropriate donor tissue depends on the requirements of the recipient site. Factors to consider in the specific selection of a donor site include ease of surgical dissection, morbidity associated with loss of the donor tissue, matching of donor tissue to recipient requirements, and the ability to access both donor and recipient sites simultaneously. Free tissue transfer has been described as the art of "robbing Peter to pay Paul." The surgeon must ensure that Peter does, in fact, have what Paul needs and that, by stealing it, Peter will not suffer undue consequences.

Technical Considerations

Successful free tissue transfer depends on detailed advance planning. Familiarity of the surgical team with the procedure, patient positioning, stability of the patient under anesthesia, and selection and preparation of recipient vessels all may affect outcome.

Angiosomes

An angiosome is defined as a region of tissue or tissues perfused by a single-source artery and vein (Figure 41-26).[9] Adjacent angiosomes are interconnected by vessels termed choke anastomoses. These communications are of obvious biologic advantage. After vascular injury, an angiosome normally dependent on the injured vessel generally receives adequate vascular supply from adjacent angiosomes. However, anatomic continuity of angiosomes does not necessarily ensure physiologic continuity of vascular supply in the event of vascular injury.

The concept of the angiosome is central to the development of free tissue flaps. Tissue incorporated in a free flap should lie, ideally, entirely within the primary angiosome of the source artery and vein, to ensure survival after revascularization. Demonstration of tissue survival beyond the primary angiosome has been demonstrated with cutaneous axial pattern pedicle flaps and with some pedicled muscle flaps.[10-12] As a general rule, a single, smaller angiosome adjacent to the primary angiosome survives when incorporated into the flap design. Dissection

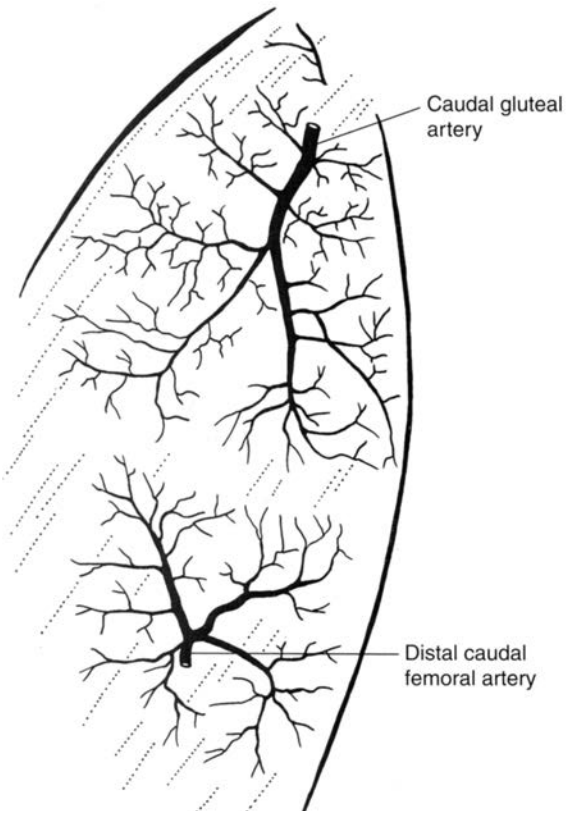


Figure 41-26. The biceps femoris muscle contains two distinct angiosomes. The proximal half of the muscle is vascularized by the caudal gluteal artery and vein, whereas the distal half of the muscle is vascularized by the distal caudal femoral artery and vein.

beyond the level of a single secondary angiosome should be considered tenuous and likely to lead to partial flap failure.

Anatomic descriptions of many cutaneous and muscle angiosomes have been provided for the dog, with few specific descriptions for the cat.[13-22] Based on this information, as well as on experimental data, several regional angiosomes and free flaps have been described. The importance of understanding the anatomy, consistency, and variability of regional vascular patterns cannot be overstated when undertaking microvascular tissue transfer.

Flap Dissection

The particular approach to flap dissection depends on the tissue harvested. Several guidelines and recommendations are common to dissecting all flaps for microvascular transfer. The tissue to be harvested must be isolated to the level of its source artery and vein. All supporting microvasculature must be preserved during this process. All underlying subcutaneous tissue should be incorporated with cutaneous flap dissections; underlying superficial cutaneous musculature should be incorporated in regions where such musculature exists. For example, the cutaneus trunci muscle should be incorporated with elevation of the thoracodorsal cutaneous flap. Muscle is readily dissected because of surrounding fascial sheaths. A soft tissue envelope is incorporated with dissection of vascularized bone grafts to preserve myoperiosteal vasculature. The reader should consult references pertaining to specific flaps, as well as the first section of this chapter, for details of surgical harvest.

Tissue is generally elevated beginning at a site distant to the vascular pedicle. Flap dissection is then continued until the source artery and vein are identified. Bleeding vessels encountered during this process should be meticulously controlled with bipolar electrocoagulation, suture ligation, or vascular clips. Once the vascular pedicle is identified, the artery and vein are skeletonized. Small branches encountered during vascular dissection may be electrocoagulated or clipped with vascular clips, depending on size. The surgeon must avoid damage to the intima of the parent vessel by excessive traction on small vascular branches or aggressive electrocautery. As much surrounding ad-ventitia as possible should be removed during initial dissection of the vascular pedicle. Surgical loupes providing a magnification of 3x to 4x facilitate identification of fine anatomic detail and atraumatic dissection of the vascular pedicle.

The length of vascular pedicle depends primarily on the anatomy of the donor flap. As a general rule, as much length as possible should be included with the initial vascular dissection. Excess length may be trimmed after transfer to the recipient site. A minimum vascular pedicle length of 1 cm is preferred, to allow manipulation of vessels during microanas-tomosis.

To minimize flap ischemia time, the vascular pedicle should not be ligated and divided before preparation of the recipient site. At that time, the artery and vein are independently ligated with vascular clips and are transected using fine vascular scissors.

Recipient Site Preparation

The recipient site should be free of devitalized tissue or active infection. Judicious debridement and lavage should be used to minimize contamination and necrotic tissue in open wounds. Early reconstruction of open wounds using vascularized tissues minimizes the risk of wound complications. In my experience, most open wounds can be converted to a state suitable for microvascular reconstruction within 48 hours of injury. Minimal debridement should be required at the time of microsurgical reconstruction. The wound bed may be lavaged preoperatively with an antibacterial solution, such as 0.05% chlorhexidine gluconate, to decrease bacterial contamination.

Recipient vessels, appropriate for anastomosis to the artery and vein of the flap to be transferred, must be identified and dissected. A knowledge of regional vascular anatomy is obviously a prerequisite. In patients with severe trauma, or a past history of trauma or surgery involving the affected area, preoperative angiography should be considered to identify variations in vascular anatomy. Recipient vessels should approximate the diameter of donor vessels, assuming end-to-end anastomosis. End-to-side technique is often used for arterial anastomosis, to preserve arterial supply distal to the wound. In this event, the recipient artery should be of larger diameter than the donor artery. Recipient vessels should be dissected beyond the wound's zone of trauma. The surgical approach used for vascular dissection should involve elevation of a skin flap such that the incision will not directly overlie the vascular anastomosis after skin closure.

The free flap is secured at the recipient site before initiating microvascular anastomosis. In the case of soft tissue flaps, this is accomplished using a few strategically placed simple interrupted sutures. Cutaneous flaps are sutured under minimal tension. Muscle flaps are sutured under sufficient tension to approximate their initial resting length at the donor site. Vascularized bone grafts are stabilized using suitable orthopedic fixation. Microvascular anastomosis of the donor and recipient artery and vein is then completed using an operating microscope and standard microvascular technique. Approximating clamps are not released until the completion of both artery and vein repair.

Pedicle length must be planned to avoid excessive length and redundancy of the pedicle or insufficient length resulting in tension or kinking. The vascular pedicle must be carefully positioned to avoid compression of the anastomosed vessels during closure. The venous pedicle is particularly sensitive to these effects. The vascular pedicle is assessed for patency, and remaining sutures are placed between the flap and the recipient wound bed. Patency should be reassessed before final skin closure. Total operative time is minimized by using two surgical teams. One team harvests the donor tissue while the second simultaneously prepares the recipient site.

Flap Perfusion and Anticoagulation

Uncomplicated free tissue transfer generally requires approximately 4 hours of general anesthesia. More complicated procedures, such as those requiring orthopedic fixation, may

necessitate 6 to 10 hours of general anesthesia. Adequate flap perfusion depends on maintaining the cardiovascular stability of the patient during the operative and postoperative periods. Intravenous fluid support during and after surgery is an absolute requirement.

Hypothermia must be controlled to avoid peripheral vasoconstriction and deleterious effects on flap perfusion. Patients are maintained on circulating water blankets, and temperature is monitored both during and after the surgical procedure. A heat lamp may be placed over the flap during the immediate postoperative period, before the patient's recovery from anesthesia. Bandaging of flaps using a lightly applied, heavily padded bandage protects the flap from trauma and assists in trapping body heat.

No consistent recommendation exists on the use of antithrombotic agents before, during, or after microvascular tissue transfer. The most critical factor in preventing thrombosis of the microvascular anastomosis is appropriate surgical technique, and no amount of antithrombotic therapy can salvage a poorly performed anastomosis. Heparin and saline (10 units heparin per 1 mL saline) are used topically at the anastomotic site to clear the lumen of vessels before anastomosis. Other antithrombotic therapy is determined by the preference of the surgeon and identified patient risk factors.

Aspirin may be used at a dose of 5 to 10 mg/kg body weight preoperatively, to inhibit platelet aggregation.[23] I routinely administer dextran 40 at a dose of 10 mL/kg body weight intraoperatively. Dextran administration expands the vascular space, thereby improving flap perfusion, and it may have an inhibitory effect on platelet function.[24] Anticoagulation using systemic heparin is rarely indicated.

Tolerated flap ischemia times vary according to the tissue transferred.[25-27] Skin is considered resistant to the detrimental effects of ischemia and reperfusion. Cutaneous free flaps tolerate 6 to 8 hours of warm (room temperature) ischemia before the onset of significant injury. Muscle is sensitive to ischemia and reperfusion and may demonstrate detrimental effects after 2 to 4 hours of warm ischemia. Total ischemia times in clinical free tissue transfer rarely exceed these time frames. In my experience, flap ischemia times have varied from 60 to 180 minutes.

Occasionally, a flap fails to perfuse after an apparently successful microvascular anastomosis. This is termed a "no-reflow" phenomenon and may be attributed to many causes. In this event, the vascular pedicle extending from the anastomotic site to the flap should be inspected under the operating microscope. Active bleeding through any previously unidentified branches from the pedicle is controlled with vascular clips. Specific attention is paid to areas of potential vascular injury and vasospasm. If a region of vasospasm is identified, 2% lidocaine is placed topically on the vessel. If focal vasospasm persists, then damage to the vessel may be assumed, and microvascular anastomosis should be repeated distal to this site. No reflow may occasionally be caused by inappropriate or traumatic dissection of the flap, with subsequent injury to the supportive microvasculature. This problem is easily avoided through meticulous attention to flap dissection. Little can be done to rectify the situation after its occurrence. Extended ischemia time may lead to reperfusion injury and subsequent occlusion of venous microvasculature by neutrophil adhesion. Therapy aimed at alleviating ischemia-reperfusion injury is indicated, but it is of questionable benefit after the period of reperfusion.

Postoperative Monitoring

Free flaps entirely depend on the integrity of the microvascular anastomsoses. Free flap failure may be caused by venous or arterial thrombosis, either of which must be recognized early and investigated aggressively if the flap is to be salvaged. Venous failure of cutaneous flaps is most easily recognized by the onset of congestion in the flap (Figure 41-27). A purplish-blue discoloration is noted. Bandaged flaps may be assessed by creating a window in the bandage to allow visualization of a portion of the flap. Flaps tolerate venous outflow occlusion poorly. At the earliest indication of this problem, the patient should be returned to the operating room, and the vascular pedicle should be dissected using the operating microscope. Careful attention is paid during the approach to look for evidence of vessel compression or kinking caused by positioning of the vascular pedicle or restrictive skin closure. If this is the case, the anastomosis may actually be patent, and the problem is addressed by simple repositioning of the pedicle or release of the overlying skin incision. In the event of a thrombosed anastomosis, the



Figure 41-27. A latissimus dorsi myocutaneous flap has been used to reconstruct a large deficit over the rear quarters in this dog. Venous compromise of the flap is visually apparent because of the onset of congestion and purplish discoloration of the flap. Reexploration of the venous pedicle and, possibly, medicinal leech therapy are indicated.

region of thrombosis is excised, and venous effluent from the flap is documented. Once flow through the flap is established, venous anastomosis is repeated. Sluggish venous outflow may also be treated by application of medicinal leeches. Leeches reduce flap congestion by direct ingestion of blood and by promoting continued hemorrhage from bite wounds resulting from local infusion of hirudin.[28]

Arterial failure can be more difficult to diagnose because it is not associated initially with overt color change of the flap. Flap temperature can be monitored; a drop in temperature indicates arterial insufficiency. This method is unreliable in bandaged flaps, because the bandage traps body heat and artificially elevates flap temperature. Doppler flow probes may be used to monitor arterial patency more reliably in the postoperative period. A window is created in the bandage overlying the arterial pedicle distal to the anastomosis. A pencil Doppler probe is then easily inserted through the window to monitor arterial patency. Bleeding may be a useful indicator of flap perfusion. Cutaneous flaps are punctured with a 20- or 22-gauge hypodermic needle and are monitored for active bleeding from the site. More specialized monitoring techniques such as laser Doppler flowmetry or fluorescein clearance have been described, but they are usually beyond the realm of clinical necessity.

Monitoring of flaps that do not incorporate a cutaneous component is more difficult. Doppler techniques are useful for monitoring arterial adequacy in such flaps. Venous monitoring is difficult or impossible. Vascularized bone grafts should be assessed using [^{99m}] technetium scintigraphy within 5 days of operation.

Free Flaps in the Dog and Cat

Several free flaps have been described experimentally, clinically, or both in the dog and cat. Other flaps have been described as pedicled flaps, maintaining a vascular attachment to the donor site. These flaps may be used reliably for free transfer as well, assuming adequate dimensions of the vascular pedicle. Vessel diameters for most described flaps in the dog approximate 1 to 2 mm. Vessel diameters of less than 0.5 mm are associated with increased rates of anastomotic thrombosis.

Cutaneous Flaps

Cutaneous angiosomes have been described extensively, and anatomic landmarks for dissection of pedicled cutaneous axial pattern flaps are well documented. Axial pattern skin flaps may be used for free transfer as well.

The superficial cervical axial pattern flap, based on the direct cutaneous pedicle of the prescapular branch of the superficial cervical artery and vein, has been documented as a free flap in a series of cases (Figure 41-28).[29,30] The vascular pedicle perforates the septum formed by the omotransversarius, cleidocervicalis, and trapezius muscles. The cutaneous angiosome extends dorsally from the point of origin to the midline and roughly incorporates the caudal two-thirds of the cervical skin in a cranio-

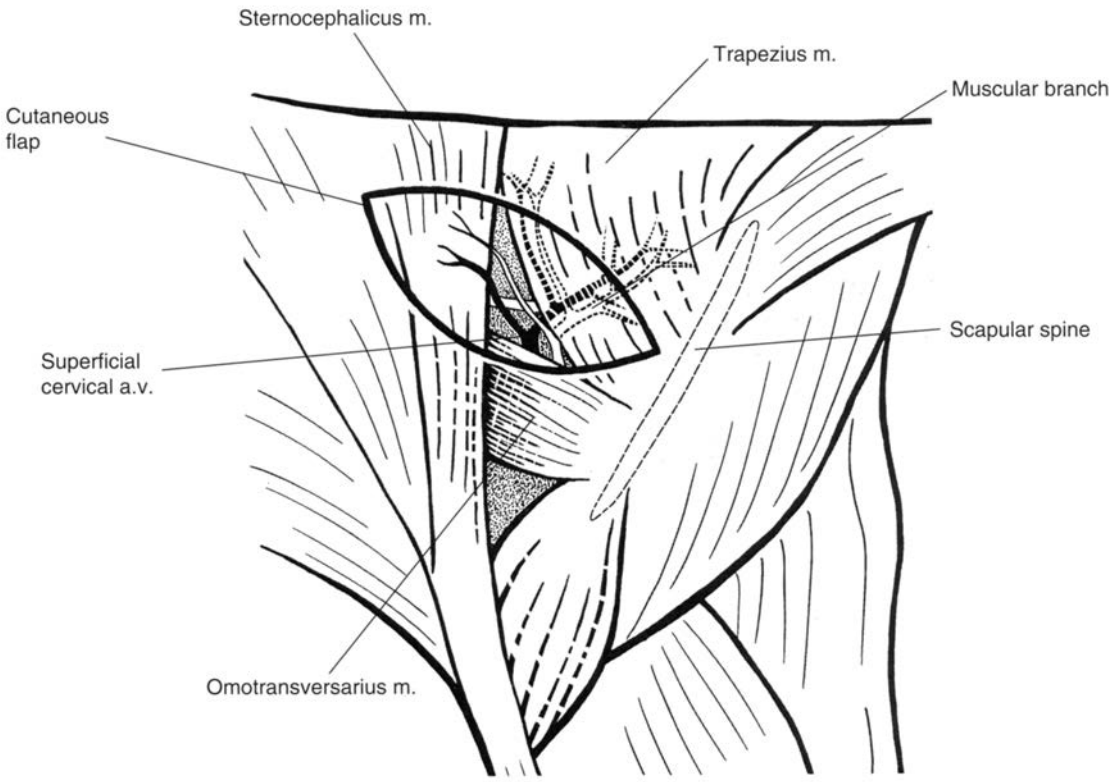


Figure 41-28. The anatomy of the superficial cervical cutaneous free flap is indicated. The direct cutaneous artery arises from a septum formed by the trapezius, omotransversarius, and sternocephalicus muscles. The muscular branch to the cervical portion of the trapezius muscle also arises from the superficial cervical artery.

caudal direction. The amount of skin harvested for transfer is determined, first, by the requirements of the recipient site and, second, by the ability to close the donor site primarily.

I have also used the caudal superficial epigastric axial pattern flap sporadically for microvascular transfer. The primary advantage of selecting an axial pattern skin flap for microvascular transfer is ease of dissection. Disadvantages include excessive bulk from inclusion of associated subcutaneous tissue and poor cosmetic result caused by differential hair growth characteristics between donor and recipient sites.

The saphenous fasciocutaneous free flap has been documented in experimental and clinical cases.[28,31] The flap is based on the medial saphenous artery and vein and includes the skin overlying the medial aspect of the thigh (Figure 41-29). Flap dissection includes the superficial fascia of the medial gastrocnemius muscle, giving the flap its designation as fasciocutaneous. Numerous small direct cutaneous vessels arise from the saphenous vessels as they course through the flap. The saphenous fasciocutaneous flap has the advantage of less bulk and improved cosmetic results compared with other free axial pattern skin flaps. The width of the flap is limited by the ability to close the donor site primarily.

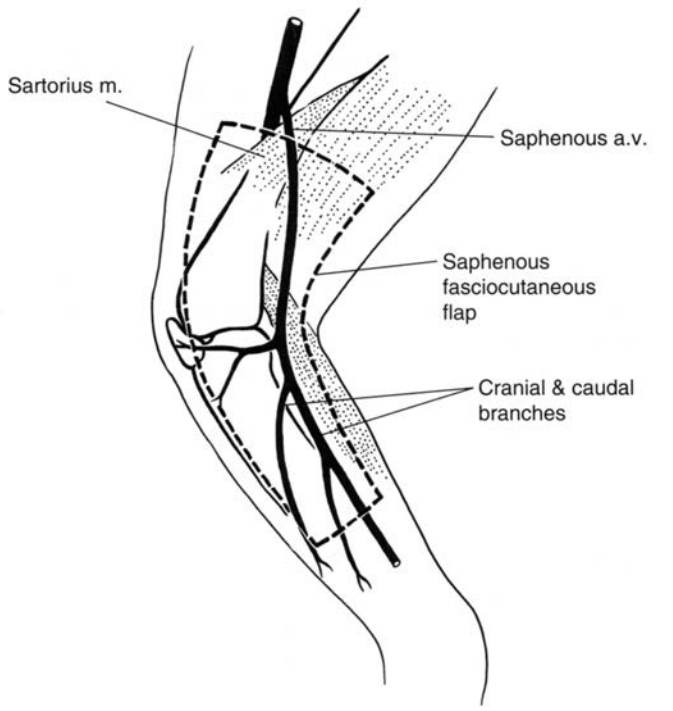


Figure 41-29. The saphenous fasciocutaneous flap is composed of skin and underlying fascia overlying the medial aspect of the thigh and tibia. The flap is based on the medial saphenous artery and vein. Inclusion of the caudal sartorius muscle is possible, by preservation of muscular branches from the saphenous vessels.

Muscle Flaps

Muscle probably has the greatest utility of any tissue used for microsurgical reconstruction. Muscle flaps are, for the most part, easily dissected. Most muscles may be harvested with minimal donor site morbidity because of the function of synergic muscle groups. Neovascularization of compromised wound beds is facilitated to a greater degree by muscle than by other tissues. Finally, donor muscles may be selected that closely match the dimensional and functional requirements of nearly any wound reconstruction.

The angiosomes of muscles may be classified into one of five types (Figure 41-30). Type I muscles have a single dominant vascular pedicle. Type II muscles have a single dominant pedicle and one or more minor pedicles. Type III muscles contain two dominant vascular pedicles, each of which has an approximately equal contribution to the muscle's blood supply. Type IV muscles have a segmental blood supply formed by numerous small pedicles of approximately equal contribution. Type V muscles have a single dominant vascular pedicle near their insertion and a segmental system near the origin of the muscle. Based on assumptions of physiologic blood supply through angiosomes, one can surmise that any type I muscle will survive entirely after free transfer based on the single dominant pedicle. Most type II muscles willl survive based on the dominant pedicle, depending on the number and relative contribution of the minor pedicles. Type III muscles are expected to survive after free transfer based on either dominant pedicle system. Type V muscles generally will survive based only on the single dominant pedicle. Type IV muscles are generally poor candidates for microvascular transfer because of the large number and small contribution of each pedicle system to the muscle's blood supply. Detailed descriptions of the vascular supply to muscles of the dog have been published.[21,22] The foregoing assumptions given serve as guidelines only. The ultimate reliability of any muscle in reconstructive microsurgery is proved only through experimental or clinical trials that establish its utility. If at all possible, muscle transfers should be limited to single angiosomes or previously documented free flaps.

Trapezius Muscle Flap

The vascular supply of the cervical portion of the trapezius muscle has been thoroughly described, as has the entire angiosome of the prescapular branch of the superficial cervical artery and vein (Figure 41-31).[32] The cervical portion of the trapezius muscle has a type II vascular supply, with the prescapular branch of the superficial cervical artery forming the dominant pedicle. Experimentally and clinically, survival of the entire cervical portion of the muscle has been consistently documented based solely on this dominant pedicle.

Dissection of the trapezius muscle flap is through a curvilinear incision beginning approximately 2 to 3 cm cranial to the point of the shoulder, extending dorsally parallel to the scapular spine and curving cranially below the dorsal midline.[33] Skin and subcutaneous tissue are dissected from the superficial fascia of the muscle, with care taken to identify and ligate the direct cutaneous branch as it exits the septum formed by the trapezius, omotransversarius, and cleidocervicalis muscles. The cervical portion of the trapezius muscle is sharply incised from its attachment to the scapular spine. Fascial attachments dorsally are incised, and the muscle is elevated carefully. Several muscle branches extending into deep musculature of the neck are identified and are ligated with vascular clips. At this point, the vascular pedicle should be located. The location of the pedicle is variable as it courses deep

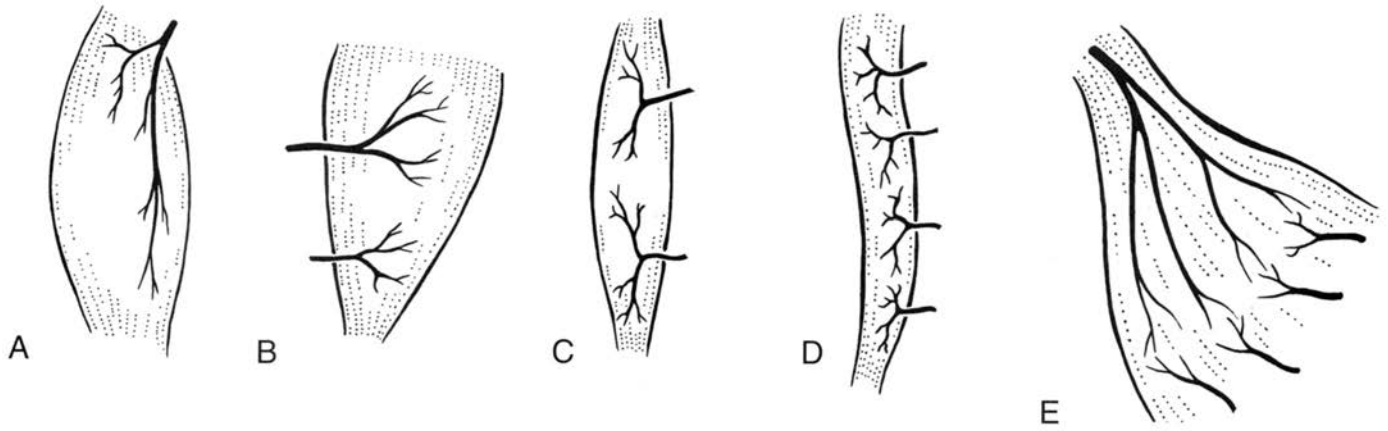


Figure 41-30. Diagrammatic representation of the five basic vascular patterns to skeletal muscles. **A.** Type I muscles have a single vascular supply. **B.** Type II muscles have one dominant pedicle and one or more minor pedicles. **C.** Type III muscles contain two equally dominant pedicles. **D.** Type IV muscles have a segmental blood supply derived from numerous small pedicles. **E.** Type V muscles have a single dominant pedicle near their insertion and a second segmental system near their origin. Type IV muscles are the least suitable for microvascular application.

to the trapezius muscle. It is most commonly located immediately beneath the cranial border of the muscle coursing from ventral to dorsal. In a few instances, the vascular pedicle lies immediately cranial to the cranial border of the trapezius muscle and gives off several smaller muscular branches to the muscle as it extends dorsally. Dissection in these patients must be performed with caution, to preserve the integrity of the vascular pedicle. After identification of the prescapular branch of the superficial cervical artery and vein, remaining muscle attachments are dissected. One or two small muscular branches to the omotransversarius muscle are identified and clipped, and the artery and vein are skeletonized and dissected for a length of at least 2 to 3 cm. The prescapular lymph node is intimately associated with the vascular pedicle and may either be included with the pedicle or carefully excised.

I used the trapezius muscle free flap for distal extremity reconstruction in a series of 20 cases. The trapezius muscle is broad and flat, lending itself well to conformation to many wound beds. Bulk of the flap is minimal and decreases dramatically over the course of several weeks because of denervation atrophy. Despite denervation atrophy, transferred muscle maintains a constant vascular density beneficial to the wound bed. The trapezius muscle is resurfaced using a full-thickness skin graft harvested from a donor site with hair growth characteristics similar to those of the recipient

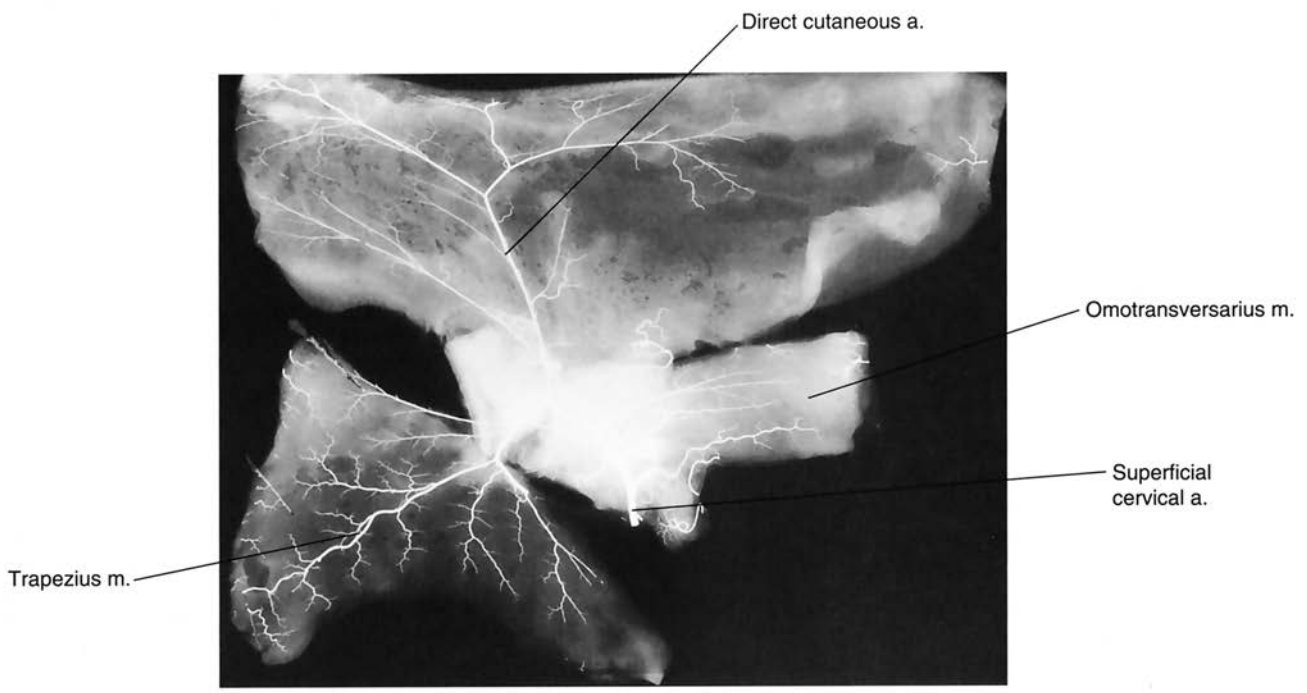


Figure 41-31. Barium has been infused into the superficial cervical artery to demonstrate the regional angiosome of this vessel. The superficial cervical artery gives rise to the dominant pedicle of the cervical portion of the trapezius muscle, the superficial cervical direct cutaneous artery, and a minor pedicle to the omotransversarius muscle. Any or all of these tissues may be included in a microvascular flap based on this vascular pedicle.



Figure 41-32. A. Cosmetic results are less than optimal after reconstruction using the trapezius myocutaneous flap because of the excessive subcutaneous bulk and poor match of hair characteristics. **B.** Contour and hair characteristics are much more closely matched by using the trapezius muscle flap and resurfacing with a full-thickness skin graft.

site. This technique has resulted in improved cosmetic results, compared with cutaneous or musculocutaneous free flaps (Figure 41-32). Seroma formation at the donor site is common and should be managed with drain placement for 5 to 7 days.

Latissimus Dorsi Muscle Flap

The latissimus dorsi muscle has, historically, been the workhorse for microsurgical reconstruction of complex distal extremity wounds in human patients. Pedicled latissimus dorsi muscle flaps have been used for chest wall reconstruction and experimental cardiomyoplasty in the dog and have been described experimentally for microsurgical transfer in the cat.[34] The latissimus dorsi muscle reliably survives in its entirety based solely on the dominant thoracodorsal artery and vein, which enter the deep surface of the muscle near its insertion (Figure 41-33). The muscle is approached through a curvilinear skin incision beginning at the axilla and extending dorsally and caudally to the level of the muscle's origin. Skin and subcutaneous tissues are dissected from the superficial muscle fascia, with care taken to identify and ligate the direct cutaneous branch of the vascular pedicle, located near the caudal shoulder depression. The origin of the latissimus muscle is identified and is sharply incised. Muscle elevation reveals numerous small muscular branches ex tending from the intercostal arteries. Segmental pedicles are cauterized or ligated and are transected as they are encountered. Dissection continues toward the muscle's insertion, and the dominant thoracodorsal artery and vein are identified on the deep surface of the muscle. After identification of the vascular pedicle, the muscle's tendon of insertion is transected, and the thoracodorsal artery and vein are skeletonized for a length of at least 2 to 3 cm. The cat occasionally has a minor pedicle originating from the lateral thoracic artery and vein, which enter

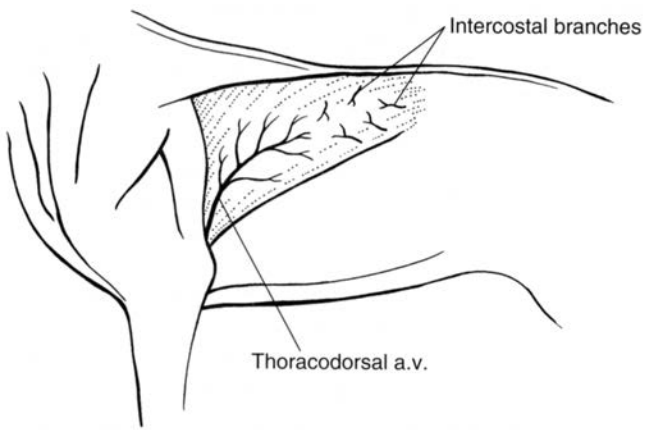


Figure 41-33. The latissimus dorsi flap is based on the dominant thoracodorsal vascular pedicle. The entire muscle survives based on this dominant pedicle.

the deep surface of the muscle ventrally near its tendon of insertion. This pedicle must be identified and ligated. The thoracodorsal pedicle in the cat has a diameter of approximately 0.4 mm, making microvascular anastomosis difficult. Dissection in the cat is therefore continued to the level of the origin of the subscapular artery and vein from the axillary vessels to facilitate subsequent anastomosis.

The dimensions of the latissimus dorsi muscle exceed the requirements of most wound beds in the dog. Its clinical use therefore has been sporadic. The latissimus dorsi muscle is useful as a free flap in patients with massive soft tissue loss secondary to trauma or ablative cancer surgery. I have used the latissimus dorsi free flap for cranial reconstruction after partial

craniectomy and orbitectomy for a sebaceous adenocarcinoma in a dog and for reconstruction of a massive rear limb degloving injury with associated orthopedic trauma. Clinical experience with this flap, however, is limited.

Vascularized Bone Grafts

The veterinary literature has no clinical reports, and few experimental descriptions, of autogenous vascularized bone grafts. Numerous reports of vascularized canine bone grafts appear as experimental models in the human literature. The indications, contraindications, and clinical utility of nonvascularized cortical bone grafts are well established. Nonvascularized cortical bone grafts provide immediate structural support in orthopedic reconstruction. Ultimate success depends on revascularization of the cortical graft from the wound bed, followed by gradual resorption and new bone deposition. This process requires years to complete and depends on a favorable wound environment. Osteomyelitis, structural weakening of the graft, and delayed healing of graft-bone interfaces are common complications.

Autogenous vascularized bone grafts are advantageous in that they maintain a vascular supply and, therefore, viability of cellular elements within the graft. Graft bone actively contributes to bone healing and remodeling. Vascularized grafts are more resistant to infection than nonvascularized grafts, lending themselves to the reconstruction of large segmental defects or vascularly compromised wound beds. Vascularized bone grafts described in the dog include rib, fibula, proximal ulna, and distal ulna.[35]

Vascularized Fibula Graft

The canine fibula graft has been used as an experimental model for the study of vascularized bone graft biology (Figure 41-34).[36] The popliteal artery branches into a larger cranial tibial and a smaller caudal tibial artery. The caudal tibial artery enters the interosseous space between the fibula and tibia and is intimately associated with the flexor hallucis longus muscle. The nutrient artery of the fibula arises from the caudal tibial artery and enters the fibula medially in its central third. Dissection of the fibula is performed to maintain a surrounding muscle cuff. Particular care is taken to preserve the flexor hallucis longus muscle with the graft. Subperiosteal dissection of the tibia is required to preserve vasculature within the interosseous space. The fibula may be transferred based either on the caudal tibial artery or on the popliteal artery. Dissection to the level of the popliteal artery necessitates ligation and transection of the cranial tibial artery. Use of the caudal tibial artery as a pedicle may be limited by the diameter of these vessels. Iatrogenic damage to the peroneal nerve must be avoided during proximal dissection of the graft and vascular pedicle. The vascularized fibula graft has not been used clinically in the dog and likely has limited utility for segmental long bone reconstruction because of its poor structural integrity.

Vascularized Rib Graft

Microsurgical transfer of the rib has been used in the dog as an experimental model for bone transfer.[37] Either the dorsal or the ventral part of the intercostal vascular system may be used as a vascular pedicle for rib transfer. Inclusion of the nutrient artery with the transfer mandates dorsal dissection.

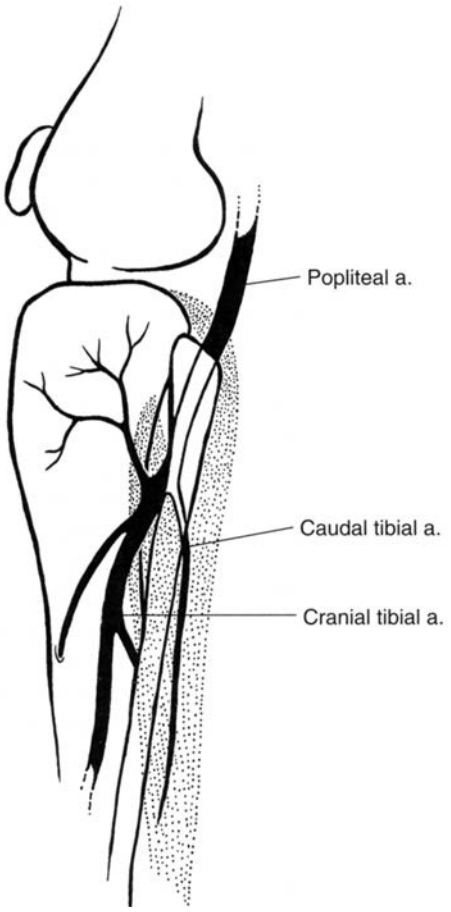


Figure 41-34. The anatomy of the vascularized fibula graft is demonstrated. The fibula may be harvested based on the caudal tibial artery. Dissection to the level of the popliteal artery gives rise to a more manageable pedicle for microvascular anastomosis, but it necessitates ligation of the cranial tibial artery.

Ventrally dissected grafts survive based on an intact musculoperios-teal vascular supply. The dorsal intercostal arteries arise from the thoracic aorta. Immediately before entering the intercostal space, a dorsal branch supplying the spinal cord and epaxial muscles is given off. The nutrient artery branches from the dorsal intercostal artery just distal to the tubercle of the rib and extends dorsally to enter the nutrient foramen. The dorsal intercostal artery continues distally in the costal groove on the caudal aspect of the rib, giving off numerous periosteal branches. A lateral cutaneous branch is formed from the dorsal intercostal artery before its anastomosis with the ventral intercostal artery. Intercostal veins parallel the arterial supply, with eventual drainage into the azygous vein. Clinical utility of the rib graft likely will be limited by its curvature and weak structural characteristics. Vascularized rib grafts may prove to have some usefulness in mandibular reconstruction, although this remains to be documented.

Vascularized Proximal Ulna Graft

The canine ulna may be harvested with little resulting functional impairment to limb use. This fact, along with the obvious structural integrity of the ulna, makes it a logical choice for segmental long bone reconstruction. The proximal ulna bone graft is harvested based on the common interosseous vascular

pedicle.[38] The common interosseous artery arises from the median artery at the level of the proximal radius, immediately enters the interosseous space from the medial side, and bifurcates into caudal and cranial interosseous branches. The caudal interosseous artery continues distally in the interosseous space, where it gives rise to the nutrient arteries of the radius and ulna, as well as to multiple periosteal branches. The nutrient artery of the ulna enters near the junction of the proximal and central thirds of the bone. The cranial interosseous artery emerges from the interosseous space laterally, where it gives rise to muscular branches to the extensor carpi ulnaris and the lateral and common digital extensor muscles.

Dissection of the proximal ulna graft is performed through a curvilinear caudolateral skin incision. Fasciotomy of the flexor and extensor muscle groups facilitates muscle dissection and identification of vascular structures. Separation between the extensor carpi ulnaris and the lateral digital extensor muscles proximally reveals vascular branches to these muscles. These muscular branches serve as a consistent landmark indicating the level of the vascular pedicle of the flap (Figure 41-35). The lateral radial periosteum is incised along the cranial surface of the abductor pollicis longus muscle, and subperiosteal dissection of the radius is continued into the interosseous space. The medial radial periosteum is similarly incised and elevated. Distal osteotomy of the ulna is then performed using an oscillating bone saw. The caudal interosseous artery and vein are identified within the interosseous space, ligated, and divided. Proximal osteotomy of the ulna is performed proximal to the level of the vascular pedicle. Circumferential subperiosteal dissection of the ulna is performed at this level, and the ulna is osteotomized. Muscular branches to the extensor muscles are ligated and divided. Cautious elevation of the os-teotomized ulna reveals the common interosseous pedicle on the medial aspect of the graft. The common interosseous artery and vein are dissected to their point of origin from the median artery and vein.

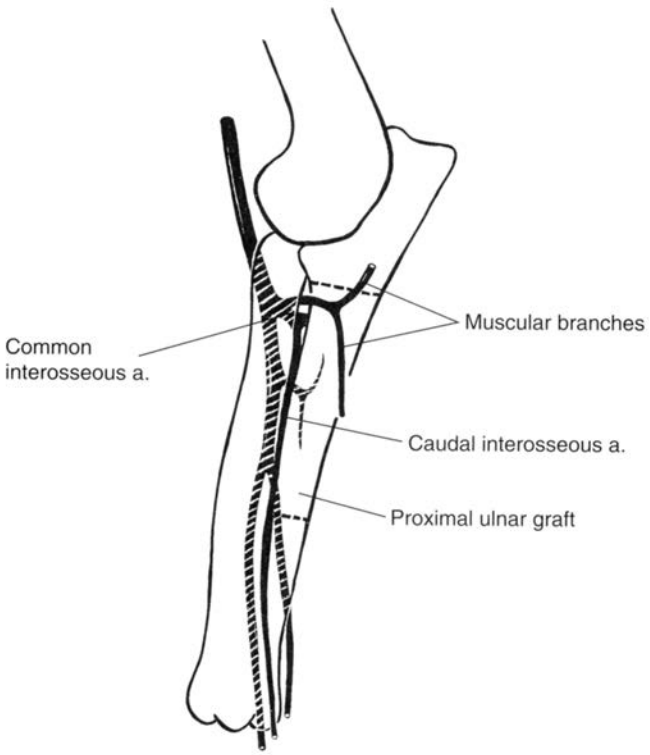


Figure 41-35. The proximal ulna vascularized bone graft is based on the common interosseous pedicle and preserves both the periosteal and nutrient vascular systems. Muscular branches to extensor muscles indicate the approximate level of the common interosseous pedicle.

Advantages of the proximal ulna graft include structural integrity and provision of a nutrient blood supply. Primary disadvantages include the necessity of proximal osteotomy adjacent to the elbow joint, difficult dissection of the vascular pedicle because of its medial location, and limited length of the vascular pedicle. The proximal ulna graft has been documented experimentally, but it has not yet been used clinically in the dog.

Vascularized Distal Ulna Graft

The distal ulna graft has great potential for clinical use in the dog.[39] The approach to initial dissection of the graft is identical to that described for the proximal ulna graft. After fasciotomy of the flexor and extensor muscle groups, the caudal interosseous artery and vein are identified as they exit the interosseous space caudomedially at the level of the distal ulna. These vessels are ligated and transected. The ulna is circumferentially dissected immediately distal to this level and is osteotomized using an oscillating bone saw. Dissection of the medial and lateral radial periosteum is performed as described for the proximal ulna transfer and is continued proximally. Subperiosteal dissection of the radius must be performed with great caution to avoid damage to the caudal interosseous vessels as they course through the interosseous space. The length of graft required for recipient site reconstruction is calculated. Proximal osteotomy is performed after circumferential subperiosteal dissection of the ulna. The proximal osteotomy should be performed such that the resulting length of bone graft is 2 to 3 cm longer than that required for the reconstructive procedure (Figure 41-36). The caudal interosseous artery and vein are located within the interosseous space, ligated with vascular clips, and transected. Once harvested, the interosseous artery and vein are dissected for a length of approximately 3 cm. The bone graft is then shortened to its required length by osteotomizing that portion of proximal ulna from which the vascular pedicle has been dissected.

The distal ulna graft depends entirely on an intact musculoperiosteal circulation for survival. An intact musculoperiosteal cuff must be included with the dissection, to include the ulnar head of the deep digital flexor, the pronator quadratus, and the abductor pollicis longus muscles. External skeletal fixation is recommended to minimize implant-associated embarrassment of the periosteal vasculature.

The utility of the vascularized distal ulna graft has been demonstrated experimentally.[40] I have used the distal ulna graft for reconstruction of the distal radius after limb-sparing surgery for osteosarcoma and for reconstruction of a mandibular nonunion and segmental defect caused by a gunshot injury.

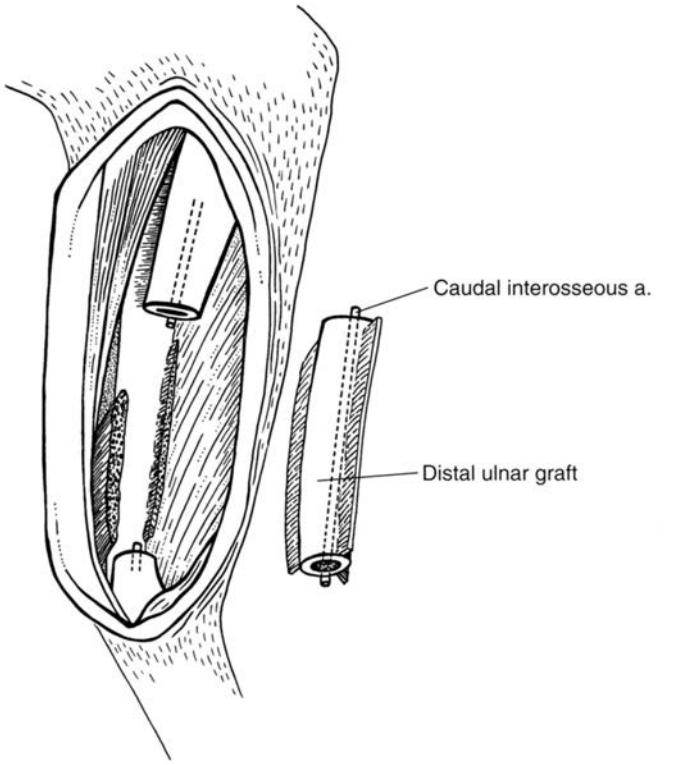


Figure 41-36. The distal ulna vascularized bone graft is based on the caudal interosseous artery and vein. Dissection preserves only the periosteal vascular supply. Inclusion of a surrounding muscle cuff is required to preserve this blood supply.

Compound Flaps

Compound free flaps incorporate tissues of more than one type. They may be useful for the reconstruction of complex trauma involving loss of multiple tissue types. A detailed knowledge of vascular anatomy allows the surgeon the flexibility of designing many compound flaps.

Musculocutaneous flaps combine both muscle and skin in the transfer. The superficial cervical axial pattern skin flap may easily be included with the cervical portion of the trapezius muscle by maintaining the direct cutaneous branch rather than by ligating it during dissection. The vascular supply to both muscle and skin is based on the prescapular branch of the superficial cervical artery and vein. Similarly, the thoracodorsal axial pattern skin flap may be incorporated with the latissimus dorsi muscle flap. Dissection of musculocutaneous free flaps must be carefully planned to include appropriate dimensions of the cutaneous component. With inclusion of an axial pattern skin flap, the cutaneous component may be used to overlie the transferred muscle directly and to reconstruct an associated cutaneous defect. The axial pattern skin flap may also be dissected free of the muscle flap, with care taken to maintain the direct cutaneous artery and vein. This allows use of both the muscle and cutaneous components for reconstruction of adjacent portions of large wound beds (Figure 41-37).

Myo-osseous flaps incorporate both muscle and bone. By strict definition, all vascularized bone grafts may be considered myo-osseous because of the preservation of an intact musculo-

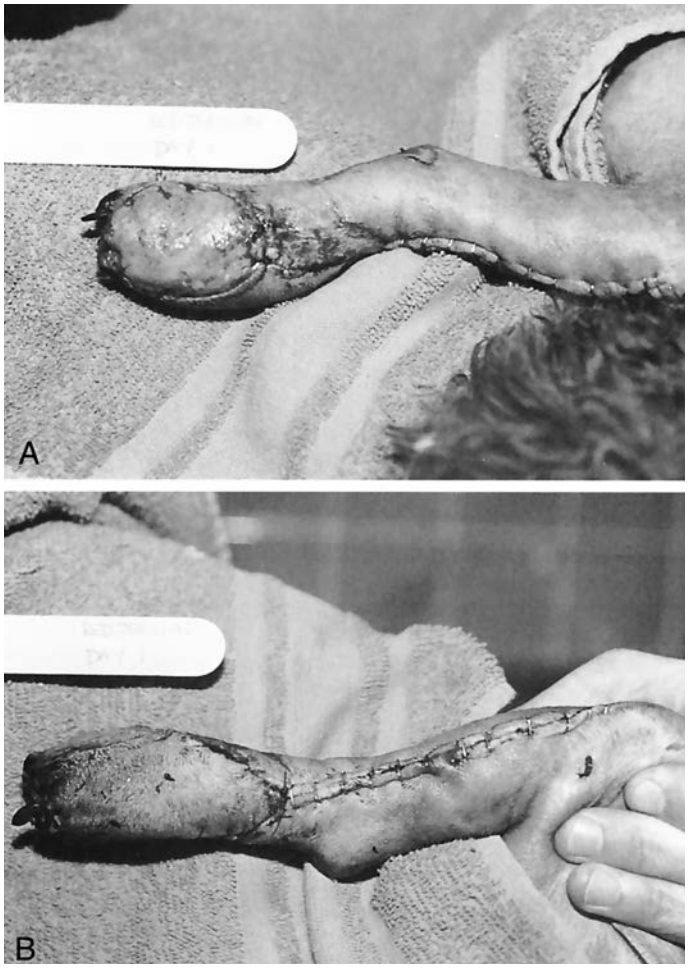


Figure 41-37. The cutaneous portion of myocutaneous flaps incorporating a direct cutaneous artery may be dissected independent of the underlying muscle. In this dog, the trapezius muscle was used to reconstruct the lateral aspect of a large degloving injury **A.** while the cutaneous portion of the flap was rotated to cover the defect medially **B.** The muscle was subsequently resurfaced with a full-thickness skin graft. Both components of the flap are based on the superficial cervical artery and vein.

periosteal cuff. However, the term is recognized to designate the inclusion of a significant muscle component used in the reconstruction. The successful inclusion of the scapular spine with the cervical trapezius muscle flap has been demonstrated experimentally (Figure 41-38).[41] Survival of the scapular spine depends on its periosteal vascular supply. Unfortunately, the scapular spine lies outside the primary angiosome of the prescapular branch of the superficial cervical artery, and this causes some concern relative to the reliability of its vascular integrity after transfer. I have used the cervical trapezius myo-osseous flap for reconstruction of metatarsal segmental defects and overlying soft tissue loss caused by a gunshot injury in a Chesapeake Bay retriever. Survival of the muscle flap and its overlying free skin graft was evident. However, postoperative [^{99m}]technetium scintigraphy of the bone graft was negative. This bone graft proceeded to rapid incorporation and healing, a finding suggesting either an intact vascular supply or rapid revascularization. Based on the negative scintigraphy results in this dog and the tenuous vascular integrity of the flap design, the cervical trapezius myo-osseous flap should be used with caution.



Figure 41-38. The trapezius flap may be extended to include the scapular spine, to form an osteomusculocutaneous flap. The scapular spine lies outside the primary angiosome of the flap, but experimentally it has been shown to survive based on perfusion through "choke" anastomoses from the trapezius muscle. Elevation of the flap based on the superficial cervical vessels is demonstrated.

The vascularized rib graft may be harvested as an osteocutaneous flap by preserving the cutaneous branch of the dorsal intercostal artery and its associated skin paddle. Maintenance of the skin paddle facilitates postoperative monitoring of vascular integrity of the flap. This flap may also be of benefit in mandibular reconstruction with associated skin loss.

Reconstruction of Weight-Bearing Surfaces

Reconstruction of weight-bearing surfaces poses a particular problem because of the stresses placed on the repair. Tissue used for such reconstruction must be durable and resilient. Local footpad transposition techniques and free pad grafts have been described for footpad reconstruction.[42-45] Marginal recipient beds may compromise the success of free grafts, and extensive trauma may preclude local transposition techniques. Free vascularized transfer of footpads may be used for reconstruction in such cases.

A microvascular transfer of the fifth digital footpad was described previously (Figure 41-39).[46] This procedure involves a digital fillet of the fifth rear digit. All phalangeal bones are dissected extraperiosteally and are excised through a dorsal skin incision. The digital pad and surrounding skin are then harvested, based on the deep plantar metatarsal artery IV and the superficial dorsal metatarsal vein IV. Sensory innervation is provided by the deep plantar metatarsal nerve IV and parallels the arterial supply to the footpad. Transfer may be accomplished as a microvascular free flap or as a neuromicrovascular free flap with repair of the donor nerve to a sensory nerve branch at the recipient site. The absolute necessity of sensory reinnervation in such flaps is not established.

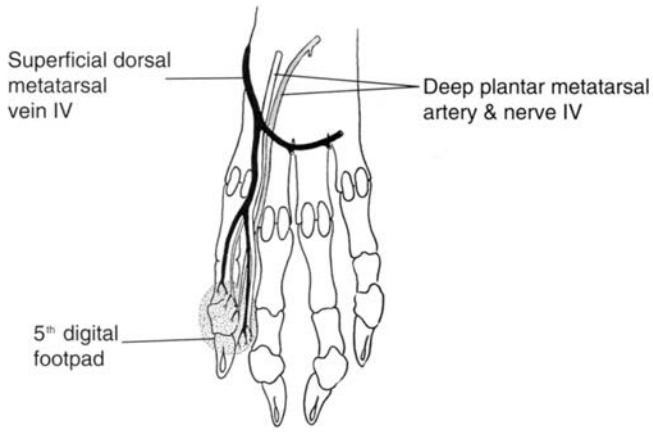


Figure 41-39. The fifth digital footpad may be harvested as a microvascular free flap for reconstruction of weight-bearing surfaces. Elevation of the flap involves a fillet of the digit through a dorsal incision. The vascular pedicle consists of the deep plantar metatarsal artery IV and the superficial dorsal metatarsal vein IV. Sensory innervation may be provided by including the deep plantar metatarsal nerve IV with subsequent repair of the nerve to an appropriate sensory recipient nerve.

The carpal pad may also be transferred as a microvascular free flap. This flap is advantageous in that a larger area of surrounding skin may be included with the flap, and harvest does not necessitate digital amputation. The smaller size and conical shape of the carpal pad make initial resurfacing of the weight-bearing surface more difficult compared with the digital pad flap. The carpal pad flap is dissected based on the caudal interosseous artery as it courses through the carpal tunnel. Two to three small venous branches from the medial aspect of the flap drain into the cephalic vein, which serves as the venous pedicle.

Both the digital pad flap and the carpal pad flap have been used for reconstruction of severely traumatized feet in dogs. The transferred pads have proved resilient to weight-bearing stresses and have undergone hypertrophic change in response to continued weight bearing. Precise positioning of the pad is essential to avoid trauma to surrounding hirsute skin. The most common complication of microvascular footpad transfer has been chronic incisional breakdown at the junction of donor and recipient skin caused by repeated tensile stresses placed on the wound. Functional reconstruction of weight-bearing surfaces is difficult. Further research and experience are needed before firm recommendations can be made regarding optimal techniques.

Complications of Free Flaps

Complications associated with microvascular tissue transfer may be divided into recipient site and donor site problems. Donor site complications are site specific, depending on the tissue harvested. Difficulties arising from loss of the donor tissue should not be seen if appropriate consideration has been given to selection of a donor site. Seroma formation is common after harvest of soft tissue flaps, particularly muscle flaps. The large amount of dead space and inherent movement between tissue planes in these instances makes prevention of seromas difficult. Tacking or walking sutures are not recommended for dead space management after dissection of muscle flaps because they restrict movement and increase postoperative discomfort. Dead space is managed by provision of surgical drainage; drainage for 5 to 7 days is adequate in most instances.

Cross-contamination from the recipient site to the donor site may result in donor site infection. Care should be taken to use separate instrumentation in each surgical field. The surgical team responsible for dissection of the donor site should avoid contact with the recipient site, and vice versa.

Recipient site complications may be caused by inappropriate preparation of the recipient wound bed or by flap-related complications. Microsurgically transferred flaps are excellent sources of vascularized tissue for reconstruction, but they should not be viewed as a panacea for a poorly prepared wound bed. Necrotic tissue and debris must be surgically removed from the wound before transfer. In the case of osteomyelitis, infected bone must be thoroughly debrided. Free flaps should not be placed onto heavily contaminated or overtly infected wound beds. Such wounds should be aggressively converted to a clean contaminated state and subsequently reconstructed.

Flap-related complications may be specific to the tissue transferred, such as loss of orthopedic fixation in vascularized bone grafts or incisional dehiscence of transferred footpads. Complications common to all flaps relate to the integrity of the microvascular anastomosis. Meticulous attention to anastomotic technique, astute postoperative monitoring and early surgical re-exploration of compromised flaps are mandatory.

The relative advantages and disadvantages of microsurgical reconstruction are well documented in the human literature. Our understanding of the potential of these techniques in veterinary surgery is expanding. Successful use of microsurgical tissue transfer requires appropriate instrumentation and a familiarity with microvascular technique, both of which are increasingly available at larger veterinary referral centers. Further experience with, and definition of, these techniques will inevitably lead to increased veterinary clinical application.

References

1. Gustilo RB, Merkow RL, Templeman D. Current concepts review: the management of open fractures. J Bone Joint Surg Am 1990;72:299-304.

2. Asaadi M, Murray KA, Russell RC, et al. Experimental evaluation of free tissue transfer to promote healing of infected wounds in dogs. Ann Plast Surg 1986;17:6-12.

3. Richards RR, Schemitsch EH. Effect of muscle flap coverage on bone blood flow following devascularization of a segment of tibia: an experimental investigation in the dog. J Orthop Res 1989;7:550-558.

4. Richards RR, McKee MD, Paitich B, et al. A comparison of the effects of skin coverage and muscle flap coverage on the early strength of union at the site of osteotomy after devascularization of a segment of canine tibia. J Bone Joint Surg Am 1991; 73:1323-1330.

5. Anthony JP, Mathes SJ, Alpert BS. The muscle flap in the treatment of chronic lower extremity osteomyelitis: results in patients over 5 years after treatment. Plast Reconst Surg 1991; 88:311-318.

6. Jaeger K, Stark GB. Clinical and experimental evidence for the improvement of perfusion from free myocutaneous flaps. In: Stuttgart DR, ed. Microsurgical tissue transplantation. Chicago: Quintessence, 1989:217-222.

7. McKee NH, Kuzon WM. Functioning free muscle transplantation: making it work? What is known? Ann Plast Surg 1989; 23:249-254.

8. Manktelow RT, Zuker RN. The principles of functioning muscle transplantation: applications to the upper arm. Ann Plast Surg 1989;22:275-281.

9. Taylor GI, Minabe T. The angiosomes of the mammals and other vertebrates. Plast Reconst Surg 1992;89:181-215.

10. Gregory CR, Gourley IM, Koblik PD, et al. Experimental definition of latissimus dorsi, gracilis, and rectus abdominis musculocutaneous flaps in the dog. Am J Vet Res 1988;49:878-884.

11. Weinstein MJ, Pavletic MM, Boudrieau RJ. Caudal sartorius muscle flap in the dog. Vet Surg 1988,17:203-210.

12. Solano M, Purinton PT, Chambers JN, et al. Effects of vascular pedicle ligation on blood flow in canine semitendinosus muscle. Am J Vet Res 1995;56:731-735.

13. Pavletic MM. Canine axial pattern flaps, using the omocervical, thoracodorsal, and deep circumflex iliac direct cutaneous arteries. Am J Vet Res 1981;42:391-406.

14. Pavletic MM. Caudal superficial epigastric arterial pedicle grafts in the dog. Vet Surg 1980;9:103-107.

15. Henney LHS, Pavletic MM. Axial pattern flap based on the superficial brachial artery in the dog. Vet Surg 1988; 17:311-317.

16. Smith MM, Shults S, Waldron DR, et al. Platysma myocutaneous flap for head and neck reconstruction in cats. Head Neck 1993;15:433-439.

17. Smith MM, Payne JT, Moon ML, et al. Axial pattern flap based on the caudal auricular artery in dogs. Am J Vet Res 1991; 52:922-925.

18. Remedios AM, Bauer MS, Bowen CV. Thoracodorsal and caudal superficial epigastric axial pattern skin flaps in cats. Vet Surg 1989;18:380-385.

19. Weinstein MJ, Pavletic MM, Boudrieau RJ, et al. Cranial sartorius muscle flap in the dog. Vet Surg 1989,18:286-291.

20. Degner DA, Bauer MS, Steyn PF, et al. The cranial rectus abdominis muscle pedicle flap in the dog. Vet Comparative Orthop Traumatol 1994;7:21-24.

21. Purinton PT, Chambers JN, Moore JL. Identification and categorization

of the vascular patterns to muscles of the thoracic limb, thorax, and neck of dogs. Am J Vet Res 1992;53:1435-1445.

22. Chambers JN, Purinton PT, Allen SW, et al. Identification and anatomic categorization of the vascular patterns to the pelvic limb muscles of dogs. Am J Vet Res 1990;51:305-313.

23. Jackson M. Platelet physiology and platelet function: inhibition by aspirin. Compend Contin Educ Pract Vet 1987;9:627-638.

24. Concannon KT, Haskins SC, Feldman BF. Hemostatic defects associated with two infusion rates of dextran 70 in dogs. Am J Vet Res 1992;53:1369-1372.

25. Zelt RG, Olding M, Kerrigan CL, et al. Primary and secondary critical ischemia times of myocutaneous flaps. Plast Reconstr Surg 1986;78:500-503.

26. Picard-Ami LA, Thomson JG, Kerrigan CL. Critical ischemia times and survival patterns of experimental pig flaps. Plast Reconstr Surg 1990;86:739-743.

27. Kerrigan CL, Zelt RG, Daniel RK. Secondary critical ischemia time of experimental skin flaps. Plast Reconstr Surg 1984; 74:522-526.

28. Degner DA, Walshaw R. Medial saphenous fasciocutaneous and myocutaneous free flap transfer in eight dogs. Vet Surg 1997; 26:20-25.

29. Fowler JD, Miller CW Bowen V, et al. Transfer of free vascular cutaneous flaps by microvascular anastomosis: results in six dogs. Vet Surg 1987;16:446-450.

30. Miller CW, Fowler JD, Bowen CVA, et al. Experimental and clinical free cutaneous transfers in the dog. Microsurgery 1991;12:113-118.

31. Degner DA, Walshaw R, Lanz O, et al. The medial saphenous fasciocutaneous free flap in dogs. Vet Surg 1996;25:105-113.

32. Philibert D, Fowler JD, Clapson JB. The anatomic basis for a trapezius muscle flaps in dogs. Vet Surg 1992;21:429-434.

33. Philibert D, Fowler JD, Clapson JB. Free microvascular transfer of the trapezius musculocutaneous flap in dog. Vet Surg 1992;21:435-440.

34. Nicoll SA, Fowler JD, Remedios AR, et al. Development of a free latissimus dorsi muscle flap in cats. Vet Surg 1996;22:40-48.

35. Fowler JD, Levitt L, Bowen CVA. Microsurgical free bone transfer in the dog. Microsurgery 1991;12:145-150.

36. Brown K, Marie P, Lyszakowski T, et al. Epiphysial growth after free fibular transfer with and without microvascular anastomosis. J Bone Joint Surg Br 1983;65:493-501.

37. Ostrup LT, Fredrickson JM. Distant transfer of a free, living bone graft by microvascular anastomoses. Plast Reconstr Surg 1974;54:274-285.

38. Levitt L, Fowler JD, Longley M, et al. A developmental model for free vascularized bone transfers in the dog. Vet Surg 1988;17:194-202.

39. Szentimrey DG, Fowler JD. The anatomic basis of a free vascularized bone graft based on the distal canine ulna. Vet Surg 1994;23:529-533.

40. Szentimrey DG, Fowler JD, Johnston C, et al. Transplantation of the canine distal ulna as a free vascularized bone graft. Vet Surg 1995;24:215-225.

41. Philibert D, Fowler JD. The trapezius osteomusculocutaneous flaps in dogs. Vet Surg 1993;22:444-450.

42. Swaim SF, Bradley DM, Steiss JE, et al. Free segmental paw pad grafts in dogs. Am J Vet Res 1993;54:2161-2170.

43. Swaim SF, Riddell KP, Powers RD. Healing of segmental grafts of digital pad skin in dogs. Am J Vet Res 1992;53:406-410.

44. Gourley IM. Neurovascular island flap for treatment of trophic metacarpal pad ulcer in the dog. J Am Anim Hosp Assoc 1978;14:119-125.

45. Basher A. Foot injuries in dogs and cats. Compend Contin Ed Pract Vet 1994;16:1159-1176.

46. Basher AWP, Fowler JD, Bowen CV, et al. Microneurovascular free digital pad transfer in the dog. Vet Surg 1990;19:226-231.

Paw and Distal Limb Salvage and Reconstructive Techniques

Mark W. Bohling and Steven F. Swaim

Indications

The paws of a dog and cat play a significant role in their ambulatory abilities; thus, when an animal has paw skin defects, some form of reconstruction or salvage surgery is necessary to preserve normal ambulation. Minor paw defects may only require a simple reconstructive surgical technique, such as suture of a pad laceration. Conversely, major defects may require a more involved reconstruction or salvage surgical technique as with a skin graft to reconstruct a massive skin defect. With severe paw trauma, limb amputation is often performed, whereas if paw salvage techniques are available, limb amputation may possibly be avoided. In other instances of severe paw trauma, limb amputation is not an option, and reconstruction or salvage becomes necessary, as in the instance of a cat with bilateral avascular necrosis of the forepaws caused by excessively tight bandages following onychectomy. In the working dog and canine athlete, in which limb and paw functions are essential for performance, strong functional reconstruction and salvage procedures are especially important.

Defects of the paws can involve the dorsal surface, palmar or plantar surface (pads), interdigital surfaces, or interpad surfaces. Certain larger wounds on the dorsum of the paw and distal limb can be managed by techniques such as skin grafts and flaps, which are described in earlier sections of this chapter. This discussion describes some of the techniques that have particular application for reconstruction and salvage of the unique injuries of the specialized structures of the paws.

A unique wound affecting greyhounds is the digital pad callus/corn. These are painful lesions in need of a technique to resolve the condition.

Dorsal Paw Wounds

Some dorsal paw wounds may be such that the wound edges can be easily apposed after debridement and lavage. In other instances, tension in wound closure may need to be overcome by using some type of tension suture pattern, such as vertical mattress sutures, horizontal mattress sutures, or far near near far sutures. Other sutures can be used to relieve tension by gradually stretching the periwound skin so that it can be apposed or nearly so. Examples of these latter sutures are presutures and adjustable horizontal mattress sutures.

When wound tension is too great to be overcome by undermining, tension sutures, or skin stretching sutures, relaxing incisions can be considered when wound size permits. These are used in lieu of skin grafts or flaps. Simple relaxing incision(s) made adjacent to the wound can be used; however, such incisions commonly result in wounds about as large as the one that is closed as a result of their use. Multiple punctate relaxing incisions provide cosmetic and quickly healing small wounds while providing skin relaxation.

Although other familiar tension suture patterns and simple relaxing incisions can be used to aid in closure of dorsal paw wounds, this section describes presutures, adjustable horizontal mattress sutures, and multiple punctate relaxing incisions. These techniques have been found especially useful in closure of distal limb and dorsal paw wounds.

Presutures

Presutures are particularly useful in the distal limb and paws, in which "walking" sutures can encroach on vessels, nerves, and tendons. Presutures are thus termed because they are placed before excision or debridement of a lesion. They stretch the surrounding skin so that it can be used to close a distal limb or paw defect. Presutures are placed with interrupted Lembert bites, using 2-0 or 3-0 polypropylene or nylon suture (Figure 41-40A and B). They are placed under tension, usually 24 hours before excision or debridement. Presutures are placed while the animal is under the effects of a tranquilizer or neuroleptanalgesia and local analgesic agent in the skin to be sutured. Following presuturing, the area is bandaged until lesion excision or debridement.

At the time of definitive surgery, the presutures are removed. The lesion is removed or debrided, and the skin, which has been stretched gradually by stress relaxation, is used to close the defect (Figure 41-40C and D).

An advantage of presutures is that they can be used in conjunction with other tension relieving techniques to provide wound closure. Between the time they are placed and the time of removal, the limb should be observed for any swelling distal to the sutures. This swelling indicates the possibility of a biologic tourniquet developing at the time of definitive surgery, and another form of reconstruction may be considered.

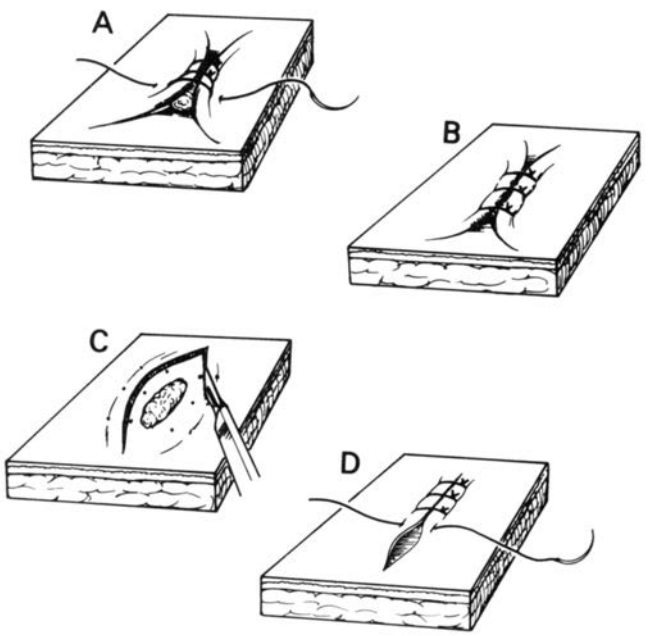


Figure 41-40. Presutures. **A** and **B.** The day before definitive surgical treatment, skin adjacent to the lesion is sutured over the lesion using a Lembert suture pattern. **C.** The next day, the presutures are removed, and the lesion is excised. **D.** The resulting defect or wound is closed using the stretched skin made available by the presuture. (From Scardino MS, Swaim SF, Henderson RA, Wilson ER. Enhancing wound closure on the limbs. Compend. Contin Educ Pract Vet 1996; 18:919.)

Adjustable Horizontal Mattress Sutures

A continuous adjustable horizontal mattress suture may be used to aid wound contraction by applying continuous tension to the skin edges of a wound that cannot be closed initially because of tension. The suture may be placed early in wound management or after granulation tissue has formed.

Synthetic 2-0 monofilament suture (nylon or polypropylene) on a cutting needle is used to place a half buried horizontal mattress suture at one end of the defect. The suture is continued as an intradermal horizontal mattress suture along the length of the wound. Each suture bite is advanced slightly, so the suture passes at an angle across the wound. Thus, as the suture is tightened, it slides through the tissues more easily. Care is taken not to disturb the attachment of skin to any granulation tissue present in the wound. At the opposite end of the wound, the needle is passed through the entire skin thickness and through a hole in a sterile button. Traction on the suture moves the wound edges toward each other. The skin edge advancement is maintained by a small fishing weight ("split shot") placed on the suture adjacent to the button. (Note: due to environmental concerns from lead, non-toxic split shot made from bismuth, tin, or antimony are now widely available, and should be used, to prevent the possibility of toxic lead exposure in the event of patient ingestion.) To prevent slippage, a second split shot is placed against the first (Figure 41-41). Excess suture is cut off about 2 inches beyond the split shot, and a bandage is applied over the wound.

On succeeding days, suture beyond the split shot is grasped with forceps, and gentle traction is applied while the limb is steadied. The wound edges move closer together, and the original split shot are pulled away from the button. Two new split shot are placed against the button to maintain suture advancement. Because of inherent skin elasticity, skin advancement is greatest in the first 2 to 3 days. When the wound edges are apposed or when they have advanced to their limit and further tension does not result in wound edge advancement or movement of the suture, the suture is removed.

Modified placement can be performed by placing the split shot button apparatus at both ends of the suture to allow tightening from both ends. With longer wounds, this maneuver is helpful because, the further the button is from the center of the wound, the less suture slippage through the tissues occurs. Therefore, pulling at each end of the wound distributes tension more evenly along the wound. During the use of an adjustable horizontal mattress suture, wounds can be treated with a topical antimicrobial or wound healing stimulant in combination with a protective bandage.

Multiple Punctate Relaxing Incisions

Multiple punctate relaxing incisions are small, parallel staggered skin incisions made adjacent to a wound to release tension and

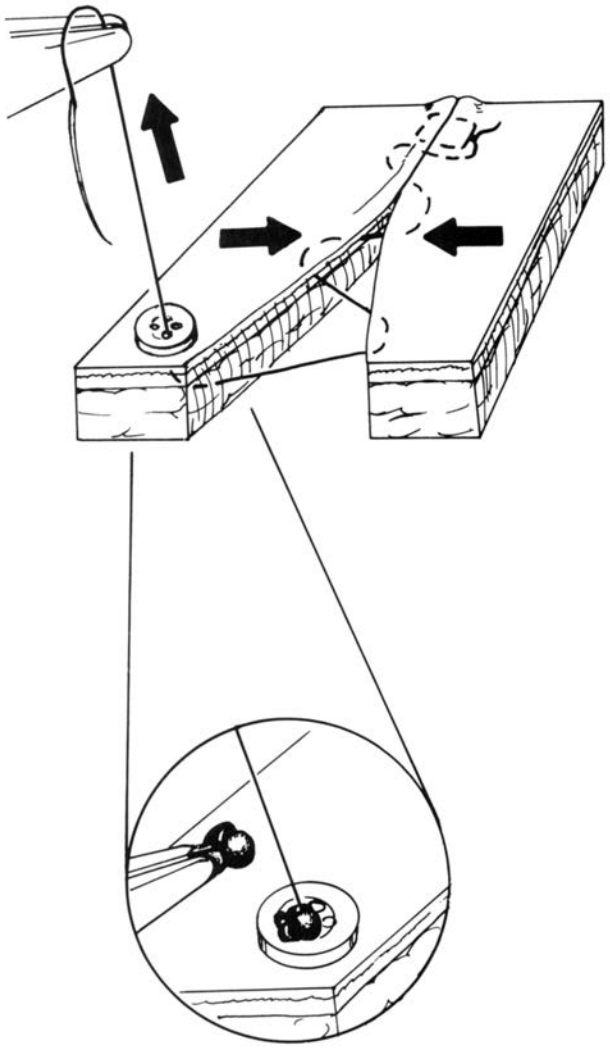


Figure 41-41. Adjustable horizontal mattress suture placement: A half buried horizontal mattress suture starts the suture at one end. The suture is advanced as an intradermal horizontal mattress suture with each bite slightly advanced (running suture). On the final bite, the needle is passed through the entire skin thickness and through a hole in a sterile button. Tension on the suture (vertical arrow) results in wound edge advancement toward the wound center (horizontal arrows). After wound edge advancement as far as possible, two split shot are used to secure the suture (inset). The suture is similarly tightened daily. (From Scardino MS, Swaim SF, Henderson RA, Wilson ER. Enhancing wound closure on the limbs. Compend. Contin Educ Pract Vet 1996; 18:919.)

to allow wound closure. The surgeon may want to use presutures or an adjustable horizontal mattress suture before making these relaxing incisions.

A continuous intradermal suture of 3-0 synthetic absorbable suture material, such as polyglyconate or polyglactin 910, is begun at one end of the wound. If the skin edges do not appose or appose with tension while placing and tightening this suture, punctate relaxing incisions are made in the skin adjacent to the wound edges on both sides of the wound. These incisions are usually 1 cm from the wound edge, 1 cm long, and 0.5 cm apart. They are made in parallel staggered rows (Figure 41-42A). After the skin edges are apposed, simple interrupted 2 0 or 3 0 polypropylene or nylon sutures are placed in the wound edges (Figure 41-42B).

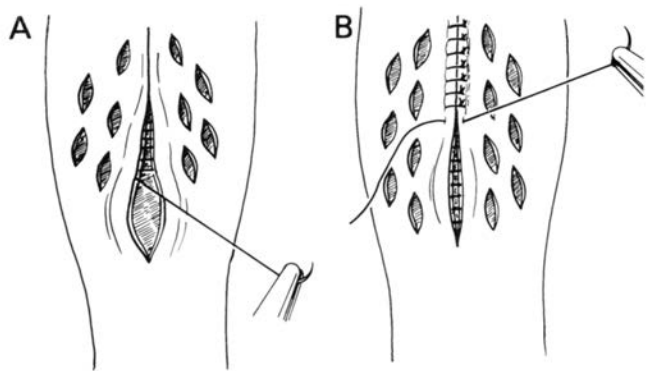


Figure 41-42. Multiple punctate relaxing incisions. **A.** As a continuous intradermal suture is placed, if wound edges do not appose, multiple punctate relaxing incisions are made bilaterally in parallel staggered rows. **B.** Once apposed, the skin edges are routinely sutured. (From Scardino MS, Swaim SF, Henderson RA, Wilson ER. Enhancing wound closure on the limbs. Compend. Contin Educ Pract Vet 1996; 18:919.)

An alternate method for performing the procedure entails placing the continuous intradermal absorbable suture along the length of the wound, but not tightening or tying it at one end. Tension is applied to the free end of the suture, and hemostats are placed under a loop of suture near its origin. If the skin edges do not appose when the hemostats are elevated, bilateral punctate incisions are made in the area of tension (Figure 41-43A and B). The procedure is repeated along the suture line to bring the wound edges into apposition (Figure 41-43C and D). Final closure is with simple interrupted 2-0 or 3-0 polypropylene or nylon sutures (Figure 41-43E).

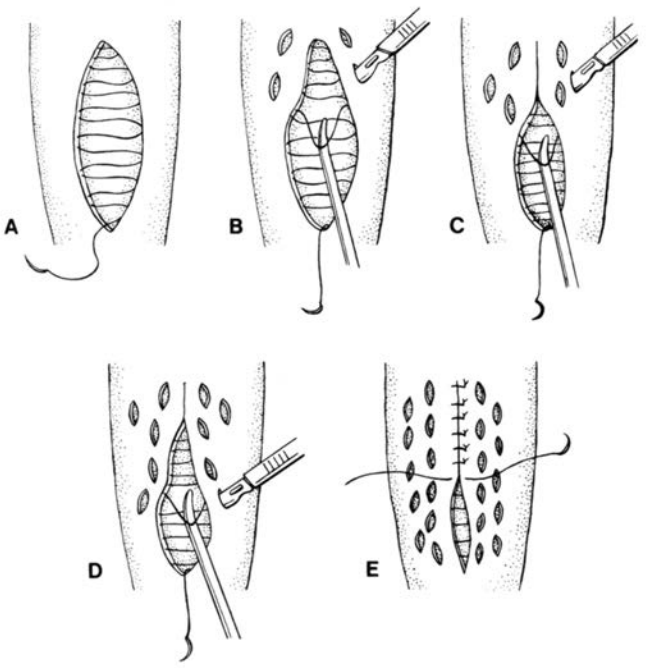


Figure 41-43. Alternate technique for multiple punctate relaxing incisions. **A.** A continuous intradermal suture is placed. **B.** If tightening a section of suture results in tension, multiple punctate relaxing incisions are made. **C** and **D.** The suture is progressively tightened, and incisions are made. **E.** Final closure is done with simple interrupted sutures. (From Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997:189.)

The more punctate incisions that are made and the larger they are, the greater the tension relief. However, the opportunity to damage the cutaneous vasculature is increased, thus increasing the risk of necrosis. Therefore, no more punctate incisions should be made than are necessary to provide wound closure without excessive tension.

The sutured wound is routinely bandaged, with daily changes in the early postoperative period to remove drainage from the wound site that occurs through the punctate incisions. A nonadherent primary bandage layer facilitates atraumatic bandage changes. As healing occurs and drainage decreases, bandages are changed less frequently.

Multiple punctate relaxing incisions break up the relaxing incision in numerous small incisions that are more cosmetic, heal rapidly, and are more acceptable to the animal's owner. However, the amount of tension relief may not be as great as that attained by one large relaxing incision.

Pad Wounds

Wounds on the palmar or plantar surface of the paw often involve the digital, metacarpal or metatarsal pads. These wounds may be as simple as a minor laceration or as serious as the loss of an entire pad. Because the pads are subject to impact stress and frictional wear, surgical techniques and aftercare require some special features to ensure adequate healing.

Suturing Pad Lacerations

Suturing of pad lacerations is indicated when the edges of the traumatized pad can be apposed. Pad lacerations require special attention before closure, first to assess the depth of the laceration and second to determine the degree of contamination of the wound. These assessments may be facilitated by inserting the tips of a pair of hemostats into the wound and opening the jaws. Most wounds are partial thickness; however, some full thickness wounds of the metacarpal and metatarsal pads may expose the digital flexor tendons.

Because of the location and function of pads, they are subject to considerable contamination when weightbearing after injury forces contaminants into the tissues. Before suturing the pad, thorough debridement and lavage must be performed to remove dirt and other contaminants. If the laceration has extended through the entire metacapal or metatarsal pad, after lavage is completed, a small, soft, latex Penrose drain is placed under, not through, the pad.

Although the deep pad tissue may appear to be apposed, placement of deep simple interrupted sutures of 3 0 polydioxanone gives support to the tissues (Figure 41-44A). The superficial pad tissues are sutured with far near near far sutures of 3 0 nylon or polypropylene (Figure 41-44B).

A small amount of cotton is placed between the digits and in the space between the digits and the metacarpal or metatarsal pad to help keep these areas dry. A nonadherent bandage pad is placed over the suture line. The success of pad sutures in helping to provide early strong healing depends on proper bandaging to help prevent spreading of the pad during weight bearing. For a large dog where pad spreading with weight-bearing could cause significant tissue damage as sutures cut through the skin, the paw should be bandaged in a "clamshell" splint (see description in Chapter 2). The bandage is changed every 2 to 3 days unless a drain has been placed under the metacarpal or metatarsal pad. In this case, more frequent bandage changes are indicated to remove drainage fluid. Sutures are usually left in place for 10 to 14 days, depending on the severity of injury and the size of the animal; for example, a severe laceration on a large dog needs sutures and bandages longer than a minor laceration on a small dog.

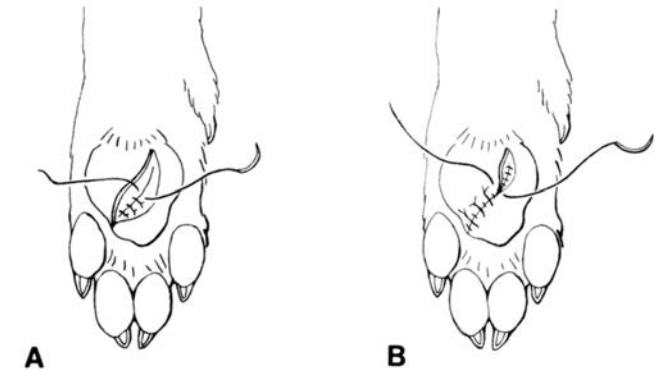


Figure 41-44. Suturing pad lacerations. **A.** Simple interrupted sutures are placed in deep pad tissue. **B.** Far near near far sutures are placed in superficial pad tissue. (From Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997: 338.)

Phalangeal Fillet

The phalangeal fillet technique is the removal of the proximal, middle, and distal phalanges from a digit to free the pad so it can be used to replace or fill defects in a metacarpal or metatarsal pad. The technique is indicated when conservative therapy has not resulted in effective healing of the pad or when the entire pad is missing.

In patients with chronic nonhealing metacarpal or metatarsal pad wounds that have not resulted from trauma, a thorough examination should be performed preoperatively. This should include cytologic examination, fungal and bacterial culture and sensitivity testing, as well as histopathologic examination. Appropriate medical and/or surgical therapy should follow if cultures reveal fungal or neoplastic disease. Surgical therapy may range from limb amputation to pad amputation and replacement (phalangeal fillet), depending on test results. If histologic examination reveals chronic nonhealing tissue, the wound should be thoroughly debrided and lavaged because the granulation tissue may have embedded dirt and sand.

Phalangeal fillet may be performed from the palmar or plantar surface of the paw. The digit nearest the metacarpal or metatarsal pad defect is selected for filleting. This is usually the second or fifth digit. A rectangular skin segment is removed from the palmar or plantar skin between the digital pad and the edge of the metacarpal or metatarsal pad defect (Figure 41-45A). The proximal, middle, and distal phalanges of the digit are removed

by incising the joint capsules and ligamentous attachments to the bones (Figure 41-45B). The phalanges and nail are removed using blunt dissection as close to the bone as possible, thus leaving the blood and nerve supply intact in the digital flap. The edge and surface of the metacarpal or metatarsal pad defect are debrided, and the pad of the filleted digit is folded back on its pedicle of skin to fill the metacarpal or metatarsal pad defect (Figure 41-45C). The edges of the digital pad are sutured to the edges of the pad defect with simple interrupted or far near near far sutures of 3-0 polypropylene or nylon suture material (Figure 41-45D). The paw is bandaged as described for pad laceration repair.

A second technique for phalangeal fillet entails phalangeal removal through a single longitudinal incision on the dorsal surface of the digit (Figure 41-46A and B). The skin is then closed with simple interrupted sutures of 3 0 polypropylene or nylon suture material (Figure 41-46C). The area where the nail was removed is left open for drainage.

The paw is bandaged with periodic bandage changes, and it is allowed to heal for 14 days. At this time, the rectangle of palmar or plantar skin is removed, and the digital pad is folded back and is sutured into the defect as previously described (Figure 41-46D-F). Bandaging is as previously described.

Palmar or plantar filleting has the advantage of being a one step procedure; however, it is more difficult, and has greater potential

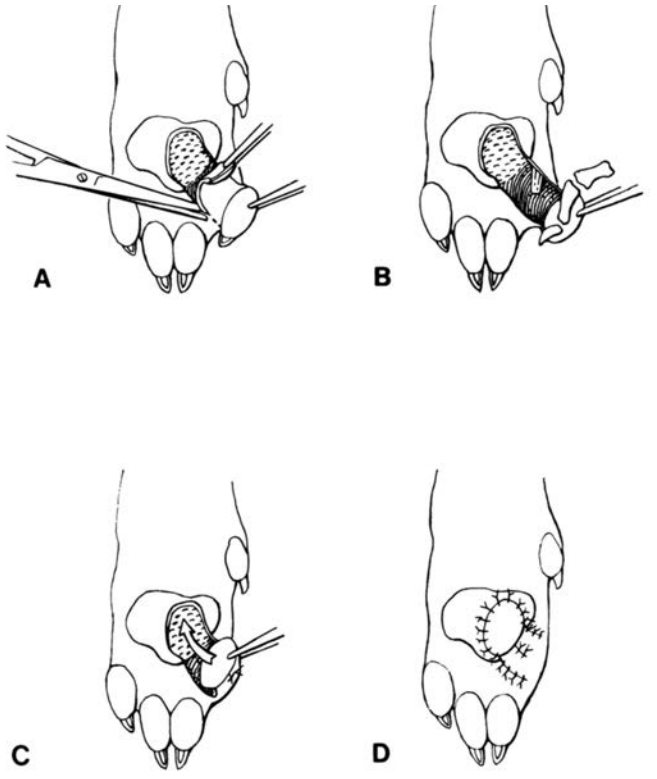


Figure 41-45. Palmar and plantar phalangeal fillet technique for pad replacement. **A.** A rectangle of skin is removed between the metacarpal and second digital pads. **B.** The proximal, middle, and distal phalanges and nail are removed. **C.** The second digital pad is folded back into the metacarpal pad defect (arrow). **D.** The second digital pad is sutured in place. (From Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997: 345.)

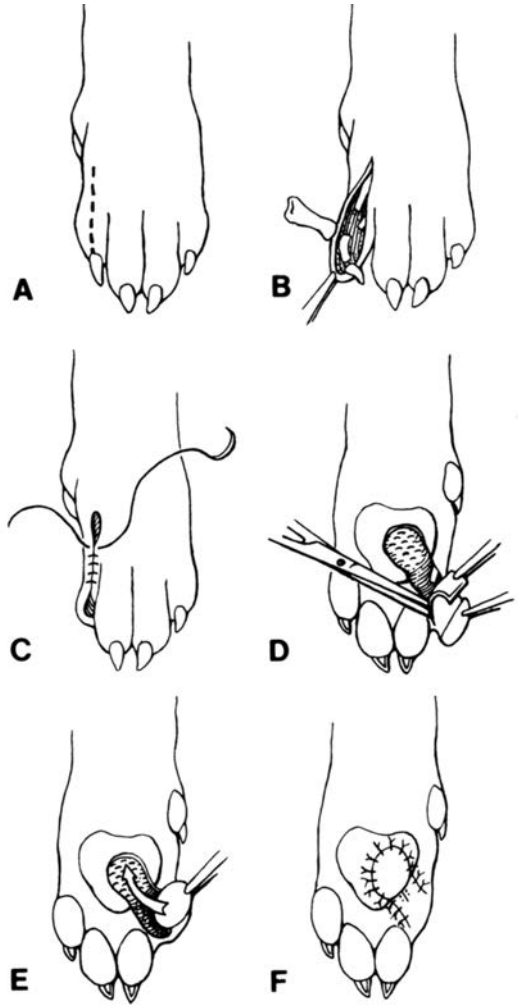


Figure 41-46. Dorsal phalangeal fillet technique for pad replacement. **A.** A longitudinal incision line is made on the dorsum of the second digit. **B.** The proximal, middle, and distal phalanges and nail are removed. **C.** The longitudinal incision is closed. **D.** Fourteen days later, a rectangle of skin is removed between the metacarpal and second digital pads. **E.** The second digital pad is folded back into the metacarpal pad defect (arrow). **F.** The second digital pad is sutured in place. (From Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997: 346.)

for damage to the blood supply of the digital pad. Dorsal filleting is easier, but the technique takes longer because it is a two step procedure, with digital pad transposition performed 14 days after the phalanges have been removed.

In some instances, if a metacarpal or metatarsal pad wound has resulted from abnormal paw position because of tendon malfunction, bone misalignment or nerve damage, digital pad transposition may not be successful. Unless the underlying cause of abnormal pad wear is corrected, the new pad may wear through just as did the original pad.

Pad Grafts

Paw pad grafts are small full thickness segments of pad tissue that are placed in a granulation tissue bed around the edges of a wound where weight bearing pad tissue is missing. They are indicated in patients with loss of the metacarpal or metatarsal

pad as well as loss of some or all the digital pads, thus precluding phalangeal fillet.

After a paw wound has been managed to the point that it has healthy bed of granulation tissue, rectangular tissue segments measuring 6 x 8 mm are traced around the wound using a template of x-ray film with a hole in its center and a sterile skin marker or splintered applicator stick dipped in methylene blue (Figure 41-47A). The rectangles of tissue are incised with a number 11 scalpel blade, and the tissue is excised using iris scissors and thumb forceps, leaving a series of rectangular depressions about 2 mm deep around the wound (Figure 41-47B and C).

In the center of other digital pads on the same animal, possibly the same paw, the same template is used to trace the same number and size of rectangles (See Figure 41-47C). Again, a number 11 scalpel blade is used to incise the grafts, and iris scissors and thumb forceps are used to remove the grafts (Figure 41-47D). All subcutaneous tissue is removed from the grafts with iris scissors.

A graft is placed in each of the rectangular depressions and sutured in place. Two simple interrupted sutures of 5-0 polypropylene can be used, with one suture on each side of the graft on the long sides of the graft (Figure 41-48A). An alternative suture pattern, which the authors prefer, is a simple interrupted suture placed at each corner of the graft (Figure 41-48B).

A nonadherent bandage pad with a small amount of 0.1% gentamicin sulfate ointment is placed over the grafted site. The remainder of the bandage is as described for pad lacerations. The graft donor sites are allowed to heal by second intention and are bandaged in a similar manner. If remaining digital pad tissue is pliable enough to allow suture closure of the donor sites, these sites may be closed with 3-0 polypropylene or nylon far near near far sutures followed by bandaging. The initial bandage is usually left in place for 3 days, followed by bandage changes every other day until 21 days postoperatively. A bootie may be indicated for a transitional period between bandage and no bandage. Sutures in the grafts are removed between 10 and 14 days postoperatively.

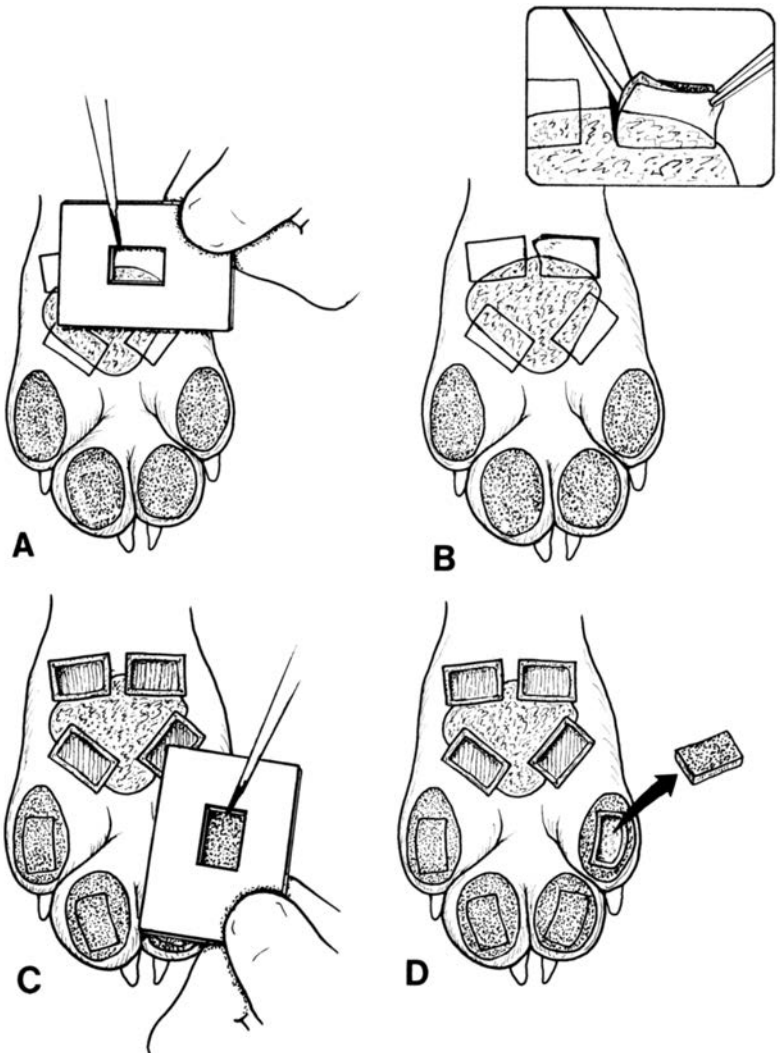


Figure 41-47. Pad grafts. **A.** A piece of x ray film with a 6 x 8 mm hole in its center is used with a splintered applicator stick dipped in methylene blue to trace graft recipient sites around the wound. **B.** After incision, thumb forceps and iris scissors are used to remove rectangles of tissue from recipient sites. **C.** With recipient sites prepared, the x ray film applicator stick and methylene blue are used to trace segmental grafts on digital pads. **D.** A segmental pad graft has been removed from a digit. (From Swaim SF, Bradley DM, Steiss, JE, et al. Free segmental paw pad grafts in dogs. Am J Vet Res 1993;54:2161-2170.)

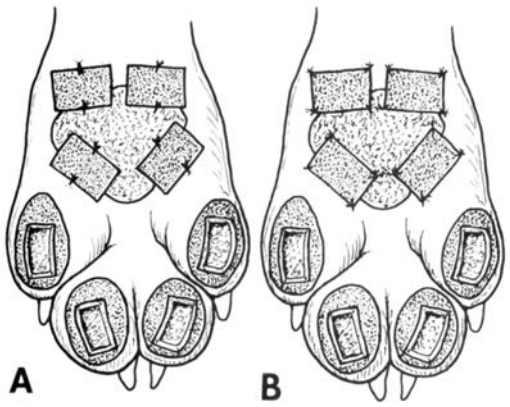


Figure 41-48. Pad graft sutures. **A.** Two simple interrupted sutures are used to suture each long side of the grafts into the recipient site. **B.** Simple interrupted sutures are used at each corner of the grafts to suture them into recipient sites, (From Swaim SF, Bradley DM, Steiss, JE, et al. Free segmental paw pad grafts in dogs. Am J Vet Res 1993;54:2161-2170.)

When sutures are removed from the grafts, the hard and dark stratum corneum usually lifts off of the graft to reveal underlying viable graft tissue that will form a new stratum corneum. As the grafts heal, two phenomena occur that provide a tough tissue on which the animal can ambulate. First, with wound contraction, the grafts coalesce toward the wound center. Second, the epithelial tissue that grows from the grafts to cover the remainder of the wound is tough keratinized epithelium that withstands the stress placed on pad tissue. If paw trauma has been severe enough so that bone is present directly under the healed pad grafts, weight bearing may cause pad trauma. Use of a pad toughening agent after the grafts are thoroughly healed has been found helpful in increasing pad durability.

Carpal Pad Flaps

Carpal pad flaps are flaps of skin on the distal forelimb that incorporate the carpal pad. They are used to provide a structure on which an animal can ambulate after amputation at the carpometacarpal articulation. These flaps may be single pedicle or bipedicle advancement flaps. Their successful use has been described in bilateral application on a small dog (single pedicle flap) and unilaterally on a cat (bipedicle flap).

Single Pedicle Carpal Pad Flaps

For a single pedicle advancement flap, a transverse skin incision is made over the cranial aspect of the limb at the carpometacarpal level. A proximally based single pedicle advancement flap is created on the palmar aspect of the limb such that it includes the carpal pad. The skin flap distal to the pad should extend to the mid-metacarpal level, to allow sufficient length for suturing the flap to the skin on the dorsum of the limb after advancement into position (Figure 41-49A).

After blunt dissection of the skin flap from underlying structures, the flexor carpi ulnaris tendon is transected, and the prominence of the accessory carpal bone is removed. The distal limb is then amputated at the carpometacarpal joint. The flap is advanced

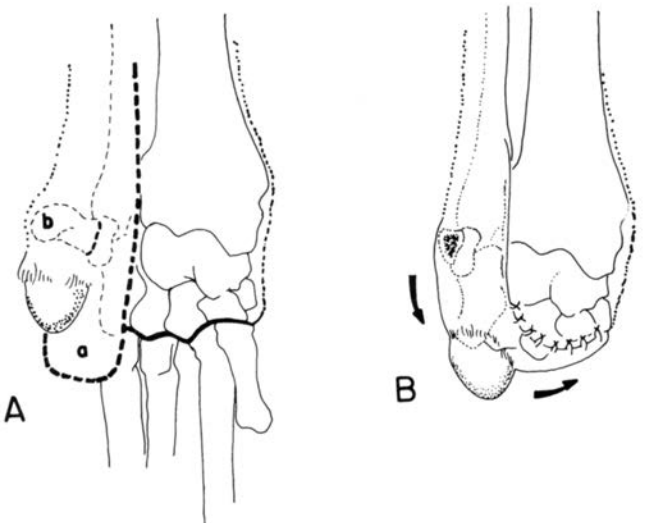


Figure 41-49. Single pedicle carpal pad flap. **A.** A dorsally based single pedicle advancement flap is designed to incorporate the carpal pad (a). The prominence of the accessory carpal bone (b) will be removed. **B.** After amputation at the carpometacarpal joint, the pad is advanced on the flap (arrows) and is sutured in position at the caudodistal end of the amputation stump. (From Barclay CG, Fowler JD, Basher AW. Use of the carpal pad to salvage the forelimb in a dog and cat: An alternative to total limb amputation. J Am Anim Hosp Assoc 1987; 23:527-532.)

distally until the carpal pad is located at the caudodistal end of the amputation stump. The pad is anchored in position with subcutaneous simple interrupted sutures of 3-0 synthetic absorbable material, and the skin is sutured with simple interrupted sutures of 3 0 nylon or polypropylene (Figure 41-49B).

The limb is immobilized in a soft padded bandage with a metal (e.g. "clamshell") splint. Sutures are removed and splinting is discontinued 2 weeks postoperatively.

Bipedicle Carpal Pad Flaps

For a bipedicle advancement flap, parallel horizontal skin incisions, one proximal to and one distal to the carpal pad, are made on the palmar aspect of the limb. The proximal incision is curved 2 to 3 mm proximally at each end to facilitate flap transposition (Figure 41-50A). After advancement of the flap under the end of the amputation stump, the flap is sutured in place with simple interrupted 3 0 nonabsorbable sutures. The palmar donor site is allowed to heal as an open wound (Figure 41-50B).

A padded splint is applied to the limb. A supplemental bar may be added to allow ambulation without disturbing the flap, or a "clamshell" bandage splint may be used. Periodic bandage or splint changes are performed until healing has occurred.

With successful carpal pad flap procedures, use by the patient results in thickening and enlargement of the pad. This provides functional weight bearing tissue.

Before performing carpometacarpal amputation and carpal pad flap repositioning, the animal's activity and intended use, and the owner's expectations after surgery should be considered. The technique has potential for use on larger dogs; however, accurate

placement of the pad may be more critical when considering the greater weight to be placed on it. Moreover, when the procedure is performed unilaterally, that limb is significantly shorter than the other limb, and the animal may tend to carry the limb or only use it intermittently.

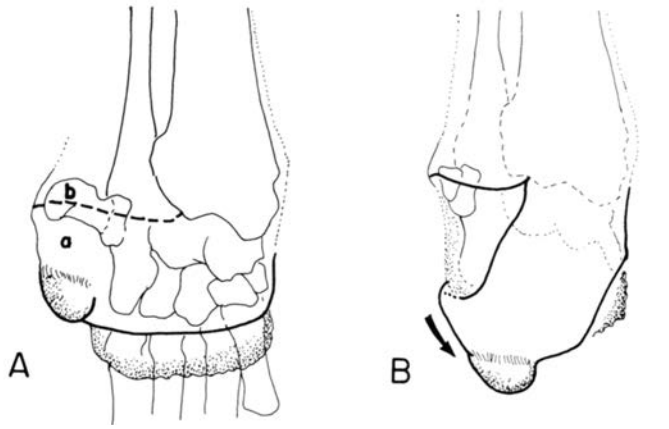


Figure 41-50. Bipedicle carpal pad flap. **A.** A bipedicle advancement flap is designed to incorporate the carpal pad and is undermined (a) The prominence of the accessory carpal bone (b) will be removed. **B.** After amputation at the proximal metacarpal area, the pad is advanced on the flap (arrow) and is sutured in position under the end of the amputation stump. (From Barclay CG, Fowler JD, Basher AW. Use of the carpal pad to salvage the forelimb in a dog and cat: an alternative to total limb amputation. J Am Anim Hosp Assoc 1987;23:521-532.)

Digital Pad Calluses/Corns

Greyhounds are subject to the development of painful fibrous scar tissue lesions on their digital pads. These callus-type lesions have been termed "corns." There are several theories as to their etiology. One theory is that of scar tissue accumulation, either from cuts and abrasions, or from a small foreign body in the pad with resulting scar tissue formation as the body attempts to isolate the foreign material. A second theory states that the lesion is caused by a papilloma virus infection, with the pressure and abrasion of walking forcing the lesion into a corn-type appearance. A third theory is that the phenotypic leanness of greyhounds is also manifested in their feet, by a lack of sufficient fibroadipose cushioning tissue in greyhound digital pads compared to other breeds of dogs. As a result, chronic low-grade pressure of the distal interphalangeal joint on the dermal pad surface results in a callus-like lesion.

Numerous treatments have been described for these lesions; the veterinary literature describes soaking of the paw and application of manual pressure to express the corn, sharp surgical excision of the corn, and partial or total amputation of the affected digit. A preliminary study has been performed to investigate the potential for placing silicone block gel particles subdermally under the digital pad skin to provide cushioning between the distal interphalangeal joint and the pad dermis, i.e., padding similar to the fibroadipose tissue of normal pads. Results of the study indicated a reduction in pad pressure at 3 months post-implantation.

Digital, Interdigital, and Interpad Wounds

Paw lesions may involve the interdigital skin or the interpad skin on the palmar or plantar surface of the paw. The lesions are usually traumatic or infectious. The phalangeal fillet technique and a fusion podoplasty technique may be used to reconstruct or to salvage paws thus involved.

Phalangeal Fillet for Digital and Dorsal Paw Resurfacing

The phalangeal fillet technique can be used as a salvage technique when patients have sustained considerable digital trauma to osseous structures of a digit with skin deficits of adjacent digits or the dorsum of the paw. If the digital and interdigital skin of the digit with osseous damage is viable, phalanges may be removed from the digit, and its skin and adjacent interdigital skin may be used to replace the skin deficit of the adjacent digits or dorsum of the paw.

The digits with severe osseous damage are carefully debrided, and the remaining proximal, middle, and distal phalanges and tendon fragments are removed (Figure 41-51A and Figure 41-52A). The skin of this digit and any available interdigital skin are cut and trimmed such that they can be used as a flap to resurface adjacent digits with large skin deficits or the dorsum of the paw (Figure 41-51B and C) and Figure 41-52B and C). The digital and interdigital skin should be cut and trimmed with care, to ensure

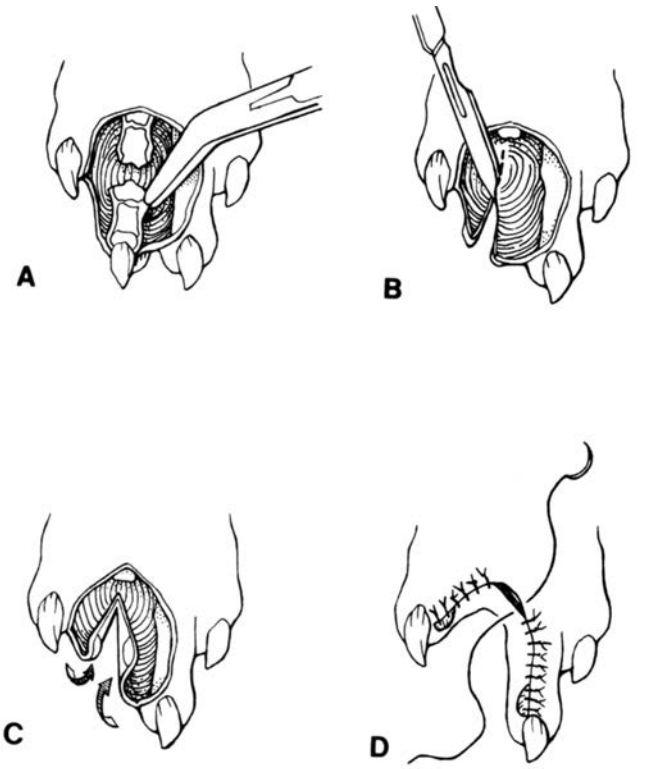


Figure 41-51. Phalangeal fillet for digital resurfacing: two flaps. **A.** The wound area is debrided, and bone and tendon fragments are removed. **B.** Digital and interdigital skin were used to create flaps. **C.** Flaps will be rotated to resurface adjacent digits (arrows). **D.** The flaps are sutured in place. (From Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997: 354.)

that sufficient skin and subcutaneous tissue remain at the base of the flap to provide blood supply. The flap is sutured, to the remaining skin of the adjacent digits or dorsum of the paw with simple interrupted sutures of 2 0 or 3 0 polypropylene (Figure 41-51D) and Figure 41-52D).

Small amounts of cotton are placed between remaining digits and in the space between remaining digits and the metacarpal or metatarsal pad for dryness. A strip of nonadherent bandage pad is placed over suture lines. Absorbent secondary bandage and adhesive tape tertiary bandages are then applied. The cup of a metal splint may also be incorporated in the bandage. Clinical judgment should be used as to whether special considerations are needed in bandaging to relieve pressure on the area, i.e., "clamshell" bandage, foam sponge "donut" pad, or digit-elevating foam sponge pad (See Chapter 2). Bandages are changed periodically for 7 to 10 days. The length of time sutures should remain in place, the frequency of bandage changes, and the length of time bandages are needed are variable factors dependent on wound tension, wound healing rate, and amount of drainage.

The disadvantages of the procedure are that filleting of digit 3 or 4 leaves a cosmetic defect in the center of the paw, and a defect in this area can cause lameness. If digits 3 and 4 have been filleted to resurface digits 2 and 5 or the dorsum of the paw, the second and fifth digits protrude and may be subject to snagging on carpets or vegetation. If the pads of the filleted digits are needed for resurfacing procedures, they may be used; however, pad tissue in an abnormal location on the dorsum of the paw may be cosmetically unappealing.

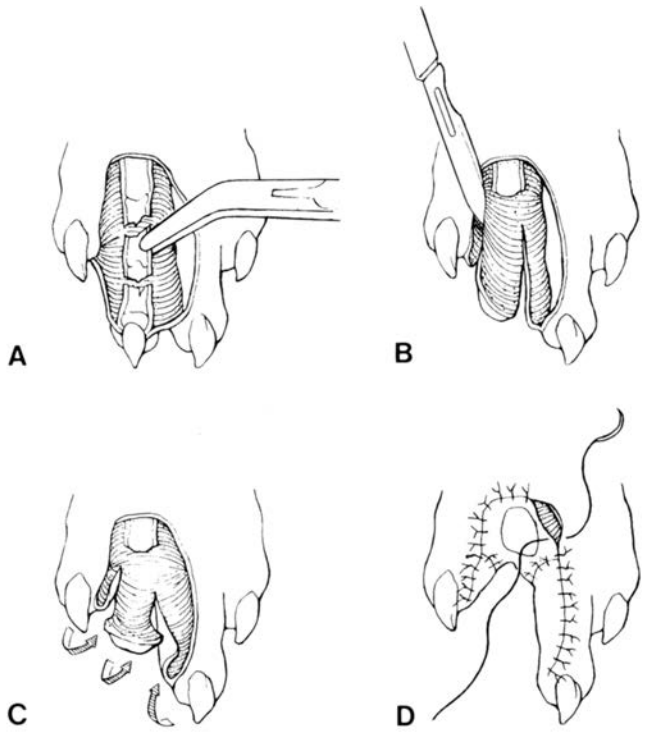


Figure 41-52. Phalangeal fillet for digital and dorsal paw resurfacing: three flaps. **A.** The wound area is debrided, and bone and tendon fragments are removed. **B.** Digital and intercligital skin are used to create flaps. **C.** Flaps will be rotated to resurface the dorsum of the paw and adjacent digits (arrows). **D.** Flaps are sutured in place. (From Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997: 354.)

Fusion Podoplasty

Fusion podoplasty is a paw salvage technique whereby all interdigital and interpad skin is removed from a paw, and the remaining strips of skin on the dorsum of the digits are sutured together, as are the digital and metacarpal or metatarsal pads. The technique is indicated for the treatment of chronic fibrosing interdigital pyoderma in dogs when other forms of medical therapy or conservative surgical approaches have been unsuccessful. The procedure is usually performed on two paws at a time when all four paws are involved. The most severely involved paws (usually the fore paws) are operated on first, followed 1 month later by the hind paws. The technique has also been described for use in treating abnormalities associated with severed digital flexion tendons to fuse the digits against the metacarpal or metatarsal pad to provide a functional paw.

When this technique is used to treat chronic fibrosing interdigital pyoderma, the dog is given systemic antibiotics based on the results of culture and sensitivity testing before the surgical procedure. At the time of surgery, a sterile marking pen is used to outline the interdigital skin to be removed. On the dorsum of the paw, lines are drawn on the digits at the junction of normal and affected skin. Lines are drawn near the nails, so 2 to 3 mm of skin remains adjacent to the nail on the axial surfaces of the digits.

Because the third and fourth digits extend beyond the second and fifth, respectively, lines on the abaxial surfaces of the third and fourth digits are drawn so they intersect the digital pad midway between their cranial and caudal ends. The technique provides skin excisions on the abaxial surfaces of the third and fourth digits that match the axial surface excisions on digits 2 and 5, respectively (Figure 41-53). This method usually incorporates all affected skin between the fourth and fifth as well as between the second and third digits.

On the palmar or plantar paw surfaces, lines are drawn to enclose all interpad skin and the cranial portion of the metacarpal or metatarsal pad. Lines are drawn around the caudal aspects of the digital pads at the junction of pad and interpad skin. No lines are drawn around the cranial edge of the pads under the claws or around the abaxial surface of pads 2 and 5. From the caudoabaxial aspect of the second and fifth digital pads, lines are drawn along the skin fold that extends from this point to the base of the metacarpal or metatarsal pad. The line is continued across the cranial surface of the metacarpal or metatarsal pad. This line is 3 to 5 mm cranial to the level at which the caudal edges of the digital pads contact the metacarpal or metatarsal pad when the digits are flexed back against this pad (Figure 41-54).

A half inch Penrose drain is applied as a tourniquet around the limb just distal to the carpus or tarsus. The tourniquet is released for 1 minute after all skin incisions have been made, and again after the excision of all interdigital skin is completed. A scalpel blade is used to incise along all previously drawn lines.

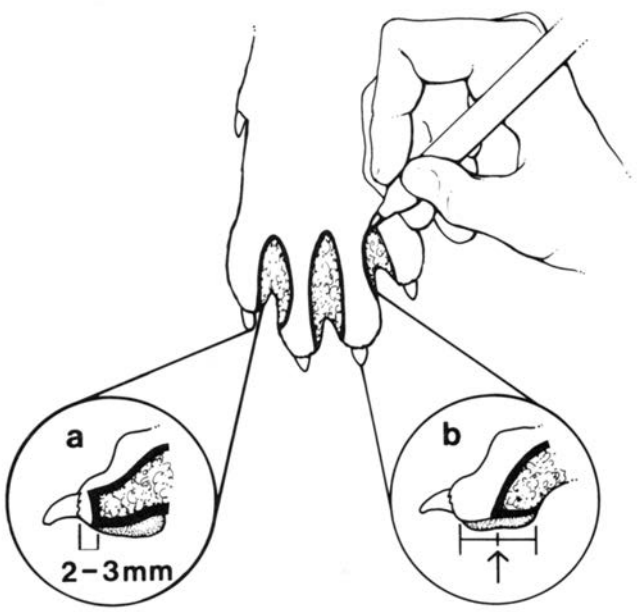


Figure 41-53. Fusion podoplasty. Interdigital skin to be removed from the dorsum of the paw is marked (bold lines). Inset: *(a)* 2 or 3 mm of skin is left near the nails on the axial surface of digits; *(b)* excision lines on the abaxial surfaces of digits 3 and 4 bisect the length of the pad (arrow). (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 199 1;27:264-274.)

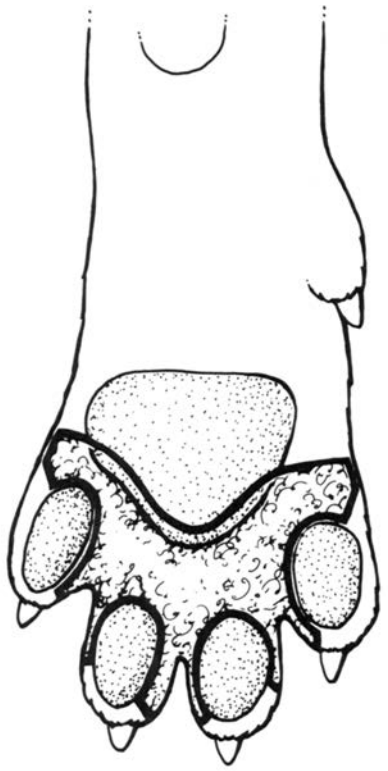


Figure 41-54. Fusion podoplasty. Interpad skin to be removed from the palmar or plantar surface of the paw is outlined (bold line) to include some skin from the cranial surface of the metacarpal or metatarsal pad. (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 199 1;27:264-274.)

Starting at one dorsal interdigital cleft, interdigital skin is dissected from the cleft toward the cranial fold of this skin. Dissection is performed as close to the dermis as possible to avoid damage to the axial and abaxial dorsal and palmar or plantar proper digital vessels and nerves. When dissection becomes difficult near the fold of the web, dissection is discontinued and an adjacent interdigital space is dissected (Figure 41-55). After all interdigital spaces have been dissected, blunt and sharp dissection is done around the caudal aspects of the pads and along the palmar or plantar surface of each digit, again dissecting as close to the dermis as possible. At the base of the metacarpal or metatarsal pad, dissection of the dermis and epidermis is carried across the cranial surface of the pad from the lateral to the medial aspects of the pad. Underlying pad tissue is undisturbed (Figure 41-56). Deep connective tissue pockets containing exudate are carefully removed. After removal of the tourniquet, fine point electrocoagulation is used for hemostasis. The paw is soaked in a 0.05% chlorhexidine diacetate solution for 1 to 2 minutes. The paw is wrapped in a snug pressure bandage, and the procedure is repeated on the opposite paw.

After pressure wrapping the second paw, the pressure wrap is removed from the first paw. Adjacent digital pads are united with three simple interrupted 3-0 polypropylene sutures (Figure 41-57). The four united digital pads are flexed back against the cranial surface of the metacarpal or metatarsal pad. Simple interrupted 3-0 polypropylene sutures are placed alternately on either side of a central suture to affix the united digital pads to the metacarpal or metatarsal pad (Figure 41-58). The primary purpose of these sutures is to hold the digital pads in position against the metacarpal or metatarsal pad while the healing process begins in the deeper tissues.

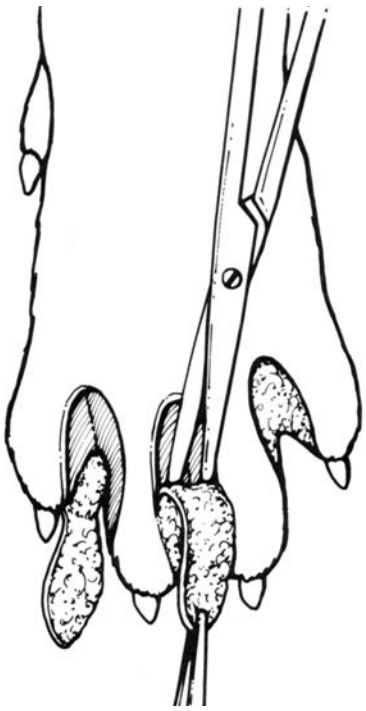


Figure 41-55. Fusion podoplasty. The dorsal interdigital skin is dissected from the interdigital spaces progressing from the digital cleft to the fold of the web. (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 199 1;27:264-274.)

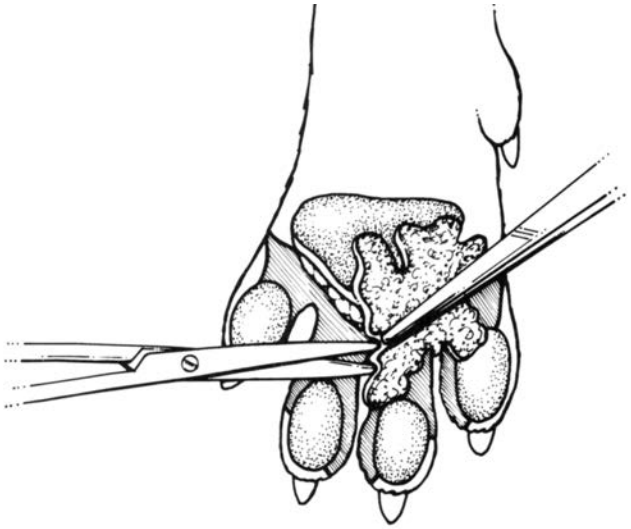


Figure 41-56. Fusion podoplasty. Interpad skin is dissected from the palmar or plantar surface of the paw. Dissection is done first along the palmar or plantar surface of the digits, then across the cranial surface of the metacarpal or metatarsal pad. (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 1991 127:264-274.)

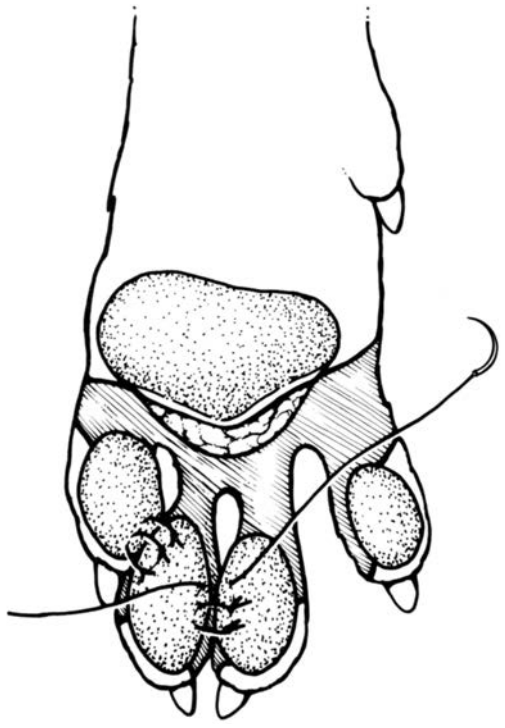


Figure 41-57. Fusion podoplasty. The digital pads are united with three simple interrupted sutures. (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 199 1;27:264-274.)

Before placing the final two sutures on either side of the paw, the tips of a pair of curved Carmalt forceps are passed deep to the pad sutures across the cranial surface of the metacarpal or metatarsal pad. A quarter inch diameter Penrose drain is grasped and pulled through the wound. It is cut with a half inch protruding on each side of the paw. The drain is anchored in place by passing the final suture on each side through the skin and drain (Figure 41-59).

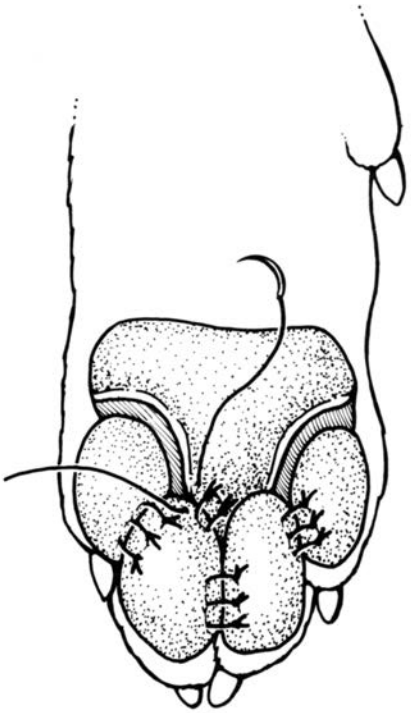


Figure 41-58. Fusion podoplasty. The united digital pads are flexed back against the metacarpal or metatarsal pad. Suturing progresses alternately to each side from a central suture using simple interrupted sutures. (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 199 1;27:264-274.)

The skin strips on the dorsum of each digit are sutured together with three to four simple interrupted sutures of 3-0 polypropylene (Figure 41-60). Areas at the ends of the digits are not sutured, to allow for drainage. After suturing the first paw, the pressure wrap is removed from the second paw, and it is sutured in like manner.

Gauze sponges are placed on the dorsal and palmar or plantar surfaces of the paws. A thin layer of 0.1% gentamicin ointment may be spread on the gauze before it is applied. A "clamshell" splint bandage is applied over the paws (See Chapter 2). These splints go to the level of the elbow on the forelimbs, or to the hocks on the hind limbs. Bandages are changed daily as long as drainage is significant, usually 10 to 14 days. With decreased drainage, bandages are changed every second or third day until 21 days. A small amount of gentamicin sulfate ointment may be placed over the suture lines and at points allowed for drainage. When the bandage is changed, if the area has a characteristic odor of Pseudomonas, the paw may be soaked in 0.05% chlorhexidine solution before being rebandaged; a biguanide-impregnated gauze (Kerlix AMD, Kendall Healthcare, Tyco Healthcare Group, Mansfield, MA, USA) is also helpful for this.

Drain tubes are removed at 10 days. Sutures are removed from the dorsal paw skin and between the digital pads at 10 to 14 days. Sutures between the digital pads and the metacarpal or metatarsal pad are removed at variable times, depending on when the tissues appear healed or whether the sutures are still apposing tissues in patients with some tissue separation in this area. Generally, all sutures and splints are removed by 21 days. A

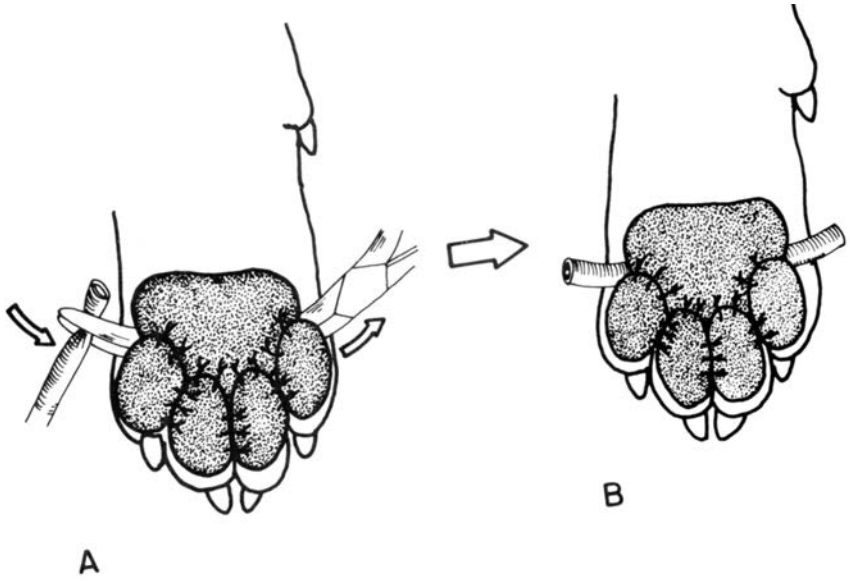


Figure 41-59. Fusion podoplasty. **A.** Curved Carmalt forceps are passed across the cranial surface of the metacarpal or metatarsal pad deep to the sutures to grasp a quarter inch Penrose drain to be pulled through the area. **B.** The drain is in place. (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 199 1;27:264 274.)

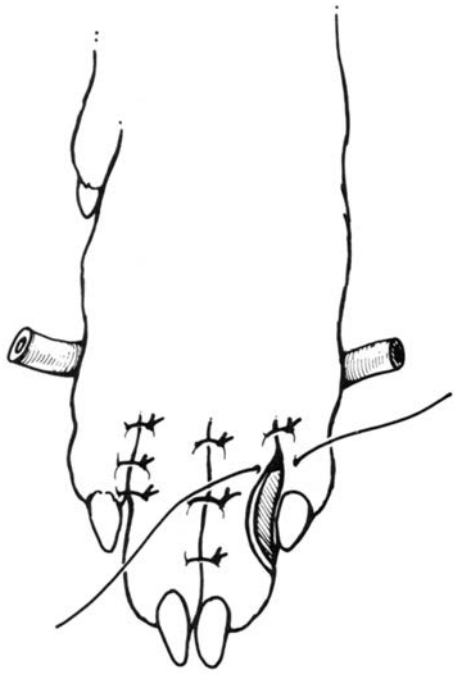


Figure 41-60. Fusion podoplasty. Simple interrupted sutures are used to suture the skin strips on the dorsum of each digit. (After Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 199 1;27:264-274.)

light bandage or a protective bootie may be used for a period as a transition between full bandaging and no bandage.

The most common complication of the procedure is separation of the suture line between the digital pads and the metacarpal or metatarsal pad. The "clamshell" splint (See Chapter 2) helps to prevent this complication; however, separation may occur and can expose an area of granulation tissue. If it appears that individual sutures are not functioning to hold the digital pads against the metacarpal or metatarsal pad, these sutures are removed, and the area is allowed to heal as an open wound. A nonadherent bandage pad is used with the remainder of the bandage until the area has epithelialized, usually by 21 days.

Massive Digital Wounds – Pandigital Amputation

Pandigital amputation is a salvage operation in which all digits are amputated at the metacarpophalangeal or metatarsophalangeal level, and the metacarpal or metatarsal pad is positioned under the ends of metacarpal or metatarsal bones to provide a weight bearing tissue on which the animal can ambulate. The procedure is indicated in cases of severe damage to all digits as the result of pressure necrosis, phlebitis, trap injury, or other sources of trauma.

A transverse incision is made in the dorsal paw skin over the metacarpophalangeal or metatarsophalangeal articulation (Figure 41-61A). On the palmar or plantar surface of the paw, the incision is made at the junction of the metacarpal or metatarsal pad with the interpad skin (Figure 41-61B). If a line of demarcation is present between viable and nonviable skin on either surface of the paw, the incision should be made approximately 3 mm proximal to the line in viable tissue.

Working from the dorsum of the paw, the skin is reflected, and dorsal axial and abaxial common or proper digital vessels are ligated with 3-0 polydioxanone ligatures and are severed distal to the ligatures. Associated nerves, extensor tendons, collateral ligaments and metacarpophalangeal or metatarsophalangeal joint capsules are severed. The sesamoid ligaments are cut, and the sesamoid bones are removed on the palmar or plantar surface of the limb. The palmar or plantar common. or proper digital vessels are ligated and are severed along with associated nerves and flexion tendons. The digits are removed (Figure 41-61C). Bone rongeurs are used to remove the heads of the metacarpal or metatarsal bones if no infection is present.

Metacarpal or metatarsal bones, especially the third and fourth bones, are trimmed back until the metacarpal or metatarsal pad can be folded cranially and positioned such that the thickest part of the pad is directly beneath the ends of the metacarpal or metatarsal bones (Figure 41-61D). The skin edge on the dorsal surface of the metacarpal or metatarsal area may also have to be trimmed to get this positioning. If infection is present, the heads are not removed from these bones in an effort to avoid the possibility of ascending infection in the marrow cavities of the bones. After infection is controlled the area may undergo reoperation to remove the heads and trim the bones.

After the metacarpal or metatarsal pad has been folded cranially into position, a quarter inch diameter Penrose drain is placed between the pad and the ends of the bones. The pad is rotated under the ends of the bones. Interrupted horizontal mattress sutures of 2-0 or 3-0 polvglyconate or polyglactin 910 are used to suture the subcutaneous tissue on the cranial edge of the metacarpal or metatarsal pad to the subcutaneous tissue overlying the cranial aspect of the metacarpal or metatarsal bones after the pad is rotated into position (Figure 41-61E). Far near near far sutures of 2-0 or 3-0 polypropylene or nylon are used to complete the closure of the metacarpal or metatarsal pad to the skin on the cranial surface of the metacarpal or metatarsal bones. Simple interrupted tacking sutures are placed at each end of the drain to hold it in place (Figure 41-61F).

A "clamshell" splint is indicated when bandaging to keep pressure off of the newly positioned pad. The drain is removed in 4 to 5 days. Sutures are removed at 10 to 14 days, and bandage support is used for 21 days. These times are subject to variation, depending on healing and the size of the animal.

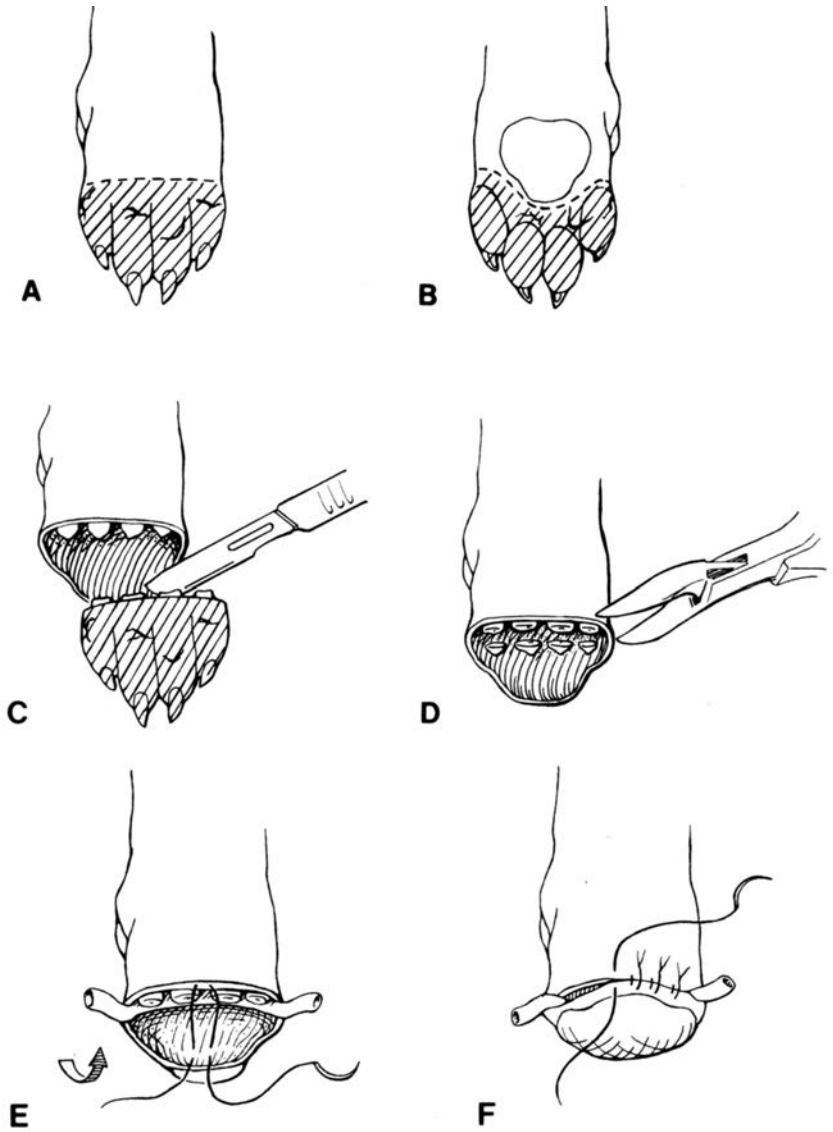


Figure 41-61. Pandigital amputation. **A.** A transverse incision is made on the dorsum of the paw proximal to the line of demarcation between viable and nonviable skin. **B.** A similar incision is made on the palmar or plantar surface of the paw cranial to the metacarpal or metatarsal pad. **C.** After severance of deep structures, the digits are removed. **D.** The distal heads of the metacarpal or metatarsal bones are removed, and the bones are trimmed to allow proper fit of the pad under their ends. **E.** A quarter inch Penrose drain is placed between the pad and the ends of the bones, and series of interrupted absorbable subcuticular horizontal mattress sutures are used to suture the pad under the metacarpal or metatarsal bones. **F.** Far near near far skin sutures are used to complete the closure. (From Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997: 360.)

Occasionally, because of a combination of the way the animal bears weight and the lack of secure connective tissue fixation of the metacarpal or metatarsal pad to underlying structures, the pad may not remain in the desired position under the metacarpal or metatarsal bones, and ulceration may develop in an area adjacent to the pad. Repositioning of the pad and placement of fixation sutures under the pad may help to secure it in place. Placement of pad grafts in the area of wear may also be considered, and is preferred by the authors.

Suggested Readings

Barclay CG, Fowler JD, Basher AW. Use of the carpal pad to salvage the forelimb in a dog and cat: An alternative to total limb amputation. J Am Anim Hosp Assoc 1987;23,527 532.

Basher AW. Foot injuries in dogs and cats. Compend Contin Educ Pract Vet 1994;16:1159 1178.

Bradley DM, Shealy PM, Swaim SF. Meshed skin graft and phalangeal fillet for paw salvage: a case report. J Am Anim Hosp Assoc 1993;29:427 433.

Bradley DM, Swaim SF, Alexander CN, et al. Autogenous pad grafts for reconstruction of a weight bearing surface: a case report. J Am Anim Hosp Assoc 1994;30:533 538.

Newman ME, Lee AH, Swaim SF, et al. Wound healing of sutured and nonsutured canine metatarsal foot pad incisions. J Am Anim Hosp Assoc 1986;22:757 761.

Pavletic MM. Atlas of small animal reconstructive surgery, 2nd ed. Philadelphia: JB Lippincott, 1999:365.

Pavletic MM. Foot salvage by delayed reimplantation of severed metatarsal and digital pads by using a bipedicle direct flap technique. J Am Anim. Hosp Assoc 1994;30:539 547.

Swaim SF. Management and bandaging of soft tissue injuries of dog and cat feet. J Am Anim Hosp Assoc 1985;21:329 340.

Swaim SF. Wound management of distal limbs and paws: reconstruction and salvage. Vet Med Rep 1990;2:128 139.

Swaim SF, Amalsadvala T, Marghitu DB, et. al. Pressure reduction effects of subdermal silicone block gel particle implantation: A preliminary study. Wounds. 2004; 16:299-312.

Swaim SF, Bradley DM, Steiss JE, et al. Free segmental paw pad grafts in dogs. Am J Vet Res 1993;54:2161 2170.

Swaim SF, Garrett PD. Foot salvage techniques in dogs and cats: options, "do's and don'ts." J Am Anim Hosp Assoc 1985; 21:511 519.

Swaim SF, Henderson RA. Small animal wound management, 2nd ed. Baltimore: Williams & Wilkins, 1997:295.

Swaim SF, Lee AH, MacDonald JM, et al. Fusion podoplasty for the treatment of chronic fibrosing interdigital pyoderma in the dog. J Am Anim Hosp Assoc 1991;27:264 274.

Swaim SF, Marghitu DB, Rumph PF, et. al. Effects of bandage configuration on paw pad pressure in dogs: A preliminary study. J Am Anim Hosp Assoc 2003;39:209-216.

Swaim SF, Milton JL. Fusion podoplasty to treat abnormalities associated with severed digital flexion tendons. J Am Anim Hosp Assoc 1994;30:137 144.

Swaim SF, Riddell KP, Powers RD. Healing of segmental grafts of digital pad skin in dogs. Am J Vet Res 1992;53:406 410.

Vig MM. Management of integumentary wounds of extremities in dogs: An experimental study. J Am Anim Hosp Assoc 1985;21: 187 192.

Section I

Cardiovascular and Lymphatic

Chapter 42

Heart and Great Vessels

Conventional Ligation of Patent Ductus Arteriosus in Dogs and Cats

Eric Monnet

Introduction

Patent ductus arteriosus is the most common congenital heart defect diagnosed in dogs. In cats, ventricular septal defects and pulmonic stenosis are more common cardiac defects. Physical findings include a continuous murmur auscultated at the left heart base and a hyperkinetic pulse. Thoracic radiographs show dilation of the descending aorta, the left atrium, and the pulmonary artery. Pulmonary overcirculation is also present. Surgical correction of the defect should be performed as soon as possible after diagnosis. Most animals with untreated patent ductus arteriosus will die within 1 year from congestive heart failure. Pulmonary hypertension may cause reversal of flow through the ductus arteriosus in a few cases. Dogs presenting with pulmonary edema should be treated with furosemide prior to surgery.

Surgical Technique

PDA ligation is accomplished through a left 4th intercostal thoracotomy in dogs, or a 4th or 5th left intercostal thoracotomy in cats. The left cranial lung lobe is reflected caudally and packed with a moistened laparotomy sponge or 4x4 gauze in smaller animals. The vagus nerve courses over the ductus arteriosus and can be used as a landmark to locate the ductus arteriosus. The vagus nerve is elevated from the mediastinum by sharp dissection and retracted gently with a suture. The recurrent laryngeal nerve should be identified as it passes caudal to the ductus. Dissection of the vagus nerve should be performed outside of the pericardial sac with a right angle forceps. Dissection of the patent ductus arteriosus starts on its caudal aspect (Figure 42-1). The forceps should be kept parallel to the transverse plane during this part of the dissection. Dissection of the cranial portion of the ductus is performed at an angle of approximately 45° to the transverse plane in a triangle delineated by the aortic arch, pulmonary artery, and patent ductus arteriosus (See Figure 42-1). Careful sharp dissection with scissors is sometimes necessary to reflect

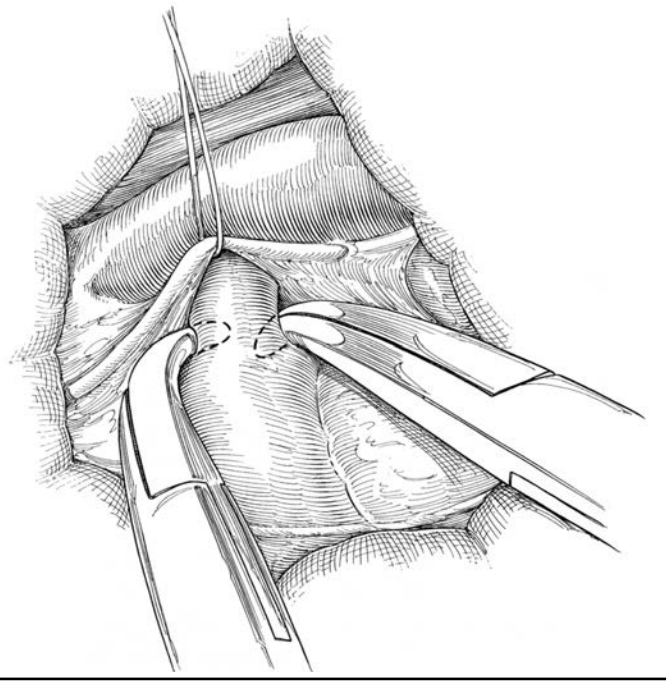


Figure 42-1. PDA ligation: The patent ductus arteriosus is isolated by blunt dissection without opening the pericardial sac. The right angle forceps is parallel to the transverse plane for the caudal dissection of the ductus. The right angle forceps is angle caudally 45° for the cranial dissection of the ductus. The ligature closest to the aorta is slowly tightened and tied first.: From E.C.Orton: Congenital Heart Defect, in Small Animal Thoracic Surgery, Williams & Wilkins, 1995, Chapt 19, p205.

the attachment of the pericardium ventrally from the aorta to expose this triangle. The dissection of the medial aspect of the patent ductus arteriosus is performed by passing the right angle forceps from caudal to cranial (Figure 42-2). Dissection should be as gentle as possible with small movements of the right angle forceps to avoid tearing the medial wall of the ductus. When the tip of the right angle forceps is clear of tissue, a #1 or 0 silk suture is grasped by the forceps and passed around the ductus. A second suture is passed around the ductus in the same manner. Alternatively, some surgeons pass a doubled strand of suture and cut the suture in the middle thus reducing the number of passes on the medial aspect of the ductus. The ligature closest to the aorta is slowly tightened and tied first (Figure 42-3). The second ligature is then tightened and tied. The palpable thrill in the pulmonary artery present prior to ligation should be completely eliminated after ligation. If the medial wall of the ductus is ruptured during dissection light pressure should be applied to control the bleeding. If the tear is not too large the bleeding will stop. However, continuing the dissection may worsen the tear and lead to uncontrollable hemorrhage. At this point, the options depend on the experience of the surgeon and on the availability of vascular instruments. One option is to abort the surgery and refer the case to a surgeon experienced in cardiovascular surgery for latter closure. Another option is to divide the ductus between two vascular forceps and close both ends with 4-0 polypropylene suture using a continuous mattress pattern. Intravenous injection of nitroprusside has been recommended to decrease arterial pressure after tearing a ductus arteriosus. Clamping of the aorta and the pulmonary artery to control bleeding has also been recommended. At

the conclusion of intrathoracic surgery, the cranial lung lobe is unpacked, replaced in its normal position, and reinflated. A thoracostomy tube is placed and the thoracotomy is closed in a routine fashion. The thoracostomy tube is usually removed in the immediate postoperative period after negative intrathoracic pressure is attained.

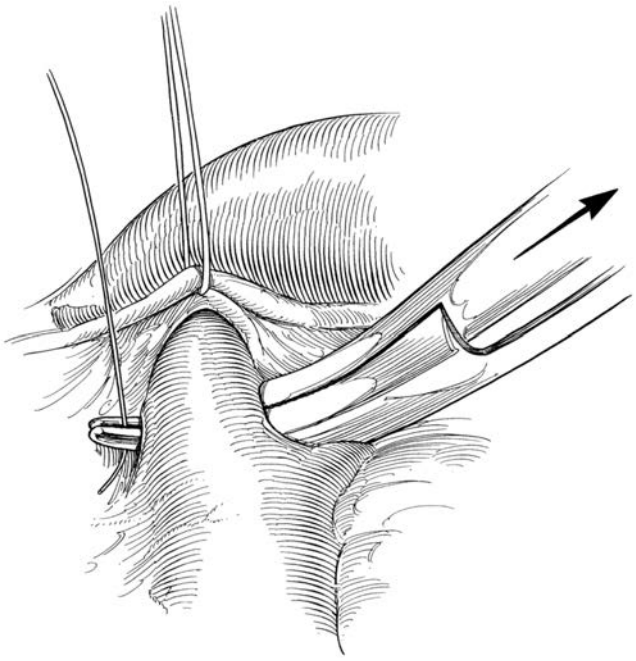


Figure 42-2. PDA ligation: Two sutures are passed from cranial to caudal around the ductus with right angle forceps after complete dissection of the ductus arteriosus. Illustration Fig 19.1. C: From E.C.Orton: Congenital Heart Defect, in Small Animal Thoracic Surgery, Williams & Wilkins, 1995, Chap19, p206.

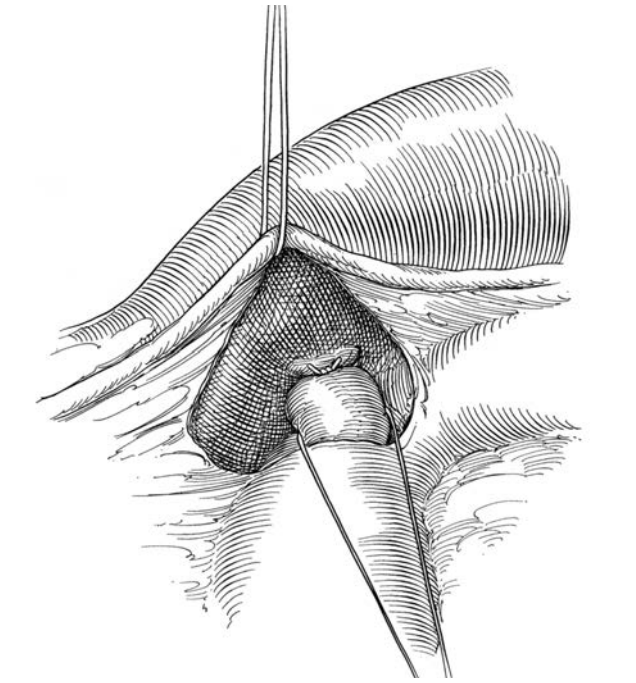


Figure 42-3. PDA ligation: The suture closest to the aorta is ligated slowly first. Illustration Fig 19.1. D: From E.C.Orton: Congenital Heart Defect, in Small Animal Thoracic Surgery, Williams & Wilkins, 1995, Chap19, p206.

Suggested Readings

Orton, E.C.: Congenital heart defect. Small animal thoracic surgery. Edited by E.C. Orton. Baltimore. Williams & Wilkins, 1995, pp 203-227.

Orton, E.C.: Cardiac surgery. Textbook of small animal surgery. Edited by D. Slatter. Philadelphia. W.B.Saunders, 2002, pp 955-986.

Eyster, G.E., Probst, M.R.: Basic cardiovascular surgery and procedures. In Canine and feline cardiology. Edited by P.R. Fox. New York. Churchill Livingston, 1988, pp 605-624.

Birchard, S.J., Bonagura, J.D., Fingland, R.B.: Results of ligation of patent ductus arteriosus in: 201 cases (1969-1988). J. Am. Vet. Med. Assoc., 196:2011, 1990.

Hunter, S. L., Culp, L. B., Muir, W. W., 3rd, et al. Sodium nitroprusside-induced deliberate hypotension to facilitate patent ductus arteriosus ligation in dogs Vet Surg, 32:336, 2003.

Hunt G.B., Simpson D.J., Beck J.A., et al. Intraoperative hemorrhage during patent ductus arteriosus ligation in dogs. Vet Surg, 30:58, 2001.

Surgical Management of Pulmonic Stenosis

Jill E. Sackman and D.J. Krahwinkel, Jr.

Introduction

Pulmonic stenosis is reported to be the third most common congenital heart disease in the dog with patent ductus arteriosus and aortic stenosis being first and second, respectively.[1] The English bulldog is the most common breed represented, however, other dogs at risk include the beagle, Samoyed, Chihuahua, schnauzer, Boykin spaniel, mastiff, and various terrier breeds.[2] The disease occurs equally between male and female except in the bulldog where the incidence in males predominates. The disease is rare in cats. Pulmonic stenosis has a genetic basis in dogs, although this is uncertain in the cat.[3]

The lesion may occur as a supravalvular, valvular, or subvalvular stenosis. With any of the three, an infundibular stenosis may occur in which the hypertrophied musculature obstructs the right ventricular outflow tract. The valvular site is by far the most common and is manifested by thickening, fibrosis, and hypoplasia of the valve leading to outflow obstruction.

Diagnosis

Many cases of pulmonic stenosis are asymptomatic early in their life; some remain asymptomatic indefinitely. More severe cases display exertional fatigue, dyspnea, and syncope. Signs of right heart failure including ascites, hepatomegaly, and arrhythmia may be present in advanced cases.[4] Physical examination reveals a systolic ejection murmur heard over the pulmonic valve that often radiates along the sternum to both sides of the thorax. A holosystolic murmur of tricuspid insufficiency may sometimes be auscultated over the right hemithorax.

The ECG usually indicates right ventricular hypertrophy, including right axial deviation, S waves in leads I, II, III, and aVF. Thoracic radiographs reveal varying degrees of cardiomegaly. The right side of the heart predominates in the enlargement. A

poststenotic dilatation of the main pulmonary artery is seen on the dorsoventral view. The pulmonary vessels appear normal or somewhat underperfused. Cardiac catheterization helps to locate the specific site of the stenosis and to measure pressure gradients for prognosis. Measuring gradients under anesthesia gives pressure readings that are usually much lower than actually exist. Angiographic features of pulmonic stenosis include thickened and dysplastic valve leaflets, narrowing of the outflow tract and valve orifice, poststenotic pulmonary artery dilatation, and right ventricular hypertrophy. In English bulldogs an anomalous left coronary artery may be seen crossing the ventricle at the level of the stenosis.

In many cases echocardiography and color flow Doppler echocardiography examination provide sufficient data making cardiac catheterization unnecessary. Typical findings are hypertrophy of the right ventricle, muscular narrowing of the right ventricular outflow tract, deformity and narrowing of the pulmonic valve, and post stenotic dilatation of the pulmonary artery. Pressure gradients measured by color flow Doppler echocardiography are more likely than catheterization to give an accurate assessment of the severity of disease because the examination does not require general anesthesia. Echocardiography and/or cardiac catheterization can usually determine the severity of the disease and locate the stenosis at the supravalvular, valvular, subvalvular, or infundibular site. This information is crucial in determining surgical candidates, selecting the correct surgical procedure, and giving prognosis. In some patients it is very difficult to delineate between a pure valvular stenosis and one that is both valvular and subvalvular. This makes selecting the proper surgical technique more difficult.

Surgical Guidelines

Nonanesthetized pressure gradients that are less than 50 mmHg are generally considered mild and do not require surgical intervention. Severe gradients exceeding 80 mmHg place the patient at risk of heart failure and death. These should have surgical intervention.[3,4] Dogs with moderate disease (gradients of 50 to 80 mmHg) may or may not require surgical correction depending on the progression of the disease. One author has recommended surgery when: 1) the right ventricular pressure exceeds 120 mmHg or a gradient exceeds 100 mmHg in a mature dog, or 2) the right ventricular pressure is 90 to 120 or a gradient of 70 to 100 in an immature dog.[5] Others recommend surgery any time the gradient exceeds 50 mmHg and right ventricular hypertrophy is significant.[6]

Any animal not undergoing surgery should be re-evaluated at three month intervals to determine if the disease is progressing. Symptomatic animals should have surgical intervention regardless of their pressure gradients. A problem of waiting to see if a patient's disease is progressive based on pressure measurements or disease signs is that they may become poorer surgical candidates with time. These animals may develop secondary infundibular muscular stenosis, worsening right ventricular hypertrophy, right ventricular fibrosis, and right heart failure. If possible surgery should be delayed until the animal is mature so the procedure is done on a fully developed heart that will not outgrow the correction.

Even though various authors have stated guidelines for surgical intervention, most of these are based upon personal observations. There have been no clinical trials in dogs with long-term follow-up to validate criteria for surgical intervention or to determine which corrective procedure gives the best results; however in a series of 72 cases of congenital pulmonic stenosis left untreated, only 65% of patients were alive after two years.[7] Unfortunately in this series, the severity of the stenosis was not described.

Anesthesia for Pulmonic Stenosis

Nearly all anesthetic agents depress cardiopulmonary function directly or alter reflex regulatory mechanisms.[8] Patients with cardiac disease may have little to no reserve for compensation; therefore, anesthetic agents must be administered carefully and in reduced dosages. Preanesthetic agents should be administered to relieve anxiety and to reduce the amount of depressant general anesthetic required. A combination of a benzodiazepine and an opioid are used for sedation. Opioid-induced respiratory depression may occur, therefore oxygen by mask should be provided during the induction process. Anticholinergics, especially atropine, are not used unless bradycardia occurs because of their propensity to induce tachycardia.

Administering low concentration isoflurane in oxygen until tracheal intubation can be accomplished completes anesthetic induction. Anesthetic maintenance is by continued low concentration of isoflurane supplemented with intermittent doses of an opioid. Intermittent positive-pressure ventilation is provided either manually or mechanically. Profound muscle relaxation can be produced by intravenous administration of atracurium, a nondepolarizing muscle relaxant.

Pulmonic stenosis patients must be closely monitored for cardiopulmonary function. Monitoring parameters should include heart rate, ECG, pulse quality, direct or indirect blood pressure, pulse oximetry, and central venous pressure. Assessment of blood volume and hemodilution is by serial determinations of packed cell volume and total plasma proteins. Measuring urine production assesses renal function. Blood pressure is maintained by a maintenance flow of intravenous crystalloids supplemented with colloids. Cross-matched whole blood must be available should major hemorrhage occur.

Surgical Procedures for Pulmonic Stenosis

Various surgical procedures have been described for correction of pulmonic stenosis.[9] These include balloon dilatation, open valvulotomy/valvulectomy, closed valvulotomy/dilatation, open and closed patch grafting, by-pass conduit, and open-heart repair with cardiopulmonary bypass. The specific procedure depends upon the location of the stenosis, size of the patient, severity of the disease, expertise of the surgeon, and equipment available. Many of the procedures have been adapted from techniques used to correct pulmonic stenosis in children although direct application to animals may be erroneous. For example, valvular stenosis in children is commonly a fusion of the valve leaflets, whereas in dogs it is usually a fibrotic, thickened, dysplastic valve. Direct comparison of the techniques or the expected results between children and dogs should not be made.

Open Valvulotomy/Valvulectomy

This procedure is a modification of the technique developed by Swan[10] using transient venous inflow occlusion and a pulmonary arteriotomy. The technique is used in patients with a valvular stenosis and minimal to no subvalvular component. The thorax is opened by a thoracotomy at the left fourth intercostal space. Dissecting between the thymus and the cranial aspect of the pericardial sac isolates the cranial vena cava. The cava is located on the right side of the thorax and ventral to the brachycephalic artery. A Rumel tourniquet of umbilical tape is placed on the vessel. Incising the caudal mediastinum immediately behind the pericardial sac and ventral to the phrenic nerve approaches the caudal vena cava. The vessel can be visualized deep in the mediastinal space to the right side of the thorax. Right angle forceps are used to place a Rumel tourniquet similar to the cranial cava. Dissection of the caudal cava may be impossible from the fourth intercostal space in dogs with severe cardiac enlargement. In these instances the caudal edge of the incised skin is retracted and a small thoracotomy incision is made at the sixth intercostal space. The cava is easily isolated from this position.

A third Rumel tourniquet is placed on the descending aorta just above the heart base. Tightening this tourniquet for 1 to 2 minutes after inflow occlusion maximizes blood flow to the heart and brain. It is released slowly as cardiac function returns to normal.

The pericardial sac is incised parallel and ventral to the phrenic nerve. Four to six stay sutures are placed in the pericardial sac and secured to the surgical drapes to "cradle" the heart (Figure 42-4). Lidocaine applied topically to the heart and an intravenous lidocaine drip help to minimize surgically induced arrhythmias. Stay sutures of 5-0 polypropylene are placed in the dilated pulmonary artery immediately distal to the pulmonary valve. Venous inflow occlusion is accomplished by tightening the caval tourniquets. After waiting a few seconds for the heart to partially empty, a 1 to 2 cm incision is made between the two stay sutures (Figure 42-5). A small retractor at the ventral end of the incision and the two stay sutures retract the arteriotomy site (Figure 42-6). Suction is used to empty the right ventricle and visualize the pulmonic valve. The dysplastic leaflets are grasped with forceps, and scissors or scalpel used to excise the valve (Figure 42-7). After all three leaflets have been excised or incised, a forceps is used to dilate the valve annulus. A "pop" can be felt as the annulus stretches. One finger is inserted into the outflow tract to assure that the stenosis is relieved. The cranial

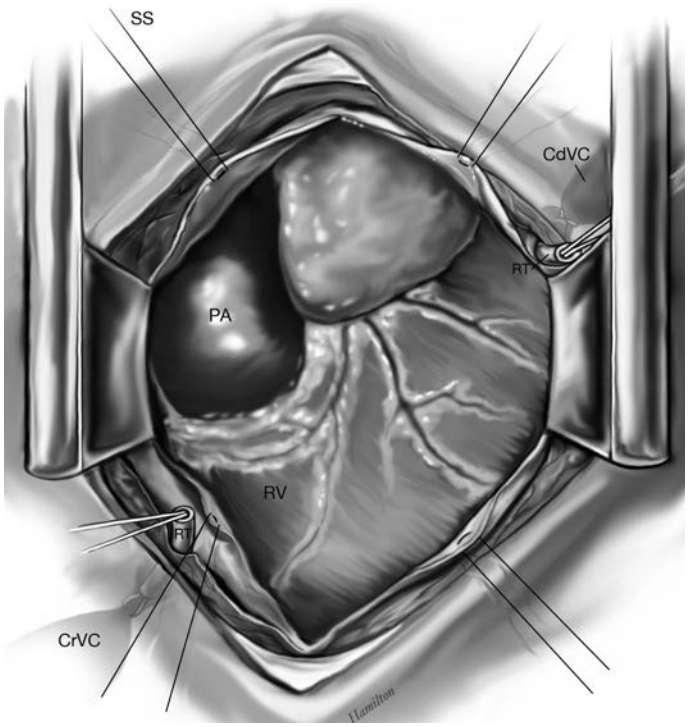


Figure 42-4. Surgical approach to the right ventricular outflow tract and pulmonary artery is shown. The pericardial sac is opened and retracted with stay sutures. Rumel tourniquets *(RT)* are placed around the cranial vena cava *(CRVC)* and caudal vena cava *(CCDVC)*. The pulmonary artery *(PA)* and right ventricle *(RV)* are exposed.

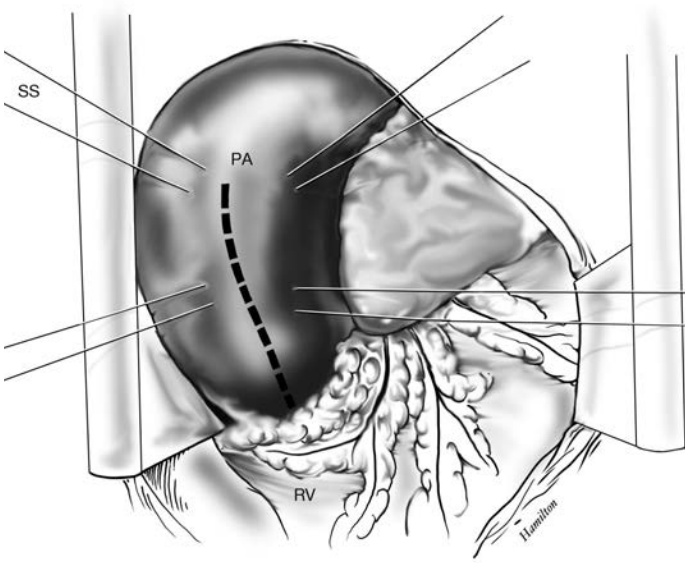


Figure 42-5. Stay sutures *(SS)* are placed in the dilated pulmonary artery. The pulmonary artery *(PA)* is opened to just above the level of the pulmonic valve *(PV)*.

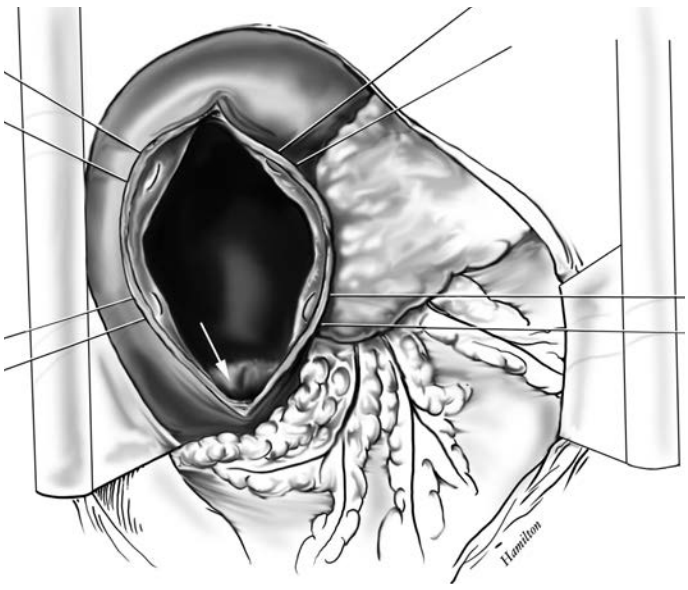


Figure 42-6. The pulmonic stenosis *(PS)* is observed near the ventral end of the arteriotomy.

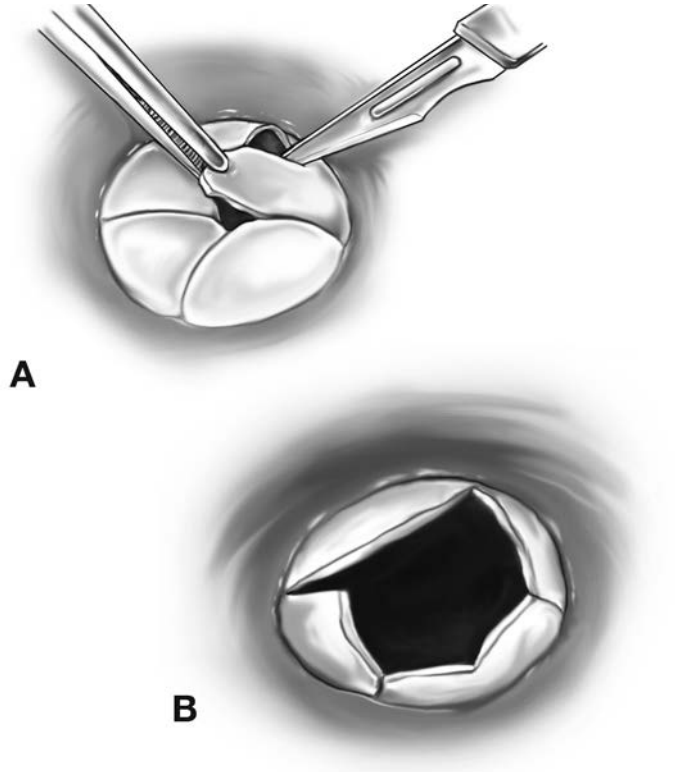


Figure 42-7. A. The dysplastic leaflets are excised using a No. 11 scalpel and/or scissors. **B.** The appearance of the valve after the leaflets have been partially excised and dilated.

Rumel tourniquet is released and the heart and pulmonary artery permitted to fill to remove all intravascular air. The stay sutures are used to elevate the edges of the artery and a Satinsky clamp placed on the arteriotomy site (Figure 42-8). The second Rumel tourniquet is released. Cardiovascular resuscitation is aided by temporarily occluding the descending thoracic aorta with the third Rumel to increase coronary and cerebral blood flow. Cardiac massage and an intravenous infusion of dopamine may be required to reestablish normal cardiac function. Total inflow occlusion of a diseased heart should not exceed two minutes. If this is not sufficient time to complete the procedure, then inflow is terminated and 10 to 15 minutes of normal cardiac function is established. A brief second inflow occlusion can be utilized to complete the procedure. Normal hearts can tolerate four or more minutes of inflow occlusion; however diseased hearts often fibrillate and are difficult to defibrillate.

The arteriotomy is closed with a double row of continuous 5-0 polypropylene sutures, and the stay sutures are removed (Figure 42-9). The pericardial sac is loosely closed with 3-0 absorbable suture. Closing the sac tightly could result in tamponade if the arteriotomy site leaks. The tourniquets are removed, and the thorax lavaged with warm saline to remove all blood. The intercostal nerves are blocked with local anesthetic for analgesia, a thoracic tube placed, and the thorax closed in a routine manner.

Closed Valvulotomy/Dilatation

This procedure is used in patients who likely cannot tolerate even brief in-flow occlusion. The surgical approach is as described above but without inflow occlusion. A purse-string suture is placed

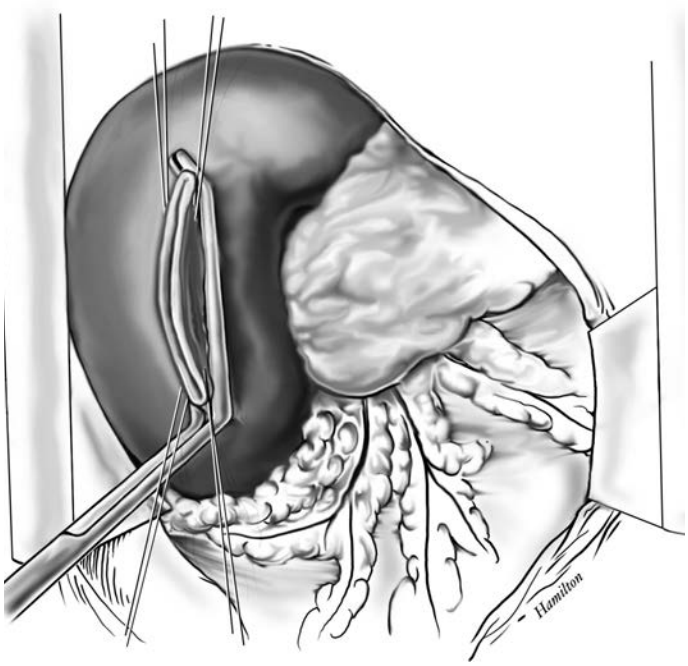


Figure 42-8. Satinsky *(SF)* forceps are used to occlude the arteriotomy site.

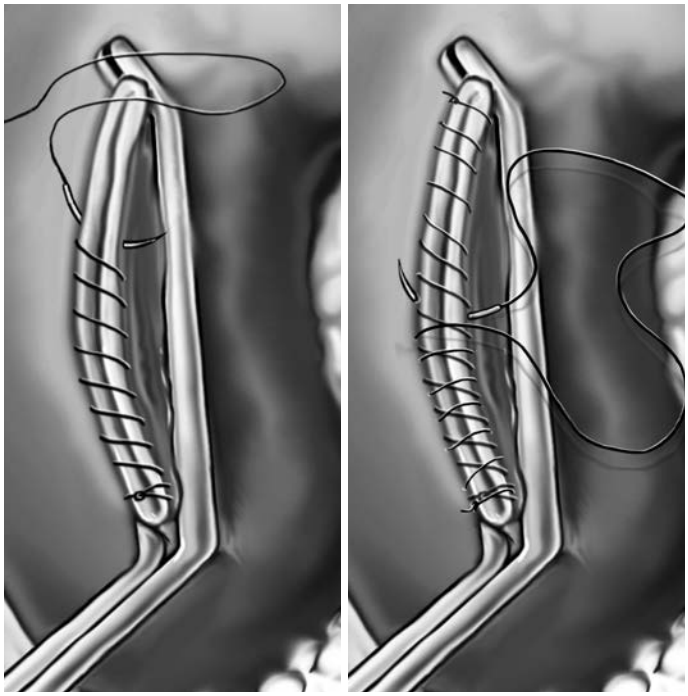


Figure 42-9. The arteriotomy is closed with a double row of continuous monofilament sutures.

in the right ventricular outflow tract just below the pulmonic valve or in the dilated pulmonary artery above the valve. The suture ends are placed through a piece of tubing similar to the Rumel tourniquet. A stab incision is made through the purse string and into the lumen of either the right ventricle or the pulmonary artery. A blunt tipped bistoury or valvulotome is passed through the valve and several blind cuts are made through the stenotic valve by cutting against backpressure applied by the surgeon's finger (Figure 42-10). A forceps is then placed through the purse string and the valve annulus dilated to completely break down

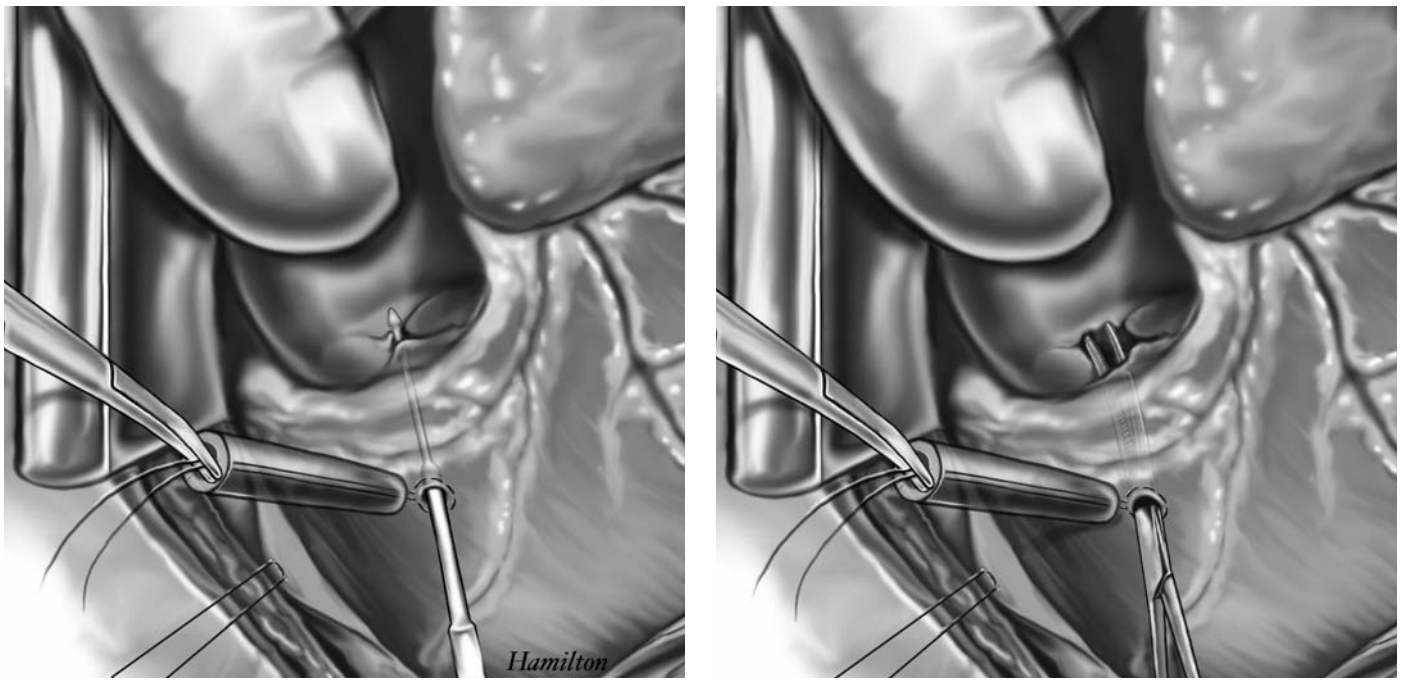


Figure 42-10. A closed valvulotome or bistoury is placed through a purse string in the right ventricle, and the dysplastic valve leaflets are incised.

the stenotic ring. In dogs with severe muscular hypertrophy and a narrow outflow tract, this procedure is more easily accomplished through a purse string in the dilated pulmonary artery. Simple dilatation without first cutting the stenotic valve may only provide temporary relief since the torn and stretched tissue may heal with scar tissue resulting in a new stenosis.

Patch Grafting

The use of patch grafting for repair of pulmonic stenosis in the dog was first reported in 1976.[11] The graft extends over the pulmonary artery to the right ventricle outflow tract and is effective in correcting valvular, supravalvular, and subvalvular stenosis while alleviating infundibular lesions. Patch grafting may be performed by either a closed or open technique. The closed patch graft technique[11,12] relies upon the placement of a cutting wire across the stenotic lesion under the applied patch. Unfortunately the technique does not allow excision of the dysplastic valve and relies upon the surgeon's ability to place a cutting wire blindly across the defect.

An open technique for patch grafting has been described[13,14] The authors prefer a modification of this technique, which is performed through a left lateral thoracotomy at the fourth intercostal space. The lungs are retracted to expose the pericardial sac. Rumel tourniquets are placed around the cranial and caudal vena cava, and the thoracic aorta as described for open valvulotomy/valvulectomy. The pericardium is incised parallel and ventral to the phrenic nerve, with an extension ventral and perpendicular. Pericardial basket sutures are placed. An elliptical shaped polytetrafluoroethylene (PTFE; Gortex, W.L. Gore and Assoc.) patch is cut so that the graft will extend both proximal and distal to the stenotic lesion. The patch is sutured to the outflow tract and pulmonary artery using 4-0 polypropylene suture and a double-armed taper point needle. Suturing is started at the ventral tip of the patch, which is placed on the ventricle with an interrupted suture. The opposite end of the patch is sutured to the pulmonary artery above the stenotic site. The margins of the patch are sutured in a continuous fashion to the ventricle and onto the pulmonary artery. It is critical that the patch is sutured in a "tented" fashion over the stenotic area. This extra graft allows for expansion of the stenotic area. Once the patch has been applied, it is incised longitudinally at an equal distance between the cranial and caudal margins (Figure 42-11A and B). The caval tourniquets are tightened to accomplish venous inflow occlusion. A stab incision with a #11 scalpel blade is made into the pulmonary artery and extended to the dorsal and ventral margins of the patch with Metzenbaum scissors. The valve is inspected and the leaflets excised (Figure 42-12). A forceps may be used to further dilate the valve and annulus. A finger is inserted into the annulus to insure that the stenosis has been relieved. Air is evacuated from the heart by releasing the cranial Rumel tourniquet. The incised patch graft is clamped using Satinsky tangential vascular occlusion clamps. The caudal Rumel tourniquet is then released. The patch graft incision is sutured with 4-0 polypropylene in a continuous pattern (Figure 42-13A and B). Total inflow occlusion time should not exceed two minutes. The Rumel on the aorta is used temporarily to improve heart and brain perfusion. The pericardium is closed loosely with interrupted sutures. A thoracostomy tube is placed and the thoracotomy incision is closed in routine fashion.

Open patch grafting is effective in young animals with severe valvular, but preferably supravalvular, subvalvular, or infundibular stenosis. Care must be taken in identifying an aberrant coronary artery, which crosses the right ventricular outflow tract occasionally in boxers and bulldogs, negating the use of this procedure.

A case series of nine dogs undergoing closed patch grafting has described significant morbidity and mortality associated with the closed patch procedure.[15] There was one intra-operative death,

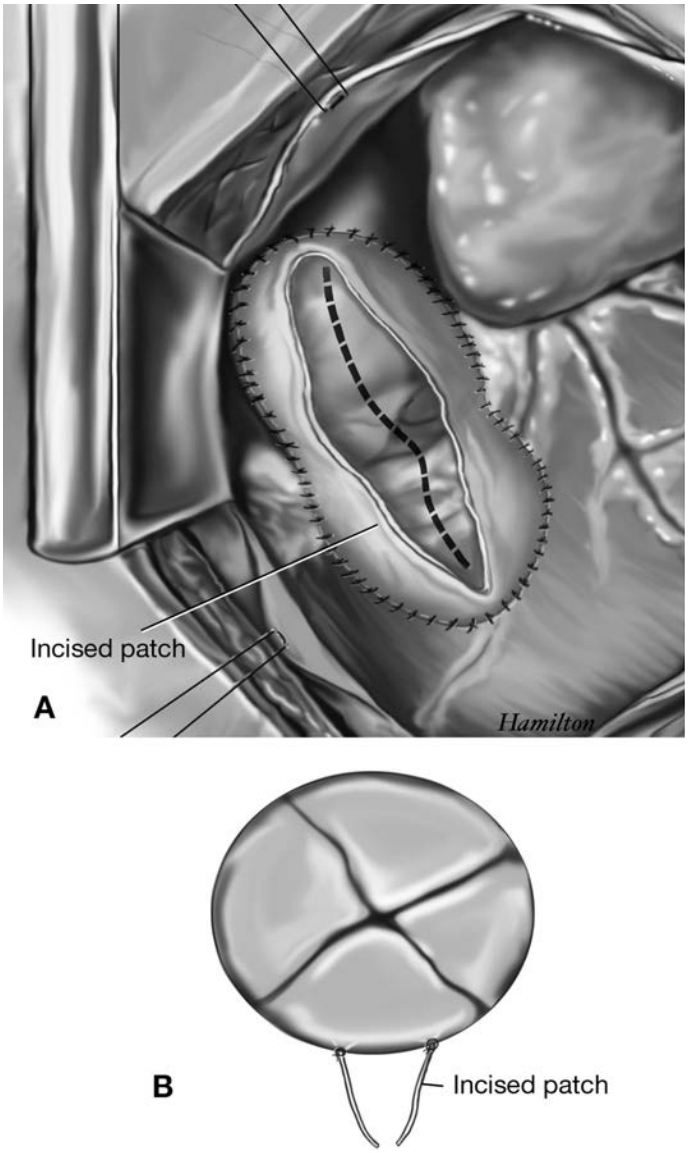


Figure 42-11. A. The patch is cut longitudinally at an equal distance between the cranial and caudal margins. **B.** Cross sectional view of patch applied across stenotic valve.

and blood transfusions were required to treat life-threatening hemorrhage in six of the nine dogs. The clinical signs improved in five of the six dogs that survived in this study. Progression of right ventricular hypertrophy was delayed, but not prevented by the procedure.

Conduits

Vascular grafts or conduits have been used to repair supravalvular pulmonic stenosis in the dog.[16] The use of conduits from the pulmonary artery to the right ventricle may be used to bypass the stenotic pulmonary valve in animals with an aberrant coronary artery. The technique is performed through a left lateral thoracotomy at the fifth intercostal space. The pericardium is opened and sutured as previously described. The stenotic region is observed and an appropriately sized Dacron or PTFE conduit chosen. A Satinsky partially occluding vascular clamp is applied to the pulmonary artery above the site of the lesion. An arteriotomy is made with a #11 scalpel blade and extended with Potts

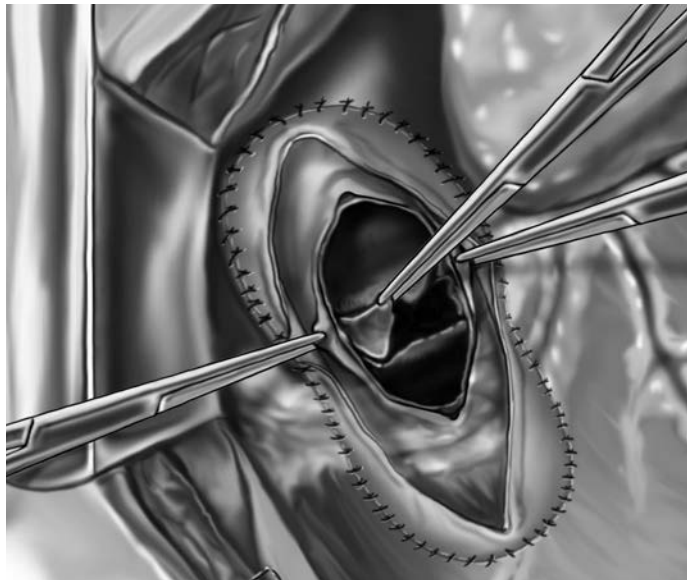


Figure 42-12. The valve is inspected and the leaflets excised.

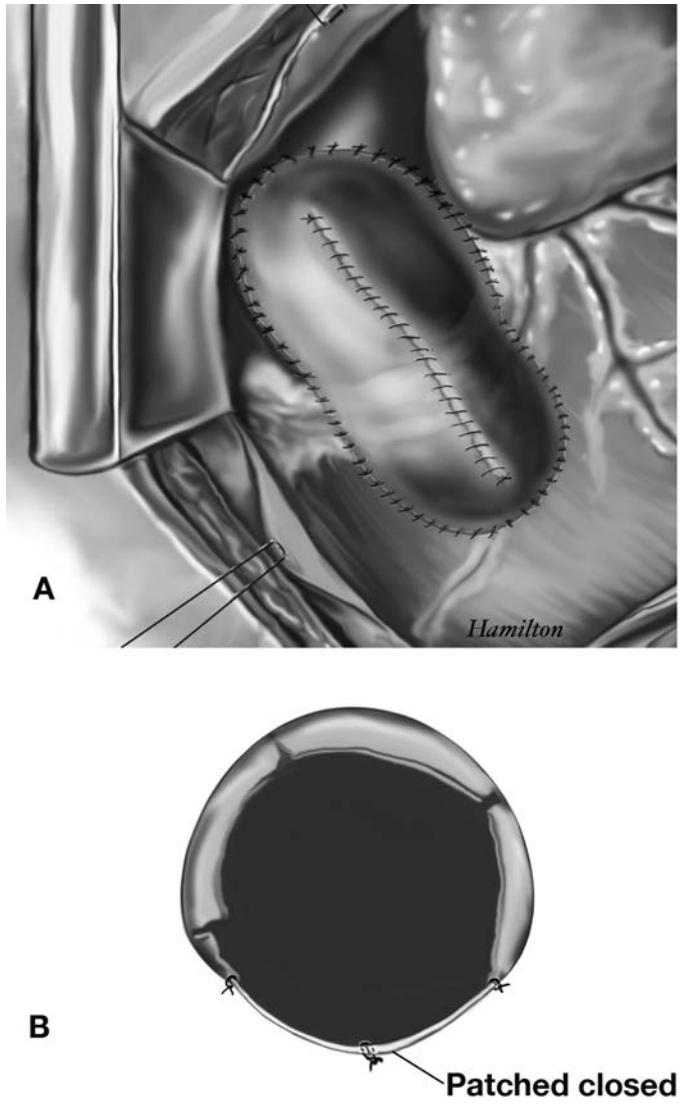


Figure 42-13. A. Completed graft sutured to pulmonary artery outflow tract. **B.** Cross sectional view of patch applied across incised pulmonary outflow tract. Note increase in outflow diameter.

scissors. The conduit is cut at an oblique angle and sutured end-to-side to the pulmonary artery with continuous 5-0 to 6-0 polypropylene suture on a double-armed taper point needle. The conduit is anastomosed to the ventricular wall in end-to-side fashion following coring a hole in the ventricular wall. Closures of the pericardium and thoracotomy incisions are routine.

Conduits, with the exception of those used in supravalvular stenosis (pulmonary artery to pulmonary artery) have been met with limited success in veterinary medicine. The procedure may be best applied under cardiopulmonary bypass.

Cardiopulmonary Bypass

Pulmonic stenosis can be repaired effectively utilizing cardiopulmonary bypass. This technique permits direct visualization and repair of the lesion without the time constraints of inflow occlusion. Valvuloplasties, patches, and conduits can all be performed with cardiopulmonary bypass permitting the surgeon to do precise surgical repairs.[17]

References

1. Buchanan JW: Causes and prevalence of cardiovascular disease. In: Kirk RW, Bonagura JD, eds.: Current Veterinary Therapy XI. Philadelphia: WB Saunders, 1992, p 647.

2. Buchanan JW: Changing breed predispositions in canine heart disease. In: Proceedings of the 10th ACVIM Forum, 1992, p 213.

3. Bonagura JD, Darke PG: Congenital heart disease. In: Ettinger SJ, Feldman EE, eds.: Textbook of Veterinary Internal Medicine. Philadelphia: WB Saunders, 1995, p 892.

4. Thomas WP: Therapy in congenital pulmonic stenosis. In: Kirk RW, Bonagura JD, eds.: Current Veterinary Therapy XII. Philadelphia: WB Saunders, 1995, p 817.

5. Eyster GE: Basic cardiac surgical procedure. In: Slater DH, ed.: Textbook of Small Animal Surgery. Philadelphia: WB Saunders, 1993, p 462.

6. Orton EC: Pulmonic stenosis and subvalvular aortic stenosis: surgical options. Sem Vet Med Surg 9:221, 1994.

7. Ewey DM, Pion PD, Hird, DW: Survival in treated and untreated dogs with pulmonic stenosis. J Vet Intern Med 2:114 (abstract),1992.

8. Hellyer PW: Anesthesia in patients with cardiovascular disease. In: Kirk RW, Bonagura JD, eds.: Current Veterinary Therapy XI. Philadelphia: WB Saunders, 1992, p 655.

9. Breznock EM: Surgical relief of pulmonic stenosis. In: Bojrab MJ, ed.: Current Techniques in Small Animal Surgery. Philadelphia: Lea & Febiger, 1990, p 513.

10. Swan H: Surgery by direct vision in the open heart during hypothermia. J Am Med Assoc 153:1081, 1953.

11. Breznock EM, Wood GL: A patch-graft technique for correction of pulmonic stenosis in dogs. J Am Vet Med Assoc 169:1090, 1976.

12. Shores A, Weirick WE: A modified pericardial patch graft technique for correction of pulmonic stenosis in the dog. J Am Anim Hosp Assoc 21:809, 1985.

13. Orton EC, Bruecker KA, McCracken TO: An open patch graft technique for correction of pulmonic stenosis in the dog. Vet Surg 19:148, 1990.

14. Hunt GB, Pearson MRB, Bellenger CR, Malik R: Use of a modified open patch-graft technique and valvulectomy for correction of severe pulmonic stenosis in dogs: eight consecutive cases. Aust Vet J 70:244, 1993.

15. Staudte KL, Gibson NR, Read RA, Edwards GA: Evaluation of closed pericardial patch grafting for management of severe pulmonic stenosis. Aust Vet J 82:33, 2004.

16. Ford RB, Spaulding GL, Eyster GE: Use of an extra cardiac conduit in the repair of supravalvular pulmonic stenosis in a dog. J Am Vet Med Assoc 172:922, 1978.

17. Orton EC: Cardiopulmonary bypass for small animals. Sem Vet Med Surg 9:210, 1994.

Interventional Catheterization for Congenital Heart Disease

Jonathan Abbott

Introduction

For much of its early history, the technique of cardiac catheterization was utilized exclusively for diagnosis. However, beginning in the 1960's, resourceful pediatric cardiologists developed methods of transcatheter therapeutic intervention. Since that time, the indications for interventional catheterization in both pediatric and adult cardiovascular medicine have expanded remarkably. Obstructive lesions are addressed by balloon dilation, pathologic shunts are occluded by transcatheter techniques, stents have been used to maintain patency of vessels and conduits and more recently, percutaneous methods of valve replacement and repair have been investigated. In veterinary medicine, transcatheter therapy has been confined primarily to balloon dilation of outflow tract obstruction and occlusion of patent ductus arteriosus (PDA). This chapter reviews the current applications of transcatheter intervention in veterinary patients with congenital cardiovascular disease.

Transcatheter Occlusion of Patent Ductus Arteriosus (PDA)

Etiopathogenesis of PDA

The ductus arteriosus connects the ventral aspect of the proximal descending aorta with the dorsal aspect of the pulmonary artery bifurcation. The histology of the normal duct is distinct from that of the aorta and this is relevant to normal closure as well as to the angiographic appearance of the persistently patent duct. The tunica media of the aorta consists primarily of elastic fibers. In contrast, the media of the duct is comprised of smooth muscle fibers in both circumferential and spiral orientations.[1] During fetal life, pulmonary vascular resistance exceeds systemic vascular resistance and the ductus diverts the majority of the right ventricular output to the systemic circulation. Maintenance of fetal ductal patency primarily depends on production of prostaglandin-E.[2]

In normal, term neonates, closure of the ductus begins shortly after birth and initially results from contraction of ductal smooth muscle. The mechanism of ductal closure is complex and likely has a multifactorial basis. However, increases in oxygen tension associated with parturition limit the production of dilative prostaglandins, initiate a vasoconstrictive prostaglandin cascade and decrease the sensitivity of ductal smooth muscle to dilative

stimuli.[2] The time required for functional closure of the duct is species-dependent but generally is within 3 to 5 days of birth. Anatomic ductal closure occurs later and is associated with the development of intimal edema, cellular degeneration and necrosis or apoptosis; the result is the arterial ligament.[1,3]

The cause of post-natal ductal patency in most if not all affected dogs is a deficiency of ductus-specific smooth muscle.[4] In dogs that ultimately develop a patent duct, ductal smooth muscle is replaced by elastic tissue which generally extends from the aortic side of the duct toward the pulmonary artery. In the most severely affected individuals, the media of the entire duct is replaced by elastic tissue. The result is a tubular, large diameter duct that is associated with neonatal pulmonary hypertension and a bidirectional or right-to-left shunt.[5] In less severely affected individuals, the elastic tissue extends a variable distance from the aortic-ductal junction. Because of persistence of functional smooth muscle in the more distal aspect of the ductus, most left-to-right shunting PDA have a conical shape and are narrowest where the ductus joins the pulmonary artery. The duct is widest at the attachment of the aorta and the flask-shaped dilation is known as the ductal ampulla. The cranial aspect of the ampulla is partially roofed by a shelf of tissue, known as the *crista (or plica) reunions,* which extends caudally from the ventral wall of the proximal descending aorta.[1] PDA is heritable in miniature poodles[5] and, based on breed predispositions, PDA likely has a genetic basis in other purebred dogs.

Pathophysiology

The ductus provides a communication between the pulmonary and systemic circulations. The size of the shunt is primarily determined by ductal diameter and the relationship between pulmonary and systemic vascular resistance. When pulmonary vascular resistance is less than that of the systemic circulation, blood shunts from aorta to pulmonary artery. The resultant increase in pulmonary venous return imposes a volume load on the left atrium and ventricle. Most canine PDAs provide resistance to ductal flow so that aortic pressure exceeds pulmonary artery pressure. Even then, the shunt volume can be considerable resulting in left ventricular dilation and hypertrophy, left atrial enlargement, functional mitral valve regurgitation and potentially the development of systolic myocardial dysfunction.

A large, non-restrictive duct necessarily results in systemic pulmonary artery pressures. In this setting, the development of obstructive vascular disease potentially results in suprasystemic pulmonary vascular resistance and shunt reversal. However, shunt reversal is uncommon in dogs and generally occurs in neonates. Patients with right-to-left shunting PDA are not candidates for operative therapy and are treated medically. Shunt direction associated with canine PDA is most commonly left-to-right. The remainder of this discussion relates to the diagnosis and management of left-to-right shunting PDA in the dog.

Clinical Findings

In many, if not most cases, the PDA does not cause clinical signs before the age of 4 to 6 months and the lesion is detected incidentally during routine physical examination. There is a distinct gender predisposition; about two thirds of the affected population is female. Distinct breed predispositions are also evident; Maltese, Pomeranian, miniature poodles, Bichon Frise and Shetland sheepdogs are more likely to have PDA than are mix breed dogs.[6] PDA has been reported in cats but it is uncommon.

A left-to-right PDA results in a continuous murmur; the murmur begins during systole, peaks in intensity at the time of the second heart sound, and persists through at least a portion of diastole. When the heart rate is very slow, or there is pulmonary hypertension related to a large shunt and high pulmonary vein pressures, the murmur may be inaudible during late diastole. More often, the murmur persists through the entire cardiac cycle and has a typical aorticopulmonary or "machinery" quality. The intensity of the murmur generally correlates with the size of the shunt. Very soft and focal murmurs are usually associated with a small shunt while moderate or large shunts typically result in a loud murmur that radiates widely. In patients with large shunts, a distinct systolic murmur due to functional mitral valve regurgitation sometimes can be heard. The third heart sound is audible in some patients; generally this finding reflects a large shunt and high left atrial pressures. When the shunt is moderate or large, the decrease in diastolic arterial pressure widens the pulse pressure and results in a hyperkinetic, or "bounding", arterial pulse.

Diagnostic Evaluation

In the absence of cardiac arrhythmias, the electrocardiogram (EKG) contributes little to diagnosis although most patients do have electrocardiographic evidence of left ventricular hypertrophy.[7] thoracic radiographs of patients with PDA typically have distinctive, if not diagnostic, features. Usually, there is cardiomegaly with left-sided emphasis. Evaluation of the pulmonary vessels may provide evidence of pulmonary hyperperfusion. Prominence of the proximal descending aorta is perhaps the most consistent radiographic feature. In some patients, the main pulmonary artery and left atrial appendage are also prominent resulting in the appearance of three closely associated bulges in the dorosoventral or ventrodorsal projection.

Echocardiography demonstrates variable degrees of left ventricular and left atrial enlargement. Echocardiographic measures of cardiac performance such as fractional shortening, usually are normal or mildly depressed. However, ventricular loading conditions are altered by the shunt and often, by concurrent mitral valve regurgitation which complicates interpretation of functional indices such as fractional shortening. Indeed, evaluation of the end-systolic ventricular dimension provides echocardiographic evidence of myocardial dysfunction in most patients with long-standing, uncorrected PDA. Doppler studies confirm the presence of continuous, disturbed flow within the main pulmonary artery. Although it is sometimes technically difficult to do so, the pulmonary-ductal junction, if not the entire duct, can be echocardiographically identified in the vast majority of patients (Figure 42-14). Transesophageal echocardiography may have a particular utility for more completely defining the dimensions and morphology of the PDA (Figure 42-15).

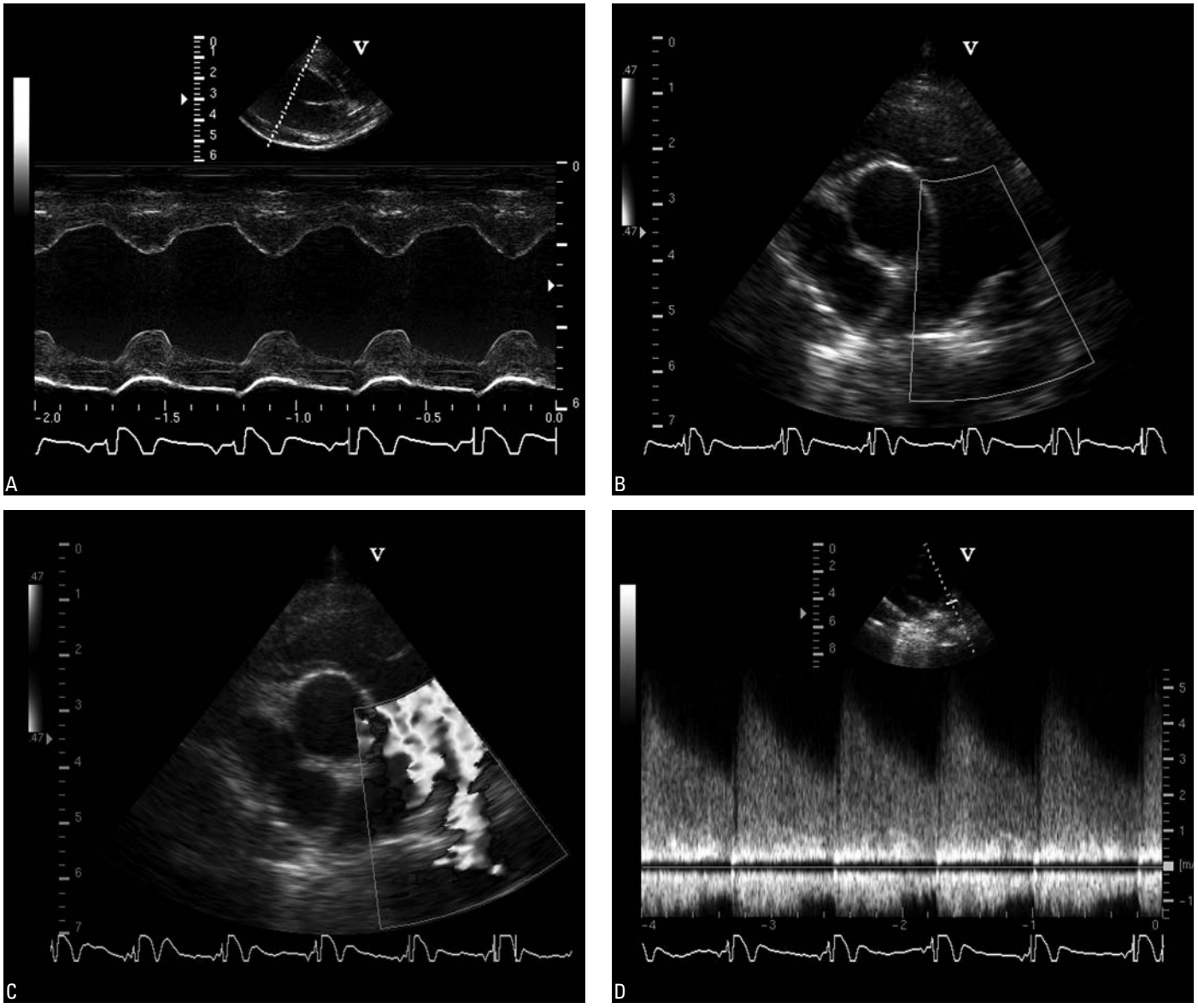


Figure 42-14A-D. Echocardiographic Images from a patient with a moderately large patent ductus arteriousus. An M-mode image **A.** of the left ventrical demonstrates left ventricular dilation and hypertrophy. Cranial, left parasternal images of the main pulmonary artery with **B.** and without **C.** a superimposed color-flow Doppler map show the ductal ampulla and ductal orifice. A continuous-wave Doppler spectrogram **D.** provides evidence of contuous flow into the main pulmonary artery. The velocity close to 5 m/s suggesting that the orifice is resistive.

Other than PDA, there are few disorders that result in a continuous murmur. When it is certain that there is a single continuous murmur and not distinct systolic and diastolic murmurs as can result from ventricular septal defect complicated by aortic insufficiency, the diagnosis is generally assured and the need for further evaluation can be debated. However, echocardiography is recommended in order to confirm the diagnosis before intervention, evaluate myocardial function and identify concurrent malformations which occasionally can complicate the presentation. The need for pre-procedural echocardiography is particularly acute when transcatheter ductal occlusion is contemplated because echocardiographic data can be used to provide a preliminary assessment of the ductal size and morphology.

Management of PDA – General Statements

It is accepted that mortality for canine patients with uncorrected PDA is high and that the risk associated with operative correction is relatively low. Therefore, occlusion of the duct, either by transcatheter methods or surgical ligation is advisable for nearly all patients with PDA. Mortality in uncorrected PDA is primarily due to congestive heart failure; other complications such as ductal endocarditis and progressive vascular disease are uncommon. Because of this, watchful waiting that includes echocardiographic surveillance is probably appropriate for the occasional patient that has a small ductus and minimal or no ventricular enlargement. With respect to treatment decisions, it is relevant that PDA is most common in small breed dogs. Dogs of this signalment are predisposed to the development of geriatric mitral valve degeneration (MR) and conceivably, the development of MR might result in clinical decompensation in older individuals with a previously tolerated ductus. Although there is a small risk associated with correction of PDA, the ratio of risk and benefit is in favor of repair for nearly all patients. The only exception to this general principle is the patient with

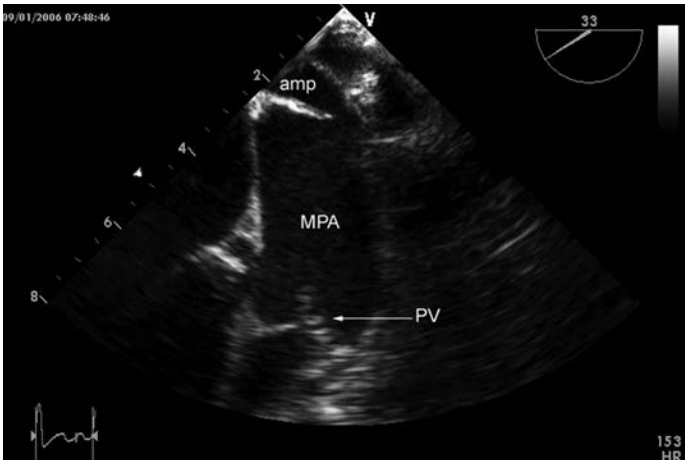


Figure 42-15. This transesophageal *(TE)* echocardiogram was obtained from a Borzoi with a patent ductus arteriousus. The junction of the ductus with the pulmonary artery is distinct. *MPA* = pulmonary artery, *amp* = ductal ampulla, *PV* = pulmonary valve.

a complex cyanotic malformation such as tetralogy of Fallot in which the ductus contributes to pulmonary perfusion.

Transcatheter Occlusion

Transcatheter PDA occlusion using different devices and subtly different techniques has been reported.[8-19] Initially, thrombotic Gianturco coils were used most commonly in veterinary medicine, but use of the recently developed, purpose-designed Amplatz® canine ductal occluder (ACDO) has, to a great extent, superseded that of Gianturco coils in veterinary practice.

Basic Technique – Transcatheter Occlusion

Numerous variations on the basic technique of transcatheter ductal occlusion have been reported. The retrograde trans-arterial approach is described here. After induction of general anesthesia, access to the femoral artery is percutaneously obtained using the modified Seldinger technique or is obtained by arteriorotomy after a small inguinal incision. In the former technique, a needle or short catheter is used to puncture the femoral artery while the patient is dorsally recumbent. When blood pulses from the entry needle, a wire-guide is introduced through the needle into the vessel lumen. The needle is then removed while hemostasis is maintained by digital pressure. A catheter or more often, a vessel sheath-introducer system with hemostasis port, is advanced along the wire into the femoral arterial system. The percutaneous technique is in almost universal use in pediatric and adult catheterization laboratories and has advantages with respect to vessel preservation. However, dogs tolerate post-procedural ligation of the femoral artery without apparent long-term sequlae and furthermore, complications of the percutaneous approach can be catastrophic.[20] If the femoral artery is entered proximal to the inguinal ligament, post-procedural attempts at hemostasis may be ineffective resulting in potentially fatal intra-abdominal hemorrhage. Additionally, severe subcutaneous hemorrhage can result despite appropriate vessel entry site and post-procedural hemostasis.[17] For these reasons, surgical isolation and arteriotomy may be the superior method of arterial access.

Regardless of technique used for vessel access, the use of a hemostasis sheath is advisable to facilitate catheter exchange and the movement of catheters through the femoral artery. The patient is positioned in lateral recumbency and the fluoroscopic image intensifier is centered over the cardiac shadow. Using fluoroscopic guidance, an angiographic catheter such as a pigtail is advanced to the ascending aorta. Central aortic pressures are evaluated and an angiogram is recorded after injection of contrast material in the proximal descending aorta. It is important that the angiogram clearly delineates the entire ductus including the pulmonary-ductal junction (Figure 42-16). The angiographic appearance can be classified according to ductal morphology.[14,21]

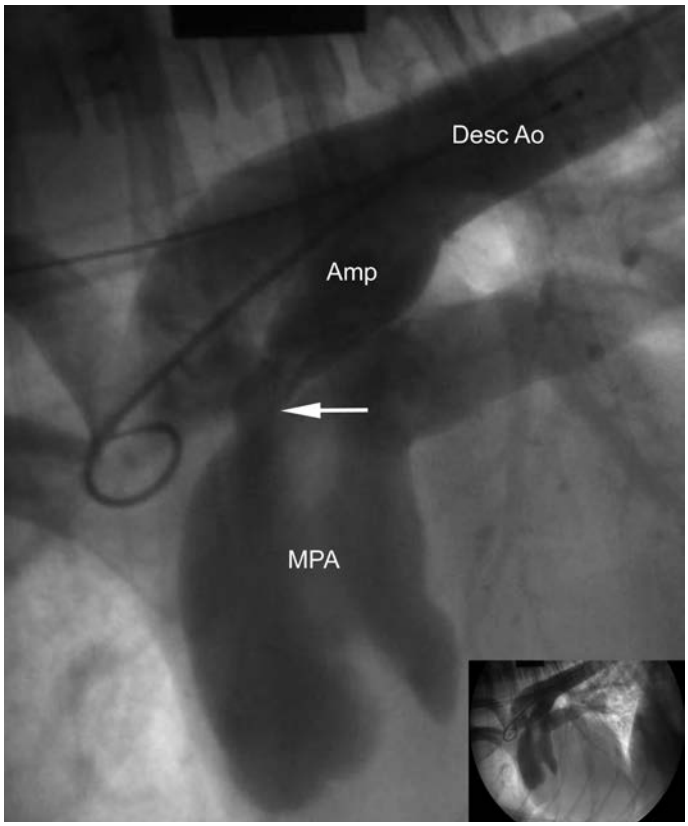


Figure 42-16. Lateral projection of a ductal angiogram obtained from a 6 year old female-spayed Springer Spaniel. Contrast material was injected into the aortic arch through a 5 F pigtail angiographic catheter. The ductal orifice of the pulmonary artery *(arrow)* is moderately large; it measured approximately 5 mm. *Asc Ao* = Ascending aorta, *Desc Ao* = Descending aorta, *MPA* = main pulmonary artery, *Amp* = Ductal ampulla. The inset image includes a larger portion of the thorax to provide anatomical orientation.

Amplatz® Canine Ductal Occluder - Technique

In collaboration with a manufacturer of cardiovascular devices, two veterinary cardiologists, Ngyuenba and Tobias, developed a metallic plug that was specifically designed to occlude the canine ductus.[22] This device, the ACDO, became commercially available in 2007. The ACDO is constructed from 2 to 3 layers of a fine nitinol mesh. The device is both collapsible and self-expanding; in its unstressed state, a waist separates a flat distal disk from a larger proximal, cupped disk. The ACDO is available in a range of sizes that are defined by diameter of the waist. The device is provided by the manufacturer within a tubular cartridge

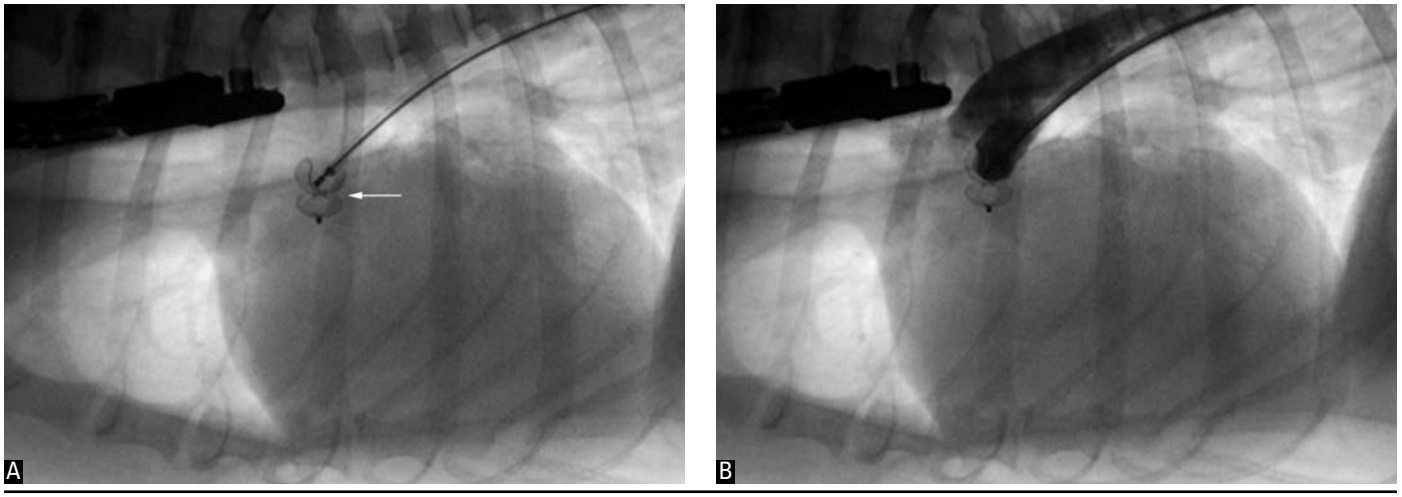


Figure 42-17. An Amplatz Canine Ductal Occluder (ACDO) was deployed across the ductus arteriousus of a 6 year old female Welsh corgi. These fluoroscopic images were obtained **A.** before and **B.** AFTER CONTRAST WAS INJECTED THROUGH THE DELIVERY SHEATH TO PROVIDE A PRELIMINARY ASSESSMENT OF DEVICE POSITION. To ensure device stability, it is important to confirm that the proximal disk assumes it unstressed, cup-shaped configuration prior to device release. In this case, after minor manipulation of the delivery cable, the device assumed its native cup-shape and was then released from the delivery cable.

and attached to a delivery cable. The ACDO is deployed using a retrograde approach after angiographic delineation of the ductus. Femoral arterial access is routine but because some ACDO require relatively large delivery catheters, exteriorization of the artery after inguinal incision is probably the most appropriate technique. The size of the ACDO is selected based on the smallest angiographic diameter of the duct and therefore, careful, quantitative assessment of ductal size is crucial. A device with a waist that is approximately twice the diameter of the minimum ductal dimension is said to be optimal.[19,22] After angiographic evaluation, the duct is crossed with a curved catheter such as an MPA which is then exchanged over a wire-guide for a long sheath or guiding catheter. Alternatively, contrast material for angiography can be injected through a long sheath such as a Mullins, Ansel or CHB type, and if it is possible to cross the duct with a wire-guide advanced through the sheath, this technique obviates the need for a catheter exchange.[23] Predictably, larger devices must be deployed through larger catheters and this must be taken into account not only as the delivery catheter is advanced, but also initially, when a short, vascular access sheath is placed in the femoral artery. When the distal end of an appropriately sized guiding catheter or long vascular sheath is in place within the main pulmonary artery, the device is introduced into the hub of the catheter or sheath using the loading cartridge and then advanced using the delivery wire. The proximal disk is deployed within the pulmonary artery at which time the wire and catheter are withdrawn together until the disk is firmly apposed to the ductal orifice. Then, the catheter is retracted so that the remainder of the device is deployed within the ductus. Suitability of positioning is then evaluated through manipulation of the wire, injection of contrast material through the side-arm of the catheter and potentially, through transesophageal echocardiography (Figure 42-17). If positioning is inappropriate, the device can be withdrawn into the deliver catheter. When the device is properly positioned, and it has resumed it's unstressed configuration, it is detached from the delivery wire (Figure 42-18).

The use of the ACDO is restricted to patients that have a femoral artery of sufficient caliber to accommodate the catheter or sheath required to deploy the device. This limits the use of the ACDO to relatively large patients but a modification of the basic technique of ACDO placement that can be used in patients as small as 2.5 or 3 kg has been described. Briefly, a 4F short vascular sheath is placed in the femoral artery and after angiography, a 4F curved, end-hole catheter is used to enter the pulmonary artery via the duct at which time, the catheter and sheath are removed over an exchange wire, the distal tip of which is left in the pulmonary artery. The outer diameter of a vascular sheath is generally 2F larger than the catheter that it will accommodate; that is, the outer diameter of a 4F sheath is 6 French units. Therefore, after the sheath has been removed, a 6F guiding catheter with hydrophilic coating can generally be advanced over the wire at which point, ACDO with waist diameters as great as 6 mm can be deployed within the duct.[22]

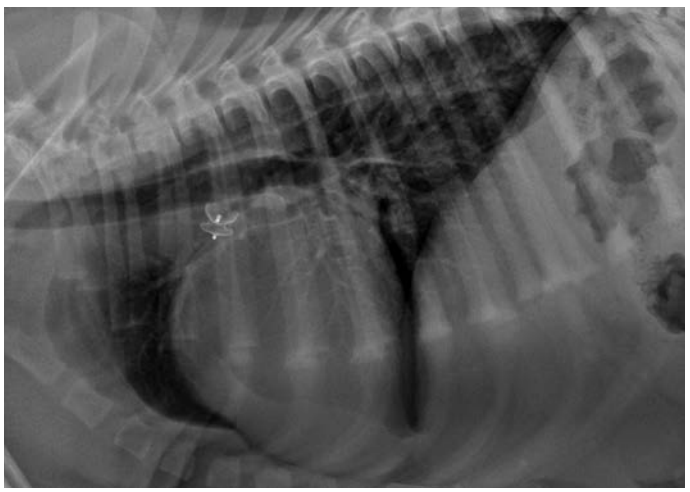


Figure 42-18. This fluroscopic image was obtained after placement of an Amplatz Canine Ductal Occluder **(ACDO)** device within the ductus arteriosus of a 6 month old male Cavalier King Charles spaniel that had concurrent valvular pulmonic stenosis; the latter malformation was addressed by balloon dilation.

Coil Occlusion – Technique

Gianturco coils are manufactured in numerous sizes and configurations but in all cases the device consists of a stainless steel or platinum wire that is tightly wound to produce a helix with a diameter between 0.014-0.043 inches. The wire made up of these primary windings is coiled to produce loops, the specific number of which depends on the length of wire and the diameter of the loop. Dacron tufts are attached to the wire and this makes the coil thrombogenic. The devices are packaged in tubular cartridges. Because the steel has structural memory, the loops reform when the coil is extruded from the cartridge or an intravascular catheter. The size and configuration of each coil is defined by three characteristics: wire diameter, loop diameter and wire length. Wire diameters of 0.035 in, 0.038 in and 0.052 in have all been used for coil occlusion of PDA in veterinary patients. Coils that form loops of numerous sizes ranging from 3 to 20 mm are available. In addition to characteristics that define loop size, number and deformability, some coils such as the Cook Detachable coil and the Cook Flipper are designed for controlled release into the circulation.

After angiographic evaluation, a curved, end-hole catheter such as a Judkins (right), JB-1, MPA or vertebral catheter is advanced to the ductus. Sometimes it is necessary to use a straight but floppy-tipped wire-guide to enter the ductal ampulla. It is useful to advance the catheter across the duct and into the pulmonary artery while monitoring intravascular pressures in order to identify fluoroscopic landmarks that relate to the pulmonary artery-ductal junction. Typically, this junction is close to the ventral border of the tracheal shadow. The dimensions of the coil to be deployed within the ductus are chosen based on measurements obtained from the angiogram or transesophageal echocardiogram. The loop diameter should be about twice the minimal ductal diameter and approximate the diameter of the ampulla. A wire-guide is used to extrude the coil from the cartridge and into the proximal end of the catheter. The coil then can be advanced through the catheter using the wire-guide until the more distal end exits the end of the catheter and begins to form a loop within the circulation. In pediatric practice, it is accepted that one or more loops of the device should be deployed in the pulmonary artery. When using non-detachable coils, most veterinary cardiologists deploy the entire coil within the ampulla of the duct. Provided that the coil forms sufficient number of loops, part of the coil can be deployed in the proximal aorta and then pushed into the ampulla. When coil position appears to be appropriate, the remainder of the coil is extruded from the catheter. When a single coil substantially occludes flow, the mean and diastolic artery pressures rise shortly after deployment but a Branham response generally is not observed. After about ten minutes the ductus is again evaluated angiographically or by transesophageal echocardiography (Figure 42-19). Ideally, the duct is completely occluded during the catheterization procedure although small residual shunts may resolve weeks or months after the procedure. If a substantial shunt persists, additional coils are placed within the first coil. A technique in which a biopsy device is used for controlled release of 0.052 in coils was described and then modified for use in veterinary patients by Miller.[24,25]

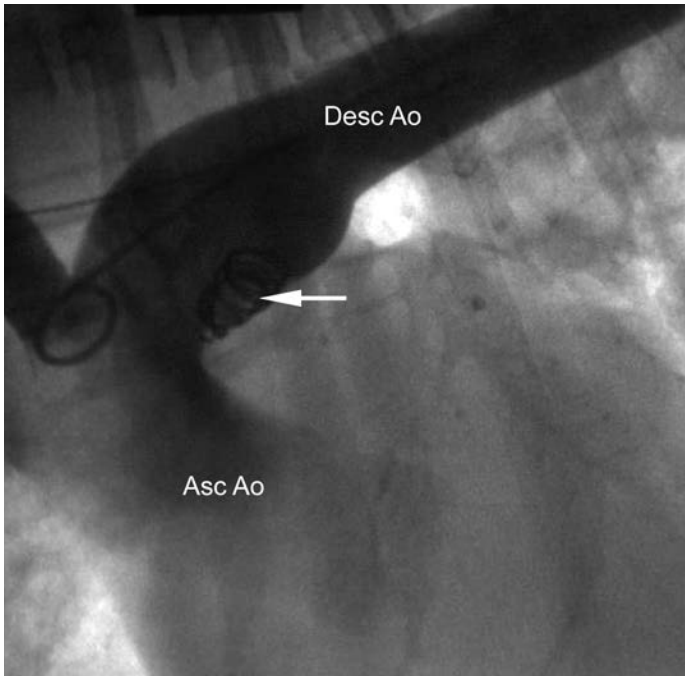


Figure 42-19. Aortogram obtained after two coils were placed in the ductus arteriosus angiographically shown in figure 42-16. A half loop of the smaller coil was deployed in the pulmonary artery. Occlusion of the ductus was nearly complete; in a subsequent frame there was minor opacification of the main pulmonary artery so additional coils were placed.

Outcome/Complications of Transcatheter Occlusion

Of cases in which the procedure is attempted, about 80% are amenable to coil placement and occlusion although this figure likely depends on echocardiographic and angiographic criteria used to select candidates.[11,26] Of patients in which coils are deployed, complete ductal occlusion during the immediate post-procedural period has been reported to occur in 34 to 100% of cases.[11,12,14,26] Specific method, patient selection and perhaps operator experience are variables that likely affect immediate occlusion rates. In general, complete, acute resolution of the shunt can be achieved in 50 to 60% of cases. Delayed ductal closure occurring in the first months after the procedure occurs in about 30% of cases in which a residual shunt is evident in the immediate post-procedural period. Although residual shunting is relatively common it is not necessarily hemodynamically important and often is clinically silent. Indeed, coil occlusion is associated with a hemodynamically satisfactory result in the vast majority of patients subject to the procedure, such that fewer than 5% of cases require a second intervention.[14,26]

The ACDO has filled an important niche in the practice of veterinary interventional cardiology. In contrast to coil occlusion, the rate of short-term occlusion is high and complications are rare. More specifically, Ngyuenba and Tobias reported the initial experience using a prototype of the ACDO.[19] Eighteen dogs with PDA were subject to cardiac catheterization and angiographic characterization of the duct. Ultimately, ACDO were successfully deployed in all patients although in one case, the device, determined afterward to be inappropriately small relative to ductal

diameter, migrated to the left main pulmonary artery. The errant device was not retrieved, adverse effects were not observed and later, during a separate procedure, an ACDO was placed without complications. Complete ductal occlusion was echocardiographically documented in 17 of 18 patients but in one, recurrent ductal patency was evident at one day and at three months after the procedure. Others subsequently confirmed the initial, encouraging results.[23] In a series of 41 canine patients with PDA, procedural success was documented in 40; the small size of one patient precluded placement of the sheath required to deploy a sufficiently large device. Complete ductal occlusion occurred within 24 hours of the procedure in all 40 patients.[19,23] Published results suggest that the ACDO is a device that can be used to successfully occlude PDA over the broad range of ductal size and morphologies. Presumably because the device firmly engages the duct and is attached to the delivery cable until the operator chooses to deploy, device embolization and other complications are rare although a single case of post-procedural device migration was recently reported.[27] Recently, patient outcomes after transcatheter occlusion by one of four different devices and techniques were retrospectively evaluated.[28] Procedural success was documented in 92% of cases but coil occlusion was associated with a greater number of complications than was placement of the ACDO. Patients were not randomized to device type and predictably, operators selected coil occlusion for the cohort for which body-size was smallest as coils can be delivered through relatively small diameter catheters.

Major complications of transcatheter intervention for PDA include intra-operative death, incomplete occlusion, post-procedural hemolysis, and device migration. Mortality associated with transcatheter intervention for PDA generally is quite low, near 2%,[14,26] although higher mortality has been reported in small studies that specifically recruited high risk patients.[29] Post-procedural hemolysis is sometimes associated with persistence of ductal flow after coil occlusion. This complication is apparently uncommon but has been reported in the pediatric literature and in dogs.[26,30]

Other Devices and Techniques

The Amplatzer® ductal occluder (ADO) is a mushroom shaped device that consists of a nitinol framework that is enmeshed with fabric; it was designed for occlusion of the human ductus. The device is extruded from a delivery sheath that is first advanced from the femoral vein, through the ductus and into the aorta. The device is pulled into the duct and released from the delivery wire. Use of this device has been reported in veterinary patients.[16,17]

The Grifka-Gianturco occlusion device consists of a nylon sac that contains Gianturco coils that are deposited in the ductus using a controlled delivery system. The use of this device in a dog has been reported in the veterinary literature.[15]

Some consideration of the relative merits of transcatheter intervention and surgical ligation is unavoidable in any discussion of the treatment of PDA. The advantages of transcatheter intervention are relatively obvious. It is a minimally invasive technique that is generally associated with low mortality. Because it is minimally invasive, morbidity and hospitalization is apt to be less than that associated with thoracotomy and surgical ligation. Certainly, ductal size and morphology are important determinants of procedural success for coil occlusion but the development of the ACDO has expanded the indications for transcatheter therapy to include PDA of diverse size and morphology. Still, patient size does have a bearing on the suitability of candidates for transcatheter intervention. A technique for transcatheter occlusion of PDA using 0.025 in coils in patients weighing less than 3 kg has been described,[13] but in general, femoral arterial access can be problematic in very small patients. To some extent, this difficulty can be overcome if a venous approach is used and indeed, this technique has been used for transcatheter coil occlusion of PDA in cats and dogs.[31,32] However, the use of venous access without concurrent arterial access may pose a risk to the patient in the event of aortic embolization. In contrast, patient-size and ductal morphology likely have a limited effect on the outcome of surgical ligation; experienced operators can successfully ligate PDA in dogs that weigh less than 0.5 kg.[33]

As discussed, there are numerous potentially serious complications of transcatheter intervention for PDA. Most of these complications do not result in patient mortality but they may require referral to a surgeon or additional catheterization procedures. While the clinical importance of hemodynamically inconsequential residual shunts has been not been defined, the prevalence of incomplete occlusion also deserves consideration in a comparison of surgical ligation and transcatheter intervention. When patients are subject to echocardiographic scrutiny after treatment of PDA, the prevalence of incomplete occlusion after surgical ligation varies but is as high as 53% when the Jackson-Henderson technique is used.[34] Furthermore, shunts that persist after coil occlusion are apt to become progressively smaller. In contrast, the mechanism of incomplete occlusion after ligation presumably relates to inadequate dissection of the periductal adventitia, an insufficiently tight ligature or loosening of knots; this being the case, late closure is not to be expected. Incomplete occlusion after placement of an ACDO is considerably less common than after coil occlusion.

Balloon Dilation of Obstructive Lesions

Pulmonic Stenosis

Etiolopathogenesis

Pulmonic (or pulmonary) stenosis (PS) refers to narrowing of the right ventricular outflow tract. PS is a common cardiac malformation in the dog but occurs infrequently in cats.[6] Acquired PS is rare and this discussion will be concerned exclusively with congenital obstruction. The obstruction of the outflow tract most often results from narrowing of the pulmonary valve although subvalvular PS and supravalvular PS are occasionally observed. Subvavular, or infundibular PS, is seldom an isolated lesion and is more often associated with complex malformations such as Tetralogy of Fallot or is the result of right ventricular hypertrophy related to valvular PS.

The cause of PS is unknown although a heritable basis has been established in beagle hounds.[35] Pedigree analyses or planned breeding studies of dogs other than beagles have not been reported. However, the disproportionate occurrence of PS in certain purebred dogs provides indirect evidence that canine PS generally has a genetic basis. The English bulldog, Samoyed, miniature schnauzer and terrier breeds are predisposed to the development of PS.[6] Interestingly, despite a proven genetic basis for pulmonary valve dysplasia in beagles, this breed is not over-represented in epidemiological surveys. PS in English bulldogs requires specific mention. In dogs of this breed, PS has been associated with concurrent coronary artery anomalies.[36] The coronary anomaly that seemingly is most common is sometimes referred to as an "R2A", and is characterized by a single right coronary ostium; the left coronary artery arises from the right main coronary artery and then encircles the infundibulum. It has been suggested that the mechanical effect of the abnormal course of the coronary artery is responsible for maldevelopment of the PV.[37] Certainly, detection of the R2A anomaly has clinical relevance because it is a contraindication for surgical patchgraft procedures and possibly a contraindication for transcatheter balloon dilation.[36,38] Minimally, detection of a circumpulmonary coronary branch requires use of a modified technique in which the diameter of the dilating balloon approximates, rather than exceeds, the diameter of the valve annulus. Recently, coronary anomalies other than the R2A have been reported which emphasizes the importance of angiographic assessment of the coronary anatomy prior to intervention.[39,40]

The pathology of PS is clinically relevant because it is an important determinant of the efficacy of therapeutic intervention. The normal pulmonary valve is a trileaflet structure. Each of the leaflets has a semilunar attachment to the interior of the proximal pulmonary artery. A true fibrous valve annulus does not exist in normal specimens but the ventriculo-arterial ring is a clinically useful landmark which is generally known as the PV annulus.[41] In the pediatric literature, PS characterized by commissural fusion of otherwise normal or mildly thick valve leaflets is known as typical PS. This form of PS is distinguished from more extensive malformation of the leaflets and annulus which is known as valvular dysplasia.[41] In cases of PV dysplasia, the leaflets are abnormally thick and mobility of the cusps is limited by rigidity and abnormal attachment to the neighboring leaflets or pulmonary artery intima. Often, the annulus of the valve is narrow and together these abnormalities serve to narrow the PV orifice. Based on echocardiographic appearance, a similar scheme for classification of canine PS has been proposed; type A PS is primarily the result of commissural fusion while type B results from narrowing of the annulus and restricted mobility of abnormal valve leaflets.[42] Post-mortem examination of beagles with hereditary PS demonstrated a continuum of lesions; some had features of typical PS while others were similar to the valvular dysplasia described in the pediatric literature. At least in beagles with heritable PS, differences in valvular morphology appear to reflect variable expression of a single disease process and therefore it may be that categories of PS are artificial. Despite this, the distinction between dogs with PS and a normal annulus from dogs with PS and annular hypoplasia is clinically useful because the two populations differ in response to transcatheter intervention.[42]

Pathophysiology

Obstruction of the outflow tract increases the impedance to ventricular ejection. In consequence, the ventricle must generate supraphysiologic systolic pressures in order to maintain perfusion pressure distal to the stenosis. As a result, there is a pressure gradient (Δ P) across the obstruction. Peak systolic Δ P that are less than 40 mmHg are generally considered to be mild and those greater than 80 or 100 mmHg, severe.[43,44] Concentric hypertrophy – an increase in myocardial mass without concomitant chamber dilation – at least temporarily offsets the increase in ventricular wall stress that results from outflow obstruction. The mechanism by which compensatory hypertrophy progresses to ventricular failure has not been resolved. Both mechanical and neuroendocrine factors likely contribute. However, the right ventricle is not geometrically suited to the development of high systolic pressures and tricuspid valve regurgitation and myocardial dysfunction are potential sequelae of severe PS.

Clinical Presentation

Canine PS is usually first detected by auscultation when pups are subject to routine veterinary evaluation. At least in young pups, a history of clinical signs related to PS is the exception rather than the rule. PS causes a systolic ejection murmur that usually is heard best over the left heart base. When PS is severe, the murmur generally is loud and typically associated with a precordial thrill. In most cases, the arterial pulse is normal. Thoracic radiographs or EKG do not provide diagnostically specific information. However, most patients with severe PS have radiographic cardiomegaly with right-sided emphasis. Often, the proximal main pulmonary artery is prominent due to development of post-stenotic aneurysm. Pulmonary hypoperfusion is often radiographically evident in patients with severe PS. Electrocardiographic evidence of right ventricular hypertrophy is commonly observed in patients with severe PS although EKG abnormalities are typically absent in patients with mild obstruction. The diagnosis can be confirmed by cardiac catheterization although echocardiography generally has replaced invasive studies for diagnostic purposes. When PS is severe, two-dimensional echocardiographic studies reveal consequences of obstruction including right ventricular hypertrophy and right atrial enlargement. Usually, the valve leaflets are abnormally thick and doming of the leaflets is sometimes observed. This latter finding, which may also be evident angiographically, reflects commissural fusion of valve leaflets and generally predicts a favorable response to balloon dilation. In healthy individuals, the annulus diameter is similar to that of the aorta but in patients with PS, varying degrees of annulus hypoplasia are relatively common. Doppler echocardiography demonstrates abnormal acceleration within the right ventricular outflow tract – a velocity step-up – which is the Doppler correlate of obstruction. Peak velocity across the obstruction is related to Δ P by the modified Bernoulli equation. Agreement between Doppler estimates of Δ P and gradients measured by catheterization is excellent but there are factors that confound the relationship. Most importantly, invasively acquired gradients are generally obtained from veterinary patients who are anesthetized. Pressure gradients depend not only on the severity of stenosis – the degree to which the cross-sectional area of the

orifice is diminished – but also on flow. Because cardiac output is decreased by anesthesia, Δ P obtained by cardiac catheterization may be as much as 50% of Δ P estimated by Doppler echocardiography in the awake or sedated patient.

Identification of Candidates for Intervention/Natural History

Little is known of the natural history of canine PS. The prognosis for children with mild PS is excellent without intervention and the same appears to be true in dogs. Canine patients in which Doppler-derived Δ P exceeds 80 mmHg are at risk of sudden death or death due to congestive heart failure; further, this risk increases incrementally in association with increasing gradient.[44] A history of exercise intolerance or collapse also predicts poor outcome in patients with severe PS.[44] The minimum gradient at which the benefit of therapeutic intervention exceeds the associated risks has not been established. Based partly on the approach adopted by pediatric cardiologists, it has become accepted that intervention is reasonable if Δ P exceeds 80 mmHg even if clinical signs are absent. Several surgical procedures for correction of PS have been described but, based on an apparently favorable risk/benefit ratio, transcatheter balloon dilation is generally recommended as the initial approach to severe PS.

Balloon Dilation

After induction of general anesthesia, access to the femoral vein or external jugular vein is obtained percutaneously or after a small skin incision. Complications of percutaneous venous access are infrequently observed and there are advantages to the percutaneous approach. The decision regarding choice of vessel is primarily one of operator preference.

It is a basic precept of catheterization technique that hemodynamic variables, including Δ P obtained by catheter pullback, are recorded before injection of contrast or attempted intervention. However in dogs, the efficacy of balloon dilation ultimately is judged by the effect on the awake, Doppler-derived Δ P not by the acute effect on measured gradients. Furthermore, in some patients with very severe PS, it can be difficult to cross the obstruction and therefore difficult to justify sacrifice of a therapeutically advantageous catheter placement for the sake of diagnostic completeness. In these difficult cases, a right ventriculogram is recorded at the outset of the procedure (Figure 42-20). Then, an end-hole catheter is fluroscopically guided to the pulmonary artery and is exchanged for a balloon dilation catheter over a long 200 to 260 cm wire guide. This catheter exchange is necessary because therapeutic balloons are carried by catheters that are too stiff to safely manipulate free in the circulation. The balloon is centered across the valve and is inflated with a mixture of saline and contrast material. The proportions of saline and contrast medium are not crucial. It is important that the inflated balloon is fluoroscopically visible but contrast material is quite viscous making rapid inflation and deflation difficult. Something less than 50% contrast material by volume likely is appropriate. The required number of inflations varies. When the dilation is successful, there is first the appearance of an indentation and then abrupt disappearance of this "waist" (Figure 42-21). During inflation, right ventricular stroke volume declines precipitously

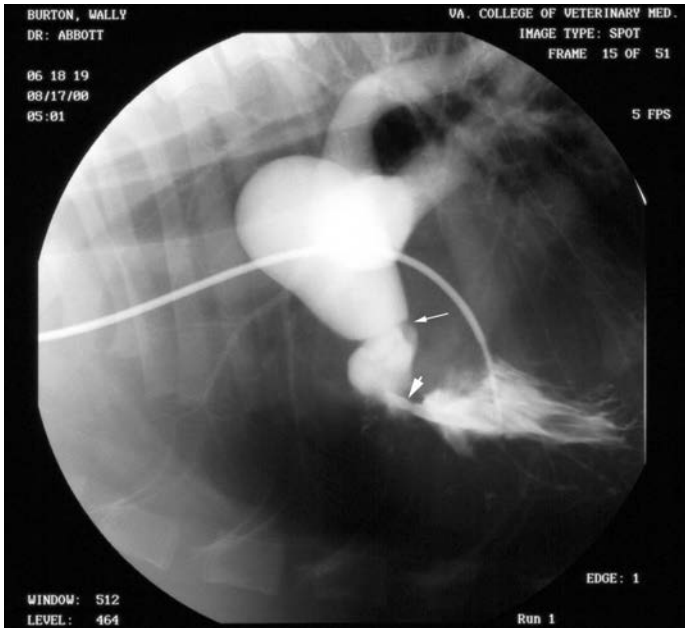


Figure 42-20. Right ventriculogram obtained after injection of contrast material into the right ventricle of a border collie with severe valvular pulmonary stenosis. The valve leaflets are thick *(arrow)* and narrowing of the infundibulum *(arrow head)* provides evidence of concurrent dynamic obstruction of the subvalvular outflow tract. There is pronounced post-stenotic dilation of the main pulmonary artery.

as does, shortly thereafter, systemic pressure and perfusion. In most cases, unassisted hemodynamic recovery occurs promptly after balloon deflation. The balloon catheter is removed over the wire guide. It is important to aspirate from the balloon port to maintain negative pressure and reduce the profile of the balloon while it is withdrawn through the heart and vessels.

Sometimes, perhaps most often in patients with dynamic, infundibular obstruction, the force of ventricular contraction causes the balloon to "pumpkin seed" through the valve orifice resulting in an ineffectual inflation. Patience and gentle tension on the catheter during inflation often will eliminate this difficulty although intravenous administration of acetylcholine immediately prior to inflation can be used to cause a brief period of ventricular asystole.

Balloon catheters are supplied by the manufacturer in numerous configurations. Generally, the balloon is constructed from a plastic polymer such as polyvinyl chloride and surrounds the distal catheter shaft. The catheter has two lumens; one that courses the length of catheter and a second that is used for inflation and deflation of the balloon. The clinically important characteristics of the catheter shaft are length, outer diameter, which is described using the French scale, and inner diameter which is measured in inches.[45] The latter property determines the diameter of guide wire which the catheter will accept. The balloon itself is described in terms of length, outer diameter, profile and material characteristics that determine burst pressure. The length of the balloon is chosen based on ventricular size which is generally related to body size. It can be difficult to maintain the position of a short balloon during inflation but overly long balloons can cause injuries including cardiac perforation and disruption of the tricuspid valve apparatus. A 3

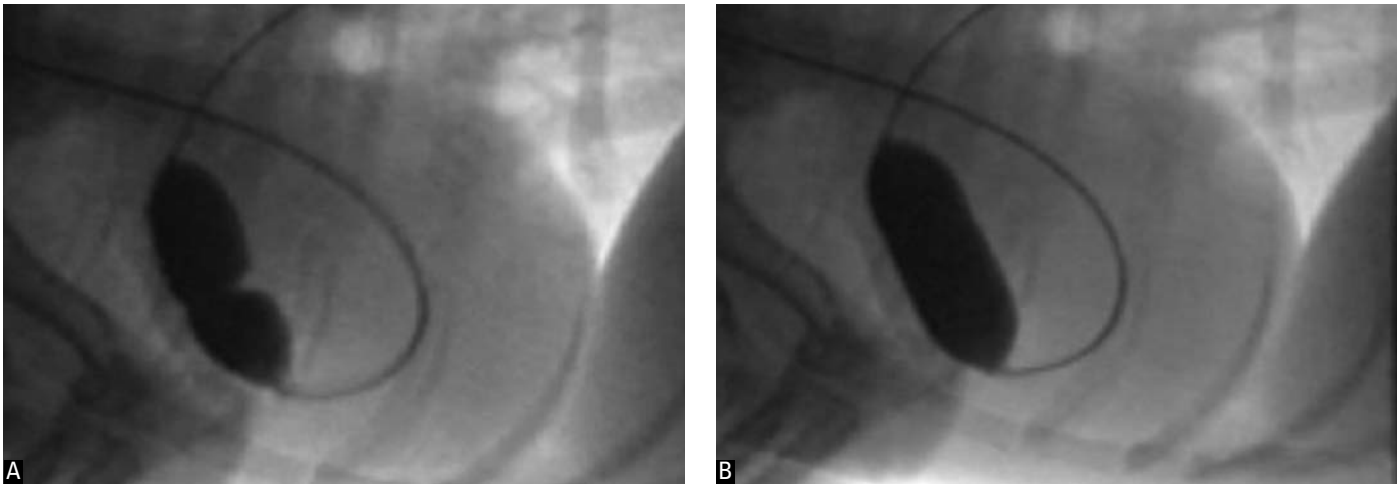


Figure 42-21. Fluoroscopic images obtained during inflation of a balloon in the right ventricular outflow tract of a patient with severe pulmonary stenosis. A "waist" was initially evident **A.** but disappeared at full inflation **B.**

cm balloon is appropriate for most canine patients. Two cm and 4 or 5 cm balloons are sometimes used for very small or very large patients. The outer diameter of the balloon is chosen based on echocardiographic or angiographic assessment of PV annulus diameter. Recommendations regarding balloon diameter have become more aggressive in the years since the introduction of the technique. A balloon diameter that is 120 to 150% of the valve annulus is believed to be optimal. Larger relative balloon sizes have been associated with cardiovascular injury in experimental models and with complications in children.[46,47] Profile is the term used to describe the increment in total catheter diameter which results from the structure of the balloon. Profile and physical characteristics that determine profile are inter-related. Balloons are best constructed of materials that exhibit low compliance and high burst pressures since this most effectively transmits radial force to the valve. However, balloons with those characteristics necessarily have a larger profile than do those with lower burst pressure. Profile is important because unnecessarily large balloons can result in intimal or valvular injury.

Advances in catheter and guide-wire construction including the development of low-profile balloons, flow directed catheters, steerable guide-wires with soft, flexible tips and tip-deflecting wires have expanded the indication for balloon dilation to include patients of virtually any size. However, balloon dilation for PS can be technically difficult in patients that weigh less than 6 or 7 kg. In small patients with tight stenosis, directing a catheter into the right ventricular outflow tract and crossing the obstruction are often the most difficult aspects of the procedure. It may be necessary to make numerous attempts with different catheters and guide-wires. Flow directed catheters often can be used to atraumatically cross a stenotic pulmonary valve. Flow-directed ("wedge") catheters are constructed of soft materials and are equipped with a small balloon near the distal catheter tip. The balloon is filled with room-air causing it to float in the circulation which carries the catheter tip in the direction of blood flow. However, marked tricuspid valve regurgitation makes it difficult to manipulate and advance these catheters. Wire-guides can be used to stiffen the catheter but sometimes this a liability in that flow-directed catheters do not generally accommodate large gauge wires. This difficulty can be circumvented by exchanging the flow-directed catheter for a thin-walled multipurpose catheter which is then, in turn exchanged for the balloon dilation catheter over a stiffer, larger gauge wire. However, this extra manipulation is time consuming and might represent a risk in a hemodynamically unstable patient. A multipurpose catheter can often be coaxed across the obstruction with or without a wire guide. In other cases, the use of specific catheter configurations such as the Judkins (right) coronary catheter or Berenstein catheter can be helpful in crossing the stenosis. Tip-deflecting wires can also be used to direct the tip of a straight catheter into the right ventricular outflow tract. Knowledge of the precise anatomical location of the catheter tip is important because tip-deflecting wires are rather stiff and cardiac perforation is a potential complication.

Results/Efficacy

The safety and efficacy of PBV in the management of PS in humans is well established. In fact, the only indication for surgical correction of isolated PS is failure of technically adequate balloon dilation to effectively decrease the associated ΔP. There are few published data that relate to the efficacy of balloon dilation in veterinary patients. Case reports and case series attest to short-term safety and efficacy of the procedure.[48-51] Recent retrospective cohort studies provide evidence that PBV is associated with a low rate of complications and generally decreases ΔP to a degree that is thought to be prognostically favorable.[42,44,52] In general, it can be stated that PBV decreases ΔP by 50% or more in roughly 75% of dogs with PS. Analysis of patient characteristics and outcome using a Cox multivariable regression model demonstrated that PBV confers a survival advantage in dogs with an initial ΔP that exceeds 80 mmHg.[44] PBV is apparently less effective in the management of canine PS than it is in the treatment of PS in people; possibly this is because of a greater prevalence of obviously dysplastic valves in affected dogs. Indeed, valve morphology is an important determinant of the efficacy of PBV in both humans and dogs. One year after PBV, the mean gradient reduction in dogs with PS normal annulus diameter was 63% while the reduction was only 39% in dogs with a small annulus and thick, immobile valve leaflets.[42] Restenosis after PBV is uncommon. In fact, the

gradient continues to decrease in the months after PBV in some dogs. Partly, this might be due to resolution of dynamic outflow gradients but it has been suggested that a progressive decrease in iatrogenic valvular edema might also be responsible.[53]

Complications

Major complications of PBV including cardiac perforation and death associated with occlusion of ventricular outflow in hemodynamically unstable patients are relatively uncommon. Death due to coronary artery avulsion was previously mentioned in the context of the r2A coronary anomaly that has been observed in brachycephalic dogs.[38] Damage to the tricuspid valve during inflation or during transit through the heart is relatively common. This complication is generally well tolerated provided balloon dilation effectively enlarges the stenotic orifice. Pulmonary valve regurgitation commonly is associated with PS and fairly often, it is worsened by balloon dilation although this seldom has clinical consequences. Arrhythmias are relatively common during manipulation of catheters through the heart but they usually are transient and resolve when the catheter is withdrawn or its position adjusted.

Balloon Dilation of Other Lesions

Subvalvular aortic stenosis (SAS) is one of the most prevalent congenital cardiac malformations in dogs. In its severe form, the lesion most often consists of a fibrous or fibrocartilaginous ring that completely encircles the subvalvular left ventricular outflow tract.[54] In a few cases, there is more diffuse subvalvular narrowing resulting in tunnel stenosis. Severely affected patients are at risk for premature death that is usually the result of sudden, presumably arrhythmic, death.[55] Balloon dilation of SAS in dogs has been reported and the technique is similar to that use in treatment of right ventricular outflow tract obstruction.[56,57] A catheter is advanced to the left ventricular apex from the external carotid or femoral artery and then exchanged over a long wire guide for a suitably sized balloon catheter. The risk of iatrogenic and clinically important aortic valve regurgitation is believed to be high and the balloon is usually chosen to approximate the diameter of the aortic annulus. Short and medium-term gradient reduction has been demonstrated but, relative to a group medically treated with atenolol, balloon dilation did not favourably affect survival.[57] This is not necessarily surprising given the nature of the lesion and the fact that successful surgical treatment failed to demonstrate a survival benefit.[58] Recently, an intervention in which the sequential use of a cutting balloon – one in which microsurgical blades are longitudinally oriented along the exterior of the balloon – and then a high-pressure balloon, has been reported but outcome data have not been published.[59]

With variable success, other less common obstructive lesions have been addressed by transcatheter dilation. Palliation of tetralogy of Fallot using transcatheter balloon dilation has been attempted the dog.[60] Both tricuspid valve stenosis and caudal caval obstruction due to cor triatriatum dexter have been treated by balloon dilation.[61-63] Additionally, balloon dilation of a mid-right ventricular outflow tract obstruction – double-chambered right ventricle – also has been reported.[64]

References

1. Buchanan J. Patent ductus arteriosus : mophology, pathogenesis, types and treatment. Journal of Veterinary Cardiology 2001;3:7-19.

2. Benson LN CK. The arterial duct: its persistence and its patency. In: Anderson RH BE, Macartney FH, Rigby ML, Shinebourne EA, Tynan M, ed. Paediatric Cardiology, 2nd ed. Edinburgh: Churchill Livingstone; 2002:1405-1460.

3. Gittenberger-de Groot AC, Strengers JL, Mentink M, et al. Histologic studies on normal and persistent ductus arteriosus in the dog. J Am Coll Cardiol 1985;6:394-404.

4. Buchanan JW, Patterson DF. Etiology of patent ductus arteriosus in dogs. J Vet Intern Med 2003;17:167-171.

5. Patterson DF, Pyle RL, Buchanan JW, et al. Hereditary patent ductus arteriosus and its sequelae in the dog. Circ Res 1971;29:1-13.

6. Buchanan J. Prevalence of cardiovascular disorders. In: Fox PR SD, Moise NS, ed. Textbook of Canine and Feline Cardiology - Principles and Clinical Practice., 2nd ed. Philadelphia: WB Saunders Co.; 1999:457-470.

7. Van Israel N, French AT, Dukes-McEwan J, et al. Review of left-to-right shunting patent ductus arteriosus and short term outcome in 98 dogs. J Small Anim Pract 2002;43:395-400.

8. Snaps FR, Mc Entee K, Saunders JH, et al. Treatment of patent ductus arteriosus by placement of intravascular coils in a pup. J Am Vet Med Assoc 1995;207:724-725.

9. Fox PR, Bond BR, Sommer RJ. Nonsurgical transcatheter coil occlusion of patent ductus arteriosus in two dogs using a preformed nitinol snare delivery technique. J Vet Intern Med 1998;12:182-185.

10. Saunders JH, Snaps FR, Peeters D, et al. Use of a balloon occlusion catheter to facilitate transarterial coil embolisation of a patent ductus arteriosus in two dogs. Vet Rec 1999;145:544-546.

11. Stokhof AA, Sreeram N, Wolvekamp WT. Transcatheter closure of patent ductus arteriosus using occluding spring coils. J Vet Intern Med 2000;14:452-455.

12. Schneider M, Hildebrandt N, Schweigl T, et al. Transvenous embolization of small patent ductus arteriosus with single detachable coils in dogs. J Vet Intern Med 2001;15:222-228.

13. Hogan DF, Green HW, III , Gordon S, et al. Transarterial coil embolization of patent ductus arteriosus in small dogs with 0.025-inch vascular occlusion coils: 10 cases. Journal of Veterinary Internal Medicine 2004;18:325-329.

14. Gordon SG, Miller MW. Transarterial Coil Embolization for Canine Patent Ductus Arteriosus Occlusion. Clinical Techniques in Small Animal Practice 2005;20:196-202.

15. Grifka RG, Miller MW, Frischmeyer KJ, et al. Transcatheter occlusion of a patent ductus arteriosus in a Newfoundland puppy using the Gianturco-Grifka vascular occlusion device. J Vet Intern Med 1996;10:42-44.

16. Glaus TM, Berger F, Ammann FW, et al. Closure of large patent ductus arteriosus with a self-expanding duct occluder in two dogs. J Small Anim Pract 2002;43:547-550.

17. Sisson D. Use of a self-expanding occluding stent for nonsurgical closure of patent ductus arteriosus in dogs. J Am Vet Med Assoc 2003;223:999-1005.

18. Hogan DF, Green HW, Sanders RA. Transcatheter closure of patent ductus arteriosus in a dog with a peripheral vascular occlusion device. Journal of Veterinary Cardiology 2006;8:139-143.

19. Nguyenba TP, Tobias AH. Minimally Invasive Per-Catheter Patent Ductus Arteriosus Occlusion in Dogs Using a Prototype Duct Occluder. Journal of Veterinary Internal Medicine 2008;22:129-134.

20. McEntee K, Snaps F, Clercx C, et al. Clinical vignette. Tetralogy of Fallot associated with a patent ductus arteriosus in a German shepherd

dog. J Vet Intern Med 1998;12:53-55.

21. Krichenko A, Benson LN, Burrows P, et al. Angiographic classification of the isolated, persistently patent ductus arteriosus and implications for percutaneous catheter occlusion. Am J Cardiol 1989;63:877-880.

22. Nguyenba TP, Tobias AH. The Amplatz(R) canine duct occluder: A novel device for patent ductus arteriosus occlusion. Journal of Veterinary Cardiology 2007;9:109-117.

23. Gordon SG, Saunders AB, Achen SE, et al. Transarterial ductal occlusion using the Amplatz Canine Duct Occluder in 40 dogs. J Vet Cardiol 2010;12:85-92.

24. Ronald G. Grifka MD TKJ. Transcatheter closure of large PDA using 0.052? Gianturco coils: Controlled delivery using a bioptome catheter through a 4 French sheath. Catheterization and Cardiovascular Interventions 2000;49:301-306.

25. Miller M. Transarterial coil occlusion of patent ductus arteriosus: outcome in 120 cases. Proceedings of the 20th Annual Forum of the American College of Veterinary Internal Medicine 2002:102.

26. Campbell FE, Thomas WP, Miller SJ, et al. Immediate And Late Outcomes Of Transarterial Coil Occlusion Of Patent Ductus Arteriosus In Dogs. J Vet Intern Med 2006;20:83-96.

27. Carlson JA, Achen SA, Saunders AB, et al. Delayed embolization of an Amplatz((R)) canine duct occluder in a dog. J Vet Cardiol 2013;15:271-276.

28. Singh MK, Kittleson MD, Kass PH, et al. Occlusion Devices and Approaches in Canine Patent Ductus Arteriosus: Comparison of Outcomes. Journal of Veterinary Internal Medicine 2012;26:85-92.

29. Schneider M SI, Wehner M, Hildebrandt N. Transvenous embolization of large PDA (>4.0 mm) with stiff and multiple coils (abstract). J Vet Intern Med 2002;16:630.

30. Van Israel N, French AT, Wotton PR, et al. Hemolysis associated with patent ductus arteriosus coil embolization in a dog. J Vet Intern Med 2001;15:153-156.

31. Schneider M, Hildebrandt N. Transvenous embolization of the patent ductus arteriosus with detachable coils in 2 cats. J Vet Intern Med 2003;17:349-353.

32. Hildebrandt N, Schneider C, Schweigl T, et al. Long-Term Follow-Up after Transvenous Single Coil Embolization of Patent Ductus Arteriosus in Dogs. Journal of Veterinary Internal Medicine 24:1400-1406.

33. Buchanan JW, Soma LR, Patterson DF. Patent ductus arteriosus surgery in small dogs. J Am Vet Med Assoc 1967;151:701-707.

34. Stanley BJ, Luis-Fuentes V, Darke PG. Comparison of the incidence of residual shunting between two surgical techniques used for ligation of patent ductus arteriosus in the dog. Vet Surg 2003;32:231-237.

35. Patterson DF, Haskins ME, Schnarr WR. Hereditary dysplasia of the pulmonary valve in beagle dogs. Pathologic and genetic studies. Am J Cardiol 1981;47:631-641.

36. Buchanan JW. Pulmonic stenosis caused by single coronary artery in dogs: four cases (1965-1984). J Am Vet Med Assoc 1990;196:115-120.

37. Buchanan JW. Pathogenesis of single right coronary artery and pulmonic stenosis in English Bulldogs. J Vet Intern Med 2001;15:101-104.

38. Kittleson M, Thomas W, Loyer C, et al. Single coronary artery (type R2A). J Vet Intern Med 1992;6:250-251.

39. Visser LC, Scansen BA, Schober KE. Single left coronary ostium and an anomalous prepulmonic right coronary artery in 2 dogs with congenital pulmonary valve stenosis. Journal of Veterinary Cardiology 2013;15:161-169.

40. Waterman MI, Abbott JA. Novel Coronary Artery Anomaly in an English Bulldog with Pulmonic Stenosis. Journal of Veterinary Internal Medicine 2013;27:1256-1259.

41. Stamm MD C, Anderson MD F, Robert H., Ho PhD F, Siew Yen. Clinical Anatomy of the Normal Pulmonary Root Compared With That in Isolated Pulmonary Valvular Stenosis. Journal of the American College of Cardiology 1998;31:1420-1425.

42. Bussadori C, DeMadron E, Santilli RA, et al. Balloon valvuloplasty in 30 dogs with pulmonic stenosis: effect of valve morphology and annular size on initial and 1-year outcome. J Vet Intern Med 2001;15:553-558.

43. Fingland RB, Bonagura JD, Myer CW. Pulmonic stenosis in the dog: 29 cases (1975-1984). J Am Vet Med Assoc 1986;189:218-226.

44. Johnson MS, Martin M, Edwards D, et al. Pulmonic stenosis in dogs: balloon dilation improves clinical outcome. J Vet Intern Med 2004;18:656-662.

45. Yeager SB FM, Keane JF. Catheter intervention: Balloon valvotomy. In: Lock JE KJ, Perry SB, ed. Diagnostic and Interventional Catheterization in Congenital Heart Disease. Boston: Kluwer Academic; 2000:151-178.

46. Ring JC, Kulik TJ, Burke BA, et al. Morphologic changes induced by dilation of the pulmonary valve anulus with overlarge balloons in normal newborn lambs. Am J Cardiol 1985;55:210-214.

47. Berman W, Jr., Fripp RR, Raisher BD, et al. Significant pulmonary valve incompetence following oversize balloon pulmonary valveplasty in small infants: A long-term follow-up study. Catheterization and cardiovascular interventions : official journal of the Society for Cardiac Angiography & Interventions 1999;48:61-65; discussion 66.

48. Bright JM, Jennings J, Toal R, et al. Percutaneous balloon valvuloplasty for treatment of pulmonic stenosis in a dog. J Am Vet Med Assoc 1987;191:995-996.

49. Sisson DD, MacCoy DM. Treatment of congenital pulmonic stenosis in two dogs by balloon valvuloplasty. J Vet Intern Med 1988;2:92-99.

50. Madron Ed, Bussadori C. Five cases of valvuloplasty with a balloon catheter for stenotic pulmonary valves in dogs. Pratique Médicale & Chirurgicale de l'Animal de Compagnie 1994;29:383-391.

51. Martin MWS, Godman M, Fuentes VL, et al. Assessment of balloon pulmonary valvuloplasty in six dogs. Journal of Small Animal Practice 1992;33:443-449.

52. Johnson MS, Martin M. Results of balloon valvuloplasty in 40 dogs with pulmonic stenosis. J Small Anim Pract 2004;45:148-153.

53. Estrada A, Moise NS, Erb HN, et al. Prospective evaluation of the balloon-to-annulus ratio for valvuloplasty in the treatment of pulmonic stenosis in the dog. J Vet Intern Med 2006;20:862-872.

54. Pyle RL, Patterson DF, Chacko S. The genetics and pathology of discrete subaortic stenosis in the Newfoundland dog. Am Heart J 1976;92:324-334.

55. Kienle RD, Thomas WP, Pion PD. The natural clinical history of canine congenital subaortic stenosis. J Vet Intern Med 1994;8:423-431.

56. DeLellis LA, Thomas WP, Pion PD. Balloon dilation of congenital subaortic stenosis in the dog. J Vet Intern Med 1993;7:153-162.

57. Meurs KM, Lehmkuhl LB, Bonagura JD. Survival times in dogs with severe subvalvular aortic stenosis treated with balloon valvuloplasty or atenolol. J Am Vet Med Assoc 2005;227:420-424.

58. Orton EC, Herndon GD, Boon JA, et al. Influence of open surgical correction on intermediate-term outcome in dogs with subvalvular aortic stenosis: 44 cases (1991-1998). J Am Vet Med Assoc 2000;216:364-367.

59. Kleman ME, Estrada AH, Maisenbacher HW, 3rd, et al. How to perform combined cutting balloon and high pressure balloon valvuloplasty for dogs with subaortic stenosis. J Vet Cardiol 2012;14:351-361.

60. Oguchi Y, Matsumoto H, Masuda Y, et al. Balloon dilation of right ventricular outflow tract in a dog with tetralogy of Fallot. J Vet Med Sci 1999;61:1067-1069.

61. Adin DB, Thomas WP. Balloon dilation of cor triatriatum dexter in a dog. J Vet Intern Med 1999;13:617-619.

62. Brown WA, Thomas WP. Balloon valvuloplasty of tricuspid stenosis in

a Labrador retriever. J Vet Intern Med 1995;9:419-424.

63. Kunze P, Abbott JA, Hamilton SM, et al. Balloon valvuloplasty for palliative treatment of tricuspid stenosis with right-to-left atrial-level shunting in a dog. J Am Vet Med Assoc 2002;220:491-496, 464.

64. MacLean HN, Abbott JA, Pyle RL. Balloon dilation of double-chambered right ventricle in a cat. J Vet Intern Med 2002;16:478-484.

Surgical Correction of Persistent Right Aortic Arch

Gary W. Ellison

Incidence

Persistent right aortic arch (PRAA) accounts for an estimated 95 percent of all clinically significant vascular ring anomalies in the dog. PRAA is the fourth most common cardiovascular malformation in dogs; only patent ductus arteriosus, pulmonic stenosis, and aortic stenosis have a higher incidence. Other vascular ring anomalies that are less commonly seen include double aortic arch, aberrant right and left subclavian artery, persistent right ligamentum arteriosum and left aortic arch with an anomalous right patent ductus arteriosus.

Purebred dogs are more susceptible than mongrels to PRAA. The condition is likely heritable with German Shepherds, Irish setters and Boston Terriers having a higher incidence than the general canine population. Increased numbers of offspring with PRAA have been observed in certain family lines and were seen in related Greyhounds in a kennel. Two German shepherd littermates with left aortic arch and anomalous right sided PDA are also reported. Single or multiple recessive genes appear to be responsible for the trait and breeding of affected animals is discouraged.

In cats, the exact incidence of PRAA is unknown, but it appears to be less common than in dogs. About one half of the feline cases occur in Siamese and Persian cats, although the absolute numbers are insufficient to make conclusions on breed predisposition.

Animals with PRAA usually are diagnosed shortly after weaning with the vast majority of cases diagnosed before six months of age. Exceptions sometimes occur, however, with dogs as old as 10 years being reported. Virtually all cases of PRAA in the dog and cat involve some degree of esophageal constriction and obstruction resulting in oral or nasal regurgitation.

Surgical Embryology

Persistent right aortic arch occurs when the right fourth arch, instead of the left develops into the functional adult aorta. The right ductus arteriosus degenerates and the left ductus arteriosus remains forming a strap that constricts the esophagus between the left pulmonary artery and the anomalous right aorta. The esophagus is thus constricted by the aorta on the right, the ligamentum arteriosum (LA) on the left dorsolaterally, the pulmonary trunk on the left, and the base of the heart ventrally. Persistent left cranial vena cava occurs concurrently with PRAA about 40 percent of the time however the left cranial vena cava is not clinically significant, as it empties into the right atrium and does not act as an esophageal constricting vascular ring. Its presence may complicate surgical dissection of the LA because it passes over the pulmonary artery and limits visualization of the surgical field. PRAA is associated with concurrent patent ductus arteriosus only about 10 percent of the time. When a patent ductus is present, blood flow through the ductus is minimal and insufficient turbulence is produced to create a murmur.

Clinical Presentaion and Diagnosis

Dogs and cats affected with PRAA are often asymptomatic before weaning but regurgitation of solid food may be observed as early as four to eight weeks of age. A ravenous appetite is typically reported, but the animal usually lags behind litter mates in size and body weight. Regurgitation may occur shortly after eating or may be delayed for several hours. The regurgitated food usually is undigested, covered by mucus, and has a neutral pH. A cough may be present, indicating the presence of aspiration pneumonia.

Auscultation of the heart is usually normal; even in cases of PRAA with patent ductus arteriosus. When present, diagnosis of the patent ductus arteriosus is usually made at the time of surgery. Lung sounds can be normal or rales can be heard if aspiration pneumonia is present. Food retained in the dilated esophagus may produce a gurgling sound upon auscultation. If dilation extends up into the central esophagus, a characteristic postprandial bulge may be seen or palpated at the thoracic inlet. Simultaneous closing of the mouth and external nares while gently squeezing the abdomen may produce bulging of the cervical esophagus.

Abnormal radiographic signs seen on survey radiographs include moderate or marked focal left curvature of the trachea near the cranial border of the heart on a VD or DV view. Ventral tracheal displacement, mediastinal widening, and occasionally a right sided descending aortic shadow may be seen on the lateral view. Ventral tracheal displacement and narrowing is caused by the dilated esophagus. If only the cranial thoracic esophagus is dilated, the trachea returns to a normal position at the tracheal bifurcation over the heart base and the trachea and theheart will be displaced ventrally.

An esophagram should be performed to confirm the diagnosis. Cranial thoracic esophageal dilation is associated with an abrupt esophageal narrowing over the heart base at the fourth or fifth rib. On the ventral dorsal view, the esophagus may be displaced to the left just proximal to the esophageal constriction with an indentation into the right side of the esophagus. The presence of a poststenotic esophageal dilatation is thought to indicate a more guarded prognosis for return to normal esophageal function. Fluoroscopic swallowing studies may be used to evaluate the quality of esophageal peristalsis in the dilated esophagus both pre and postoperatively. Esophageal endoscopy can be useful in evaluating the magnitude of esophageal dilation and also ruling out other causes of constriction of the intrathoracic esophagus. Occasionally, angiography may be needed to diagnose more complex vascular ring anomalies other than PRAA.

Presurgical Considerations

Definitive treatment for PRAA involves surgical ligation and division of the ligamentum arteriosum as soon after weaning as possible. Feeding of slurries alone without relieving the esophageal constriction is not effective since the pre-stenotic esophageal dilation often enlarges with time. Animals with PRAA are often presented in a debilitated, cachectic, and dehydrated state that requires special presurgical considerations. Fluid or electrolyte imbalances should be corrected before surgery. Aspiration pneumonia, if present, compromises the patient's ability to effectively ventilate the lungs. Placement of gastric feeding tubes to establish esophageal bypass in combination with broad-spectrum antibiotic therapy may be indicated preoperatively in patients with severe aspiration pneumonia.

We use propofol for rapid intravenous induction and tracheal intubation. Immediately after induction, the patient should be assisted in its ventilatory effort. Anesthesia is maintained with inhalant anesthesia. The dilated esophagus should be evacuated with suction prior to surgery since a grossly enlarged cranial esophagus may inhibit the ability to inflate the cranial and middle lung lobes during thoracotomy.

Surgical Technique

Surgical ligation of the LA is best accomplished through a left fourth thoracotomy. The cranial lung lobe is packed caudally with moistened surgical sponges. The esophagus, aorta, main pulmonary artery, and left vagus nerve are identified. The mediastinal pleura is transected longitudinally and the vagus nerve is reflected dorsally with 2-0 silk. The LA is usually longer than normal and is often difficult to visualize within the fibrous ring. It is most easily located cranial to the recurrent laryngeal nerve. If a persistent left cranial vena cava is present, it may have a hemizygous branch that obscures the LA. This structure can be double ligated, transected and reflected ventrally. If an aberrant left or right subclavian artery is present, it can be ignored if the vessel is not compressing the esophagus. If esophageal constriction is present, the subclavian vessel may be elevated and divided between ligatures. Adequate collateral circulation will be provided by the vertebral arteries.

The LA is carefully elevated off the esophagus from its left lateral aspect. Blunt dissection of the LA is performed in a caudal to cranial direction with right-angle Mixter or Lahey forceps (Figure 42-22A). Care must be taken during dissection near the pulmonary artery, as this vessel is easily torn. When the ligament is successfully freed and isolated, two ligatures of 0 surgical silk are placed as close to the aorta and pulmonary artery respectively as possible (Figure 42-22B). The LA is then transected between the ligatures. Traction then is placed on the ligatures, and the esophagus is dissected free of any residual fibrous bands between the aorta and pulmonary artery (Figure 42-22C). A 22 French Foley catheter is then introduced through the mouth into the esophagus and passed to the esophageal constriction. Inflation of the cuff at the constriction helps visualize any residual fibrous constricting bands and facilitates their dissection and removal. Extreme care is necessary during this dissection because the esophagus is thin and easily perforated. Passage of the inflated cuff back and forth at the stricture site will help further dilate the constriction. (Figure 42-22D).

With moderate esophageal dilation, passage of food improves once the constriction is relieved. Plication or resection of a dilated esophagus only reduces redundant tissue and does not restore normal esophageal peristalsis. If severe chronic dilation is present, plication of a redundant esophagus with Lembert-type gathering sutures of 4-0 nylon or polypropylene can be attempted but is of questionable benefit. If plication is attempted, care must be taken to not penetrate the mucosa of the esophagus, as leakage around the sutures may occur and postoperative pleuritis or pyothorax may result. Hand-sewn resection of the dilated cranial esophagus is not recommended because of its thin wall and inherent tendency for leakage. For intractable regurgitation, resection of a dilated esophagus with TA55 autostapling equipment has been attempted but with only fair results. Plication or resection of a dilated esophagus only reduces redundant tissue and does not restore normal esophageal peristalsis.

After ligation and division of the LA is completed and the esophagus freed of constricting fibrous bands, a thoracostomy tube is placed and routine thoracic closure is performed. Postoperative antibiotics are continued if aspiration pneumonia is present. I use combinations of bupivacaine rib blocks, intramuscular opioids or continuous rate infusion of opioids or ketamine and injectable NSAIDS to manage postsurgical pain (See Chapter 9). Blood glucose levels are closely monitored during recovery from anesthesia particularly in small breeds of dogs.

Postoperative Feeding

Elevated feedings of small quantities of semisolid food are provided three or more times daily starting the day following surgery. Feeding of liquid diets should be avoided. The semisolid solid food usually does not pocket in the cervical esophagus and will not reflux into the trachea as easily as liquid diets if regurgitated. The animal is held upright by the owner or is fed from a stool or platform that requires the forelimbs to be elevated off the ground. Holding the patient upright while rocking it slowly back and forth may also facilitate passage of the food. Gradually, over several days, the food is increased in consistency until feeding of solid food is attempted. If regurgitation subsides, elevated feedings are continued for at least eight weeks before horizontal feedings are attempted. Some animals will resume regurgitation with horizontal feedings, requiring that vertical feedings be adopted as a lifelong procedure.

Prognosis

Morbidity and mortality associated with persistent right aortic arch that is seen in the perioperative period is usually due to aspiration pneumonia. Animals surviving the postoperative period and leaving the hospital regurgitate less frequently following surgery and demonstrate good body weight gain with time. Those that survive at least six months do particularly well. In one study of 25 dogs, 70 percent of animals followed for two to four weeks had no regurgitation; but in those animals followed for 6 months 92 percent did not regurgitate after eating. Less

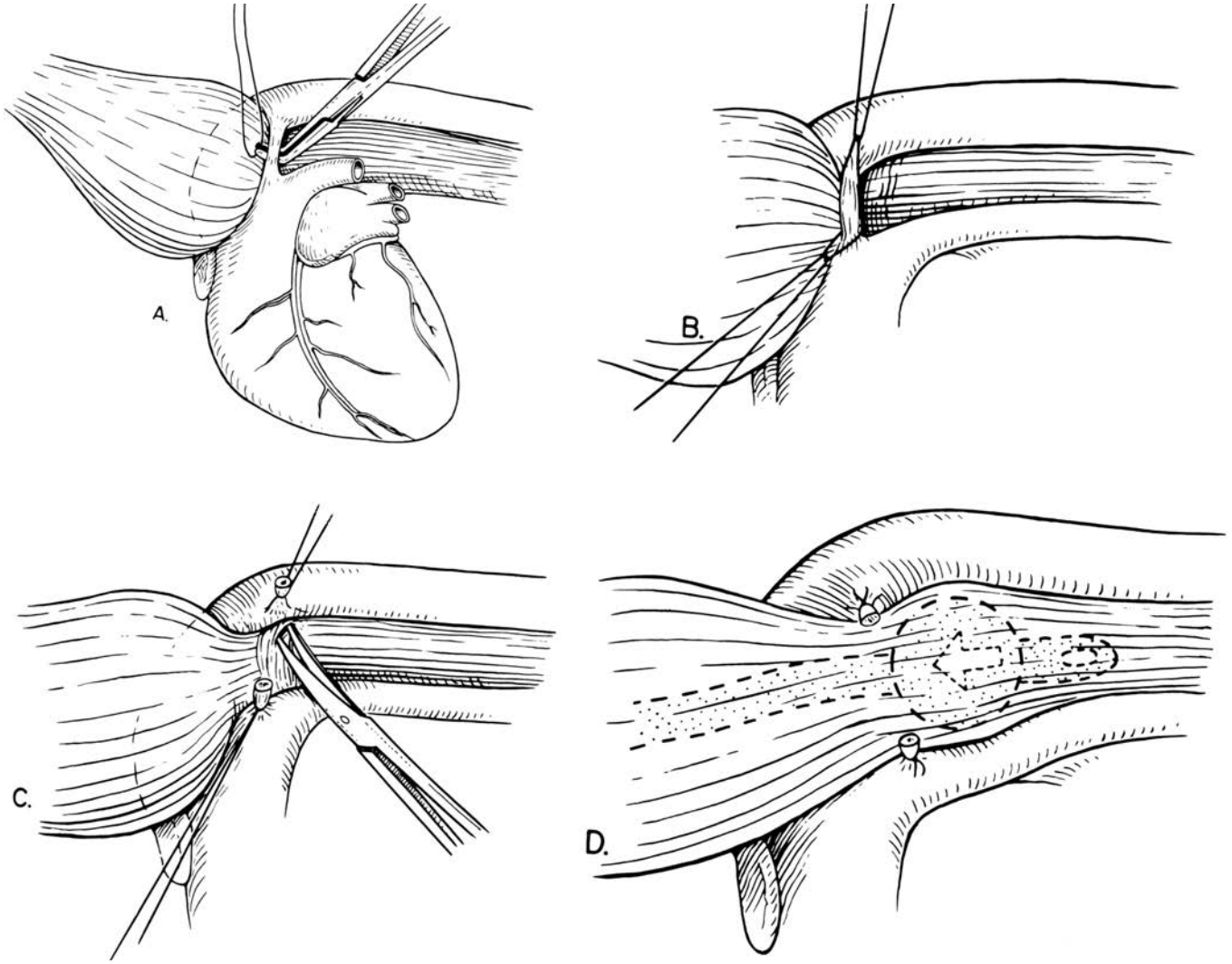


Figure 42-22. Surgical ligation and division of ligamentum arteriosum. **A.** Right-angle forceps are used to bluntly dissect around the ligamentum arteriosum and grasp 0 silk. **B.** Silk ligatures are knotted around the ligamentum arteriosum. **C.** After division of the ligamentum arteriosum remaining fibrous bands are carefully removed with Metzenbaum scissors. **D.** Use of Foley catheter to ensure that constriction has been relieved. See text for details.

than 10 percent of the cases failed to respond to surgery and were euthanized. Conversely, it is thought but not proven that dogs or cats with post-cardiac esophageal dilation tend to continue regurgitation after surgery and respond less favorably to surgery.

A contrast esophagram performed 24 to 72 hours after surgery will serve as a baseline and demonstrate adequate release of the constriction. Contrast studies performed three to four months postoperatively are recommended to evaluate the esophagus for decreasing dilation. Esophageal dilation usually decreases with time, but is not reversible. Likewise, esophageal peristalsis also usually improves with time, but never returns to normal. The exact cause of postcardial esophageal dilation associated with PRAA is unknown, but interference with the vagus nerves at the esophageal constriction may play a role in decreasing esophageal peristalsis.

At the present time, early surgical ligation and division of the ligamentum arteriosum offers patients with PRAA a reasonable long-term prognosis. Reversal of clinical signs is less likely as the age of the animal increases. In addition to surgical management, prolonged upright feeding may be required. Although some degree of esophageal dilation remains after surgery the frequency and severity of regurgitation is usually reduced over time.

Thorascopic Correction of Praa

Since the last edition of this text veterinary surgeons with an interest in minimally invasive surgery have thorascopically ligated and divided the LA in dogs with persistent right aortic arch. The reported advantages of this technique are 1) improved visualization of the LA during surgery 2) less postoperative patient discomfort, and 3) minimal intraoperative hypothermia. Disadvantages include equipment costs, technical expertise required, and the need for selective and specialized anesthesia techniques. This appears to be a promising method for surgical management of PRAA and larger clinical studies should be forthcoming.

Suggested Readings

Buchanon JW: Tracheal signs and associated vascular anomalies in dogs with persistent right aortic arch. *J Vet Intern Med* 18:510, 2004.

Ellison GW: Vascular ring anomalies in the dog and cat. *Comp Cont Ed* 2:693, 1980.

Gunby JM, Hardie RJ, Bjorling DE: Investigation of the potential heritability of persistent right aortic arch in Greyhounds. *J Am Vet Med Assoc* 224:1120, 2004.

Helphrey ML: Vascular ring anomalies in the dog. *Vet Clin N Am* 9:207, 1979.

Holt D, Heldman E, Mikel K, et al: Esophageal obstruction caused by a left aortic arch and an anomalous right patent ductus arteriosus in two German shepherd littermates. *Vet Surg* 29:264, 2000.

Macphail CM, Monnet E, Twedt DC. Thorascopic corrections of persistant right aortic arch in a dog. J Am Anim Hosp Assoc 37:577, 2001.

Muldoon MM, Birchard SJ, Ellison GW: Long-term results of surgical correction of persistent right aortic arch in dogs: 25 cases. *J Am Vet Med Assoc* 210:1761, 1997.

Shires PK: Persistent right aortic arch in dogs: a long-term follow-up after surgical correction. *J Am Anim Hosp Assoc* 17:773, 1981.

Van Gundy T: Vascular ring anomalies. *Comp Cont Educ Pract Vet* 11:36, 1989.

Vianna ML, Krahwinkel DJ: Double aortic arch in a dog. *J Am Vet Med Assoc* 225:1222, 2004.

Wheaton LG: Persistent right aortic arch associated with other vascular anomalies in two cats. *J Am Vet Med Assoc* 184:848, 1984.

Surgical Treatment of Pericardial Diseases and Cardiac Neoplasms

John Berg

Diseases affecting the canine pericardium can result in either pericardial effusion or pericardial constriction, both of which can be managed surgically. Antemortem diagnosis of feline pericardial disease is rare.

Anatomy and Physiology of the Pericardium

The pericardium is a fibrous sac composed of an outer fibrous layer and an inner serous layer. The serous layer is divided into the visceral pericardium (epicardium), which adheres firmly to the surface of the heart, and the parietal pericardium, which lines the interior surface of the fibrous pericardium. The pericardial cavity lies between the serous layers and normally contains a small quantity of clear fluid.

The fibrous pericardium forms a tough, thick sac that blends with the adventitia of the great vessels at the base of the heart. It is attached to the diaphragm in the xiphoid region by the sternopericardiac ligament ventrally and by pleural reflections caudally. The phrenic nerves course across the dorsal third of the pericardium on the left and right sides.

The functions of the pericardium are not completely understood, and its physiologic significance has been debated in literature. The following functions have been attributed to the pericardium: prevention of overdilation of the heart, protection of the heart from infection and from formation of adhesions to surrounding tissues, maintenance of the heart in a relatively fixed position within the chest, regulation of the interrelation between the stroke volumes of the two ventricles, and prevention of right ventricular regurgitation when ventricular diastolic pressure is increased.

Suggestions that the pericardium serves no vital functions have arisen from observations that humans and animals can live normally after pericardiectomy. Studies in animals suggest that the heart probably undergoes some minor dilation after pericardiectomy, although significant impairment of cardiac function has not been demonstrated.

Pericardial Effusion

Pathophysiology

Pericardial effusion is an abnormal accumulation of fluid within the pericardial sac. Severe pericardial effusion may result in cardiac tamponade, a potentially life-threatening compression of the heart in which intrapericardial pressure rises sufficiently to affect cardiac function. Cardiac tamponade occurs when enough pericardial fluid accumulates to exhaust the limits of pericardial elasticity. Once the pericardium can no longer stretch to accommodate additional fluid, the addition of small amounts of fluid begins to produce rapid increases in intrapericardial pressure.

Cardiac tamponade primarily affects cardiac function during diastole and has little effect on systolic function. Because intra-pericardial pressure is transmitted directly through the ventricular wall, diastolic filling pressures rise until the diastolic pressures within each ventricle are equal to one another and to intra-pericardial pressure. The right atrium and ventricle are more thin walled than the left, and are more susceptible to compression, so that signs of cardiac tamponade mimic signs of right heart failure. As predicted by the Frank-Starling law, decreased diastolic filling results in decreased myocardial stretching, force of contraction, and cardiac output.

The cardiovascular system attempts to compensate for falling cardiac output through peripheral arterial and venous vasoconstriction and increased heart rate.

However, these compensatory mechanisms may themselves stress the heart. The catecholamines responsible for vasoconstriction increase myocardial oxygen consumption, and tachycardia decreases coronary blood flow by decreasing the proportion of the cardiac cycle spent in diastole, when coronary flow occurs. Coronary flow is further compromised by low cardiac output and pressure on the coronary vessels produced by the pericardial fluid. These factors may produce myocardial ischemia and can eventually lead to cardiac decompensation.

Causes

The most common causes of pericardial effusion in the dog are neoplasia and idiopathic hemorrhagic pericardial effusion. Most

neoplastic effusions are hemorrhagic and result from acute or chronic hemorrhage from the tumor surface. Intra-pericardial cysts, pericardial effusions caused by bacterial or fungal infections, and other less common causes of pericardial effusion have also been reported.

The most common neoplastic cause of pericardial effusion is right atrial hemangiosarcoma. This tumor generally arises from the right auricular appendage, although the right atrial wall may be involved. German Shepard dogs and other large breeds are predisposed. The tumor is highly metastatic and almost always spreads to other organs such as the liver or lungs before it is discovered in the heart.

Chemodectomas arise from the aortic bodies located around the aorta at the heart base. The aortic bodies are composed of chemoreceptor tissue sensitive to blood pH, carbon dioxide content, and oxygen tension, and they are involved in the regulation of ventilation. Chemodectomas vary in their location around the aorta and in their degree of local invasiveness. The metastatic rate of this tumor is unknown. Although chemodectomas may occur in any breed, brachycephalic breeds may be predisposed, suggesting that chronic hypoxia may be an underlying cause. Anecdotally, the apparently high incidence of chemodectoma among dogs in Colorado further implicates chronic hypoxia in the pathogenesis of the tumor.

Other neoplastic causes of pericardial effusion are much less common. Malignant diseases that may metastasize to the heart or pericardium include hemangiosarcoma, lymphosarcoma, melanoma, and mammary adenocarcinoma. Mesothelioma can occasionally cause pericardial effusion, either alone or in combination with pleural or peritoneal effusion.

Idiopathic hemorrhagic pericardial effusion, a poorly understood syndrome, is also a common cause of pericardial effusion in the dog. It occurs predominately in large and giant breeds, has a distinct male predilection, and affects dogs of all ages. Patients have signs of acute or chronic cardiac tamponade, which may respond to either conservative treatment or surgical management. Although the cause of this syndrome is unknown, a similar syndrome in humans is suspected to be either viral or immune-mediated. Histologically, blood vessels of the canine parietal (and possibly visceral) pericardium appear to be the targets of the disease process and are the source of pericardial hemorrhage.

Intra-pericardial cysts are large, benign mass lesions that occasionally cause effusion and cardiac tamponade in young dogs. The cysts arise from the apex of the pericardial sac and resemble acquired cystic hematomas grossly and histologically. Although the cause of intra-pericardial cysts is unknown, it is possible that they develop from herniated omental or falciform fat in dogs born with small peritoneopericardial diaphragmatic hernias. Intra-pericardial cysts usually are diagnosed in dogs between 6 months and 3 years of age, although they occasionally are identified later in life.

Infectious pericardial effusion is reported to be caused most commonly by migrating grass awns. Many different species of bacteria have been cultured from the pericardial fluid of effected dogs. Pericardial effusion caused by infection with *Coccidioides immitus* has been reported in geographic areas, such as the southwestern United States, where the fungal agent is endemic. Young, large breed dogs are usually affected, and dogs may or may not have chronic histories of coccidioidomycosis. The pericardial disease is usually both effusive and constrictive.

Other potential causes of pericardial effusion include congenital peritoneopericardial hernias, left atrial rupture secondary to mitral insufficiency, blunt or penetrating trauma, congestive heart failure, and uremia. Pericardial effusion resulting from the latter two conditions is usually inconsequential and tends to be a postmortem finding only.

History and Clinical Signs

Dogs with cardiac tamponade are usually presented with acute or chronic histories of nonspecific signs suggestive of right-sided heart failure. These include lethargy, dyspnea, cough, abdominal distension, anorexia, weight loss, and exercise intolerance. Acute collapse with no prior signs is seen occasionally. In general, the history is not helpful in differentiating neoplastic from idiopathic hemorrhagic pericardial effusion; signs may be acute or chronic in either condition.

Several physical findings may suggest cardiac tamponade as the cause of right-sided heart failure. These include muffled heart sounds, pronounced jugular pulses and jugular distension, and weak arterial pulses. Hepatomegaly, ascites and peripheral edema may also be present. Pulsus paradoxus is an exaggerated pattern of change in arterial pressure with respiration, characterized by a weak pulse during inspiration and a stronger pulse during expiration. The sign is often present but overlooked in dogs with pericardial effusion, and may be best appreciated in dogs breathing slowly while lying in lateral recumbency.

Diagnostic Evaluation

The diagnostic evaluation of dogs with signs compatible with cardiac tamponade should be aimed at demonstrating pericardial effusion and determining its underlying cause. Pericardial effusion can be demonstrated in most cases using a combination of electrocardiography, thoracic radiography, and M-mode or 2-dimensional echocardiography. Diminished QRS voltages and electrical alternans are seen in a significant proportion of electrocardiograms. Diminished QRS amplitudes are likely caused by decreased conduction of electrical impulses through fluid media, although decreased ventricular filling may be involved. Pleural effusion as well as pericardial effusion can produce decreased QRS voltages. Electrical alternans is a beat-to-beat variation in QRS amplitude produced by a swinging motion of the heart within the pericardial sac.

Thoracic radiography demonstrates pericardial effusion if the volume of effusion is substantial. Generalized heart enlargement is seen, and the heart may have a characteristic globoid appearance, which is best demonstrated on dorsoventral views. Pleural effusion, ascites, hepatomegaly and distension of the caudal vena cava may also be present.

M-mode echocardiography is the most sensitive test available for detecting pericardial effusion and differentiating pericardial fluid from cardiomegaly and peritoneopericardial hernias. Effusions are demonstrated in approximately 90% of cases, and volumes as small as 75 ml can be detected.

Because pericardial effusions caused by neoplasia have a distinctly poorer prognosis than idiopathic hemorrhagic and other effusions, the detection of cardiac masses, particularly right atrial hemangiosarcomas, is an important part of the diagnostic evaluation. Cytologic examination of fluid obtained by pericardiocentesis (discussed later) generally does not differentiate neoplastic from idiopathic hemorrhagic effusions. In both cases, the fluid is hemorrhagic and non-clotting, and it contains predominately red blood cells, macrophages, and reactive mesothelial cells. Demonstration of neoplastic cells is extremely rare, and care must be exercised in cytologic interpretation because reactive mesothelial cells can have neoplastic characteristics. Exudative effusions are usually caused by bacterial or fungal infection; the causative organism may be visible on cytologic examination or identified by bacterial or fungal culture.

Two-dimensional echocardiography is the most sensitive test available for detecting cardiac masses and for determining preoperatively whether a mass is likely to be surgically resectable. In the hands of experienced cardiologists, echocardiography is highly sensitive and highly specific for both right atrial masses and heart base masses. Examination from both sides of the thorax allows accurate localization of cardiac masses. Because right atrial hemangiosarcomas are often small (1 to 2 cm in diameter), they occasionally escape detection. Involvement of the right atrial wall, which increases the difficulty of surgical excision, often can be detected echocardiographically. Chemodectomas often can be visualized in association with the ascending aorta. Small, discrete chemodectomas confined to the aortic area may prove resectable, whereas larger, more invasive masses are less likely to be resectable. Chemodectomas may be situated on either the right or left side of the aorta, and ultrasonography can assist in the selection of a surgical approach. Mesotheliomas have a diffuse growth pattern and usually are not detected with ultrasonography. Intrapericardial cysts are large lesions that are detected easily by echocardiography.

Routine laboratory tests may occasionally be useful in determining the cause of pericardial effusion. A complete blood count may show neutrophilia with a left shift in dogs with infectious effusions. Increased numbers of nucleated red blood cells or schistocytes are suggestive of right atrial or splenic hemangiosarcoma. Serum fungal titers are usually elevated in dogs with pericardial effusion caused by *Coccidioides immitus* infection. Marked elevations in serum levels of certain cardiac troponins, which are markers of myocardial ischemia and necrosis, may suggest that right atrial hemangiosarcoma rather than idiopathic effusion is present. Cardiac troponin assays are not routinely available to veterinarians at the current time.

Unfortunately, on rare occasions, it may be difficult to make a definitive diagnosis, and particularly to differentiate right atrial hemangiosarcoma from idiopathic hemorrhagic pericardial effusion, without exploratory thoracotomy.

Treatment

Pericardiocentesis

Indications: Pericardiocentesis is preformed for both diagnostic and therapeutic purposes. The removal of small volumes of pericardial fluid in patients with cardiac tamponade can result in rapid and dramatic decreases in intra-pericardial pressure and is often a lifesaving measure. Approximately 50% of dogs with idiopathic hemorrhagic pericardial effusion can be successfully treated by periodic pericardiocentesis, performed when necessary to relieve cardiac tamponade. Multiple pericardiocenteses, days to weeks apart, may be necessary to produce a resolution, and recurrence of pericardial effusion is reported to occur as late as 4 years after pericardiocentesis. Owners of dogs treated by pericardiocentesis alone should be made aware of the potential for sudden recurrence of cardiac tampondade. The advantages of pericardiectomy over pericardiocentesis are discussed below.

Technique: Pericardiocentesis is performed at the right third, fourth, or fifth intercostal space near the costochondral junction. Excellent descriptions of this procedure are available elsewhere.

Pericardiectomy

Indications: Pericardiectomy is used most often to treat idiopathic pericardial effusions and effusions caused by neoplasia, intrapericardial cysts, infection, and penetrating foreign bodies. Effusions caused by congestive heart failure or uremia usually are treated medically. The specific goals of pericardiectomy depend on the primary disease being treated. Pericardiectomy may be performed either by open thoracotomy or with thoracoscopy.

In pericardial effusion caused by neoplasia, the pericardium is often excised to allow surgical exploration of the heart. Pericardiectomy alone, without excision of the neoplastic mass, traditionally has been thought to be of little or no value. However, a study of dogs undergoing thorascopic partial pericardiectomy without mass excision showed that all dogs with neoplastic effusions experienced palliation of signs of cardiac tamponade. Median survival of treated dogs was only 1 month; however, some dogs survived beyond 1 year. In addition, 2 separate studies have shown that dogs with chemodectoma can have prolonged survival after open pericardiectomy alone: median survival times were greater than 2 years in both studies, and were significantly longer than survival times of dogs that did not undergo pericardiectomy. Although it seems reasonable to assume that pericardiectomy combined with excision of neoplastic masses should produce superior results to pericardiectomy alone, this has not yet been proven in controlled trials. Excision of right atrial hemangiosarcomas, chemodectomas, and intrapericardial cysts is discussed below.

Idiopathic hemorrhagic pericardial effusion can be treated successfully by creation of a pericardial window or by partial pericardiectomy below the level of phrenic nerves which allow any persistent effusion to be removed by the large absorptive area of the pleural space. Although the condition often is manageable by periodic pericardiocentesis, early pericardiectomy has some advantages. Treatment by pericardiocentesis

alone risks a sudden recurrence of life-threatening cardiac tamponade. Pericardiectomy does not entail long term risks for the patient, and, unlike pericardiocentesis, eliminates most of the tissue responsible for the effusion. Some evidence suggests that idiopathic pericardial effusion may progress to pericardial constriction, although this appears to be uncommon; surgery is technically simpler, and is associated with a better prognosis, for pericardial effusion than for pericardial constriction. Finally, early surgical exploration may allow identification of small tumors that were not revealed by echocardiography, and may offer the best chance for their removal.

The indications for open versus thorascopic pericardiectomy are not firmly established. Advantages of thoracotomy include its wide availability, the ability to more thoroughly explore the thorax, and its potential to permit resection of neoplastic mass lesions. The major advantages of thorascopic pericardiectomy are reduced postoperative pain and morbidity, and a more rapid recovery time. In thorascopic pericaridectomy, a small pericardial window is usually created, whereas with thoracotomy, partial pericardiectomy below the level of the phrenic nerves may be performed. Traditionally, creation of a pericardial window has been thought to be associated with a risk that residual pericardium would adhere to the surface of the heart, resulting in recurrent pericardial effusion. Early experience with thorascopic pericardiectomy and with percutaneous balloon pericardiotomy suggests that the risk of this complication is quite low. Minimally invasive approaches are most often indicated when there is a high index of suspicion that the effusion is idiopathic, eg. in dogs with no echocardiographic evidence of a cardiac mass who have developed recurrent effusion months after pericardiocentesis. Small masses involving the tip of the right auricular appendage may be removed with minimally invasive techniques. Thoracotomy should be chosen for resection of auricular masses not deemed amenable to minimally invasive surgery, and for heart base masses. In circumstances other than these, the choice between thorascopic and open pericardiectomy is a matter of the surgeon's and owner's preferences. The technique for thorascopic pericardiectomy is discussed elsewhere.

Surgical approach: When the cause of pericardial effusion is unknown, either a right fifth intercostal thoracotomy or a median sternotomy may be performed. Excision of right atrial tumors may be accomplished with similar ease through either approach. For the majority of dogs with idiopathic effusions, a right sided approach, followed by creation of a pericardial window and inspection of the right atrial appendage to rule out hemangiosarcoma, is a reasonable approach. When partial pericardiectomy below the level of the phrenic nerves is deemed necessary, either a median sternotomy or an intercostal approach may be used. Subtotal pericardiectomy is somewhat easier to perform through a median sternotomy, because an intercostal approach does not permit good visualization of the opposite side of the thorax. In addition, if an intercostal approach is used, the heart must be elevated as the far side of the pericardial sac is excised, a maneuver that temporarily impairs venous return. Chemodectomas are approached through either a right or left fourth intercostal thoracotomy, depending on the location of the tumor as determined by ultrasonography. Intrapericardial cysts are best approached through a median sternotomy, which facilitates subtotal pericardiectomy and allows inspection of the diaphragm for a peritoneopericardial hernia.

Technique: Once the thoracotomy is completed, the phrenic and vagus nerves are identified. The phrenic nerve may be isolated and gently retracted with a Penrose drain, although retraction of the nerve usually is unnecessary. The vagus nerve is located more dorsally and is unlikely to be damaged during pericardiectomy. To create a pericardial window, a controlled stab incision is made in the pericardium ventral to the phrenic nerve with a scalpel blade, and pericardial fluid is removed by suction. The incision is then extended with Metzenbaum scissors or electrocautery to create a window several centimeters in diameter ventral to the phrenic nerve. The right atrial appendage is inspected to rule out the presence of a right atrial mass by carefully retracting the cranial and dorsal edges of the window. If partial pericardiectomy below the level of the phrenic nerves is to be performed, the initial incision is continued cranially and caudally until it is completed circumferentially (Figures 42-23 and 4-24). If an intercostal approach has been used, completion of the pericardiectomy on the left side requires elevation of the heart. An assistant should cradle the patient's heart in one hand and gently rotate the apex of the heart laterally and dorsally to permit incision of the pericardium below the level of the left phrenic nerve. Because elevation of the heart impairs venous return, this maneuver should be performed as quickly as possible. Diseased pericardia are often thickened and extremely vascular, and care must be taken to limit hemorrhage with electrocautery. Once the sternopericardiac ligament is divided, either with electrocautery or between ligatures, the pericardial sac can be removed and submitted for histopathology. A thoracostomy tube is placed before closure, and postoperative management generally is uncomplicated. The thoracostomy tube may be removed after 12 hours if it is unproductive.

For dogs with bacterial pericardial effusion, long-term antibiotics, selected on the basis of culture and sensitively testing, should be administered postoperatively. The prognosis for these dogs is generally excellent.



Figure 42-23. A highly vascular pericardial sac as viewed through a right intercostal thoracotomy in a dog with idiopathic hemorrhagic pericardial effusion.

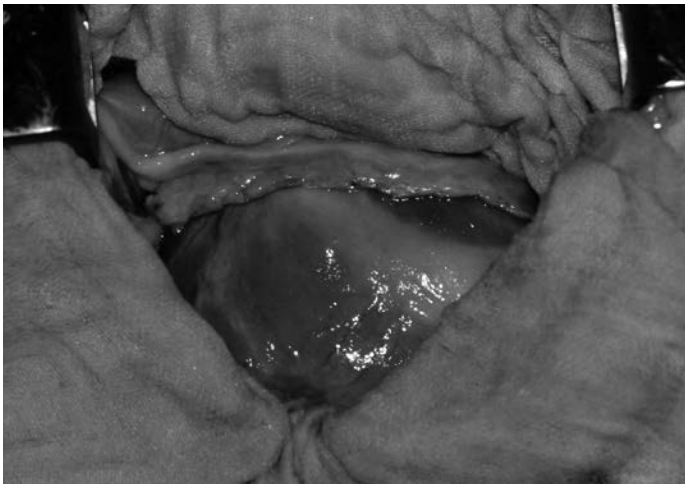


Figure 42-24. Appearance of the pericardial sac shown in figure 42-23 following partial pericardiectomy below the level of the phrenic nerves.

Excision of Intrapericardial Cysts

Intrapericardial cysts are usually located at the apex of the pericardial sac and can be excised readily by routine subtotal pericardiectomy (Figure 42-25). If the patient has an associated peritoneopericardial hernia, the edges of the hernia are incised, and the defect is closed with a row of simple continuous sutures.

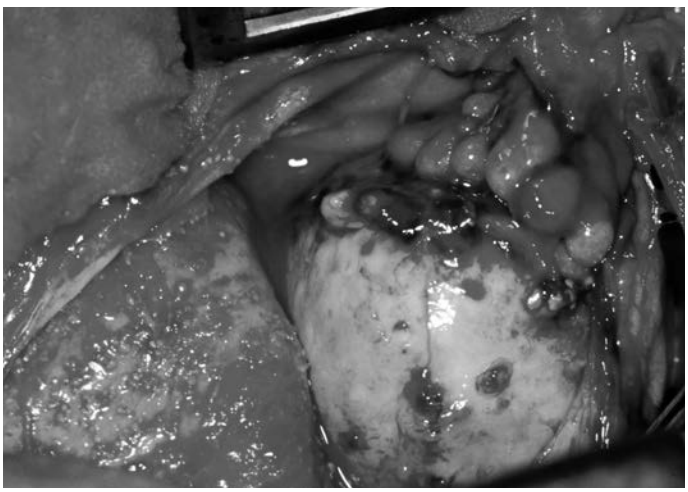


Figure 42-25. An intrapericardial cyst (right) adjacent to the apex of the heart (left).

Excision of Right Atrial Hemangiosarcoma

Indications: Excision of right atrial hemangiosarcomas should be considered palliative, because the tumor almost invariably metastasizes prior to detection. The goal of surgery is to prevent a recurrence of cardiac tamponade. Many hemangiosarcomas are confined to the right auricular appendage, and are therefore amenable to surgical excision as described below. Inflow occlusion or cardiopulmonary bypass are required to excise tumors with significant right atrial wall involvement.

Technique: After median sternotomy or right fifth intercostal thoracotomy, an incision is made in the pericardial sac approximately 1 cm below and parallel to the phrenic nerve. The pericardial incision is extended cranially and caudally as far as necessary with Metzenbaum scissors or electrocautery to fully expose the auricular appendage. Exposure may be improved by using stay sutures or Babcock forceps to retract the incised edges of the pericardial sac.



Figure 42-26. A right atrial hemangiosarcoma as viewed through a right intercostal thoracotomy.

Either conventional suturing or surgical stapling equipment may be used to remove right atrial masses. If conventional suturing is elected, a tangential vascular clamp is placed across the base of the auricular appendage. The appendage is transected immediately distal to the clamp, leaving a cuff of auricular tissue. The margin of the excised tumor should be inspected to ensure that excision was complete; if possible, at least 1 cm of normal auricular tissue should be removed with the tumor. The auricle is then oversewn with two rows of simple continuous sutures, with rows oriented perpendicularly to each other (Figures 42-26 and 42-27). 3-0 or 4-0 polypropylene suture on a tapered needle may be used.

Surgical stapling is faster and less technically demanding than hand suturing. A 55 mm thoracoabdominal stapler is used, with 3.5 mm staples (Kendall-Tyco Corp, Norwalk, CT). The stapler

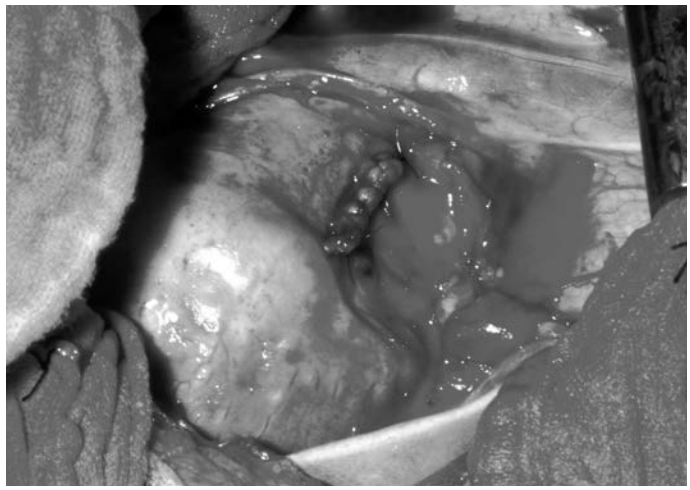


Figure 42-27. Appearance of the auricular appendage shown in figure 42-25 following excision of the mass and oversewing of the auricular incision.

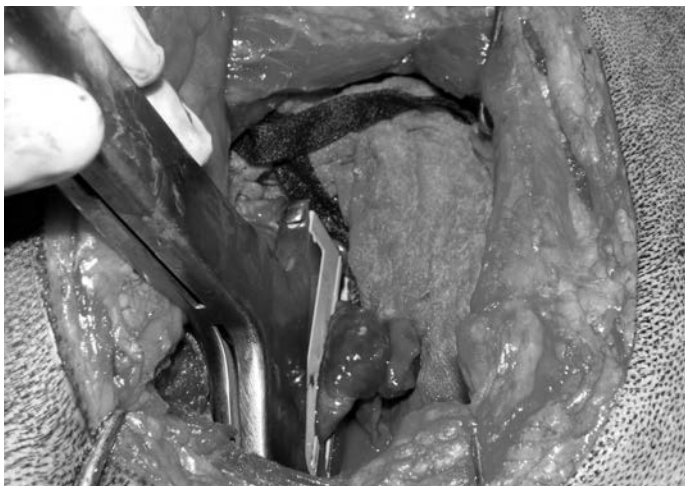


Figure 42-28. Use of a surgical stapler to excise a hemangiosarcoma of the right auricular appendage.

should be positioned to provide a 1 cm resection margin (Figure 42-28). If there is room, a tangential vascular or other noncrushing clamp should be placed across the base of the auricle before releasing the stapler; the clamp should be slowly released as the staple line is inspected for bleeding. If necessary, the staple line may be oversewn with a layer of simple continuous suture. After tumor excision, a partial pericardiectomy should be performed.

Prognosis: Because right atrial hemangiosarcoma is a highly metastatic tumor, surgical excision is purely palliative. Mean survival time after surgery is reported to be approximately 4 months. Euthanasia is performed in most affected dogs because of distant metastases, usually to the liver or lungs, within a few months of surgery. Unfortunately, no compelling evidence yet exists to suggest that survival times in dogs with either splenic or right atrial hemangiosarcoma can be significantly prolonged with adjuvant chemotherapy, and prospective controlled clinical trials are needed.

Excision of Chemodectomas

Because of the difficult location of chemodectomas, their highly vascular nature, and the excellent survival times reported following pericardiectomy alone, pericardiectomy without tumor excision should be considered a viable alternative to tumor excision for this disease.

Technique: Control of hemorrhage is the major difficulty encountered during attempts at tumor excision. Because of their location, chemodectomas must be marginally excised at the gross limits of the tumor; wide margins are impossible to provide. Excision is best accomplished by slow, meticulous, sharp dissection with the help of electrocoagulation. Care must be taken to avoid perforating the aorta or pulmonary artery; cotton-tipped swabs are useful for slowly dissecting the tumor away from these structures. Before closure, the tumor bed should be closely inspected, and residual points of hemorrhage should be controlled with precise electrocoagulation.

Prognosis: Chemodectomas seem to be slow-growing tumors, and limited experience suggests that dogs undergoing excision of small chemodectomas can have prolonged survival postoperatively. Whether surgical excision improves survival beyond that associated with pericardiectomy alone is unknown. Studies investigating the efficacy of chemotherapy or radiation therapy have not yet been reported.

Pericardical Constriction

Pathophysiology and Causes

As in cardiac tamponade resulting from pericardial effusion, pericardial constriction restricts diastolic volume. Diastolic filling is limited by the fibrotic pericardium, which acts as a noncompliant shell around the heart.

Pericardial constriction in dogs usually is idiopathic. Like idiopathic hemorrhagic pericardial effusion, the condition occurs predominately in medium-size and large breeds, although no evidence of male sex predilection exists. Some evidence based on isolated case reports indicates that idiopathic hemorrhagic pericardial effusion can progress to pericardial constriction, although this seems uncommon. Whether idiopathic pericardial constriction and idiopathic hemorrhagic effusion are different manifestations of the same syndrome, or are separate disease entities, is unknown.

Dogs with pericardial disease caused by *Coccidioides immitus* infection most commonly have a combination of effusive and constrictive pericarditis. This condition should be considered in any dog with pericardial disease in geographic regions where the fungus is endemic.

History, Clinical Signs, and Diagnosis

Dogs with constrictive pericardial disease are usually presented with signs of chronic right-sided heart failure. Abdominal distension, dyspnea, weakness or syncope, exercise intolerance, and weight loss are common signs. Typical physical examination findings are ascites, jugular distension, and weak arterial pulses. Poorly auscultable heart sounds are also common. A "pericardial knock," produced as blood is rapidly compressed against the rigid ventricular wall, may be heard on auscultation. Approximately half of dogs with pericardial effusion-constriction caused by *C immitus* infection have chronic histories of coccidioidomycosis, producing signs such as lameness, dermatopathy, and uveitis.

Definitive diagnosis of pericardial constriction may require surgical exploration, although a presumptive diagnosis can often be made preoperatively based on a combination of physical, electrocardiographic, imaging, and hemodynamic findings. One or more abnormalities may be present on electrocardiographic examination. Decreased QRS amplitudes and increased P-wave duration are the most common findings. Radiographs may reveal free pleural fluid and mild to moderate cardiomegaly. Echocardiographic findings that support the diagnosis include decreased end-diastolic diameter, decreased fractional shortening, flattening of left ventricular free-wall motion during late diastole, and rapid premature diastolic closure of the mitral valve. Dogs with pericardial effusion-constriction caused by *Coccidioides immitus* infection usually have elevated serum

titers for antibodies against the organism. In general, a diagnosis of pericardial constriction should be considered in dogs with signs of right-sided heart failure that cannot be explained by pericardial effusion, congenital or acquired heart disease, or pulmonary hypertension. Surgical exploration should be performed if the condition is suspected.

Subtotal Pericardiectomy for Pericardial Constriction

Technique: Because significant epicardial fibrosis usually is not present in dogs with idiopathic pericardial constriction, most dogs can be treated successfully by subtotal pericardiectomy, as previously described. Median sternotomy is the preferred approach because it allows visualization and division of any epicardial adhesions that may be present. In dogs with significant epicardial fibrosis, epicardial decortication may be necessary. This is a difficult procedure that may require partial removal of myocardial tissue. Caution is necessary to avoid inadvertent damage to coronary vessels. Epicardial decortication is associated with significant perioperative morbidity and mortality.

In dogs with effusion-constriction caused by *C immitus* infection, extensive mature adhesions to the epicardial surface of the heart are likely to be present, and pericardiectomy may be significantly complicated by hemorrhage. Adhesions may be disrupted manually and by careful instrument dissection. Strips of pericardium overlying the coronary vessels may be left in place if there are firm adhesions to the vessels. If fibrosed, the epicardium may be removed from areas distant from the coronary vessels, using scissors or a periosteal elevator to carefully lift the epicardium from the myocardium. The perioperative mortality rate in a series of dogs with *C immitus* pericarditis undergoing partial pericardiectomy was 23.5%, and among dogs that were discharged from the hospital, the 2 year survival rate was 82%.

Suggested Readings

Aronson LR, Gregory CR. Infectious pericardial effusion in five dogs. Vet Surg 1995; 24:402-407.

Aronsohn M. Cardiac hemangiosarcoma in the dog: a review of 38 cases. J Am Vet Med Assoc 1985; 187:922.

Berg RJ, Wingfield WE. Pericardial effusion in the dog: a review of 42 cases. J Am Anim Hosp Assoc 1984; 20:721-730.

Berg RJ, Wingfield WE, Hoopes PJ. Idiopathic hemorrhagic pericardial effusion in eight dogs. J Am Vet Med Assoc 1984; 185:988-992.

Christensen EE, Bonte FJ. The relative accuracy of echocardiography, intravenous CO_2 studies, and blood pool scanning in detecting pericardial effusions in dogs. Radiology 1968; 91:265.

Chun R, Kellihan HB, Henik RA, Stepien RL. Comparisonof plasma cardiac troponin 1 concentrations among dogs with cardiac hemangiosarcoma, noncardiac hemangiosarcoma, other neoplaasms, and pericardid effusion of nonhemangiosarcoma origin. J Am Vet Med Assoc. 2010; 237:806-811.

Ehrhart N, Ehrhart EJ, Willis J, Sisson D, et al. Analysis of factors affecting survival in dogs with aortic body tumors. Vet Surg 2002; 31: 44-48.

Heinritz CK, Gilson SD, Soderstrom MJ, Robertson TA, et al. Subtotal pericardiectomy and epicardial excision for treatment of coccidioidomycosis-induced effusive-constrictive pericarditis in dogs: 17 cases (1999-2003). J Am Vet Med Assoc 2005; 227: 435-439.

Holt JP, The normal pericardium. Am J Cardiol 1970; 26:455.

Lombard CW. Pericardial disease. Vet Clin North Am 1983; 13:337.

McDonald KA, Cagney O, Magne ML. Echocardiographic and clinicopathologic characterization of pericardial effusion in dogs: 107 cases (1985-2006). J AM Vet Med Assoc 2009; 235:1456-1461.

Patnaik AK, Liu SK, Hurvitz AI, et al. Canine chemodectoma (extra-adrenal paragangliomas): a comparative study. J Small Anim Pract 1975; 16:785-80.

Shaw SP, Rozanski EA, Rush JE. Cardiac troponins I and II in dogs with pericardial effusion. J Vet Int Med 2004; 18: 322-324.

Sidley JA, Atkins CE, Keene BW, DeFrancesco. Percutaneous ballon pericardiectomy as a treatment for recurrent pericardial effusion in 6 dogs. J Vet Int Med 2002; 16: 5431-546.

Sisson D, Thomas WP, Ruehl WW, et al. Diagnostic value of pericardial fluid analysis in the dog. J Am Vet Med Assoc 1984; 184:51-55.

Sisson D, Thomas WP, Reed, et al. Intrapericardial cysts in the dog. J Vet Int Med 1993; 7:364-369.

Thomas WP, Sisson D, Bauer TG, et al. Detection of cardiac masses in dogs by two-dimensional echocardiography. Vet Radiol 1984; 25:65-72.

Thomas WP, Reed JR, Bauer TF, et al. Constrictive pericardial disease in the dog. J Am Vet Med Assoc 1984; 184:546-553.

Vicari ED, Brown DC, Holt DE, Brockman DJ. Survival times of and prognostic indicators for dogs with heart base masses: 25 cases (1986-1999). J Am Vet Med Assoc 2001; 219:485-487.

Chapter 43

Lymphatics and Lymph Nodes

Management of Chylothorax

MaryAnn Radlinsky

Etiology

Chyle is a fluid made up of lymph and chylomicrons absorbed by the intestinal lacteals; as a result of digestion, the fluid is high in triglycerides. Chylothorax refers to the accumulation of chyle in the pleural space. Normally, chyle is returned to the systemic circulation by the thoracic duct, which is the continuation of the cisterna chyli. The cisterna chyli receives lymph from the abdominal organs and the pelvic limbs and lies in the dorsal retroperitoneal space adjacent to the aorta and left kidney. The thoracic duct variably consists of many branches lying dorsal to the thoracic aorta and ventral to the azygous vein on the right side of the thorax in the dog. The duct crosses to the left side in the mediastinum at the level of the fifth or sixth thoracic vertebra. The lymphaticovenous junction is associated with the left external jugular vein, its junction with the cranial vena cava, or the jugulosubclavian angle.[1] Chylothorax occurs when the flow of chyle is increased (*e.g.* increased hepatic production of lymph) or when entrance of chyle into the venous system is impeded (*e.g.* increased venous pressures or obstruction of the lymphaticovenous junction). Any process that increases the cranial vena caval hydrostatic pressure or causes complete or relative obstruction of the lymphaticovenous junction predisposes an animal to chylothorax.[2]

Increased systemic hydrostatic pressure may be secondary to cardiac disease or abnormalities of the cranial vena cava. Many disease processes associated with either right heart failure or conditions associated with compression or obstruction of the vena cava, lymphaticovenous junction, or thoracic duct have been reported to cause chylothorax (Table 43-1). Cardiac diseases associated with increased venous pressure cause an increase in lymph production secondary to hepatic congestion and thereby increase the flow of lymph in the thoracic duct.[3,4] Concurrent, increased venous pressure diminishes flow through the lymphaticovenous junction (relative obstruction). Both processes cause the accumulation of chyle within the pleural space. Direct or indirect trauma to the thoracic duct has been associated with the development of small amounts of chylous effusion within the pleural space.[5] The thoracic duct heals rapidly with linear or transverse trauma or iatrogenic trauma, and the pleural effusion should be short-lived (1 to 2 weeks) with no specific therapy required for resolution.[6]

Although many disease conditions have been associated with chylous effusion, the most common cause of chylothorax is idiopathic. Abnormal lymphatic flow or pressure within the thoracic duct is thought to lead to thoracic lymphangiectasia. Lymph leaks from the dilated, tortuous branches of the thoracic duct, which are most evident in the cranial thorax.[7] The pulmonary lymphatics may also play a role in cases of idiopathic chylothorax that fail to respond to therapy.[8] All potential underlying disease processes (Table 43-1) must be ruled out prior to diagnosing the disease as idiopathic, as failure to diagnose an underlying condition will deny the patient definitive therapy.

Table 43-1. Conditions Associated with Chylothorax in Dogs and Cats

Cardiomyopathy
Mediastinal neoplasia (Lymphosarcoma, thymoma)
Trauma
Cranial vena cava thrombosis
Fungal infection, granuloma
Dirofilariasis
Congenital anomaly (tetralogy of Fallot, cor triatriatum dexter, tricuspid dysplasia, thoracic duct anomaly)
Pericardial effusion, constrictive pericarditis
Heart base tumor
Diaphragmatic hernia
Hyperthyroidism
Lymphangioleiomyomatosis

Diagnosis

History and Physical Examination

Any breed of dog or cat of any age may develop chylothorax. The Afghan hound, Shiba Inu, Siamese, and Himalayan breeds may have an increased prevalence of the disease. Afghan hounds tended to develop the disease in middle age; young Shiba Inus, and older cats were more often affected. Both males and females developed the condition equally.[4]

The presence of pleural effusion usually results in ventilatory compromise. The volume and rapidity of fluid accumulation determine the signs present. Chylothorax may result in no significant signs until the patient becomes dyspneic. Coughing may be the first and only sign associated with chylothorax, and occasionally chylothorax is an incidental finding. The etiology of cough with chylothorax may be related to the primary problem (e.g. heart failure, neoplasia) or may be due to inflammation caused by the presence of chyle within the pleural space. The history of chronic chylothorax often includes depression, exercise intolerance, inappetance, and weight loss. If an underlying disease exists, the history may be representative of that condition.

Tachypnea or dyspnea with rapid, shallow ventilation, or a restrictive ventilatory pattern, and decreased pulmonary and cardiac sounds on auscultation are usually present in cases of pleural effusion. Cats may demonstrate a "breath holding" type of breathing pattern in which forceful inspiration is followed by delayed exhalation.[9] Lung sounds may be present with increased bronchovesicular sounds dorsally. Chylothorax is rarely unilateral. Other findings include thin body condition, pallor, arrhythmias, cardiac murmurs, or other signs associated with a primary disease. Animals with cranial mediastinal mass

lesions or thrombosis may exhibit cranial vena cava syndrome (i.e. edema of the head, neck, and forelimbs with jugular venous distention).

Diagnostic Imaging

Radiographic evaluation of the dyspneic patient is not advised in a significantly compromised patient. Oxygen supplementation, minimal handling, and dorsoventral and horizontal beam imaging rather than lateral and ventrodorsal views may decrease the stress of imaging. The index of suspicion for fluid in the pleural space must be considered prior to imaging, as therapeutic thoracocentesis can decrease the risk associated with imaging in these patients. Radiographic signs of pleural fluid include effacement of the cardiac and diaphragmatic silhouettes, retraction of the lung borders from the thoracic wall, "scalloping" of the lung edges, pleural fissure lines, rounding of the lungs, widening of the mediastinum, and obscuring of the other intrathoracic structures.[10] The presence of a large amount of fluid decreases the ability to diagnose cardiac, pulmonary, or mediastinal masses and hilar lymphadenopathy. Radiographs should be remade after removal of the thoracic effusion to increase the diagnostic efficacy of thoracic radiographs.

Failure of pulmonary expansion after therapeutic thoracocentesis should alert the clinician to the possibility of fibrosing pleuritis or pulmonary parenchymal disease such as persistent atelectasis, pulmonary neoplasia, or lung lobe torsion. Animals with fibrosing pleuritis often remain dyspneic, despite removal of pleural effusion and confirmation of minimal fluid on thoracic radiographs. Fibrosis of the visceral pleura is thought to be related to the chronic presence of chylous effusion and an alteration in mesothelial cell function, leading to an imbalance in fibrin production and degradation.

Air in the lungs will reflect sound and decrease the generation of ultrasonographic images of intrathoracic structures. Therefore, ultrasound examination of the thorax should be performed prior to removal of all pleural fluid, as the fluid will provide an acoustic window for imaging the mediastinum. Ultrasonography is also used to evaluate cardiac structure and function and to diagnose whether pericardial effusion is present.

Computed tomography (CT) and magnetic resonance imaging (MRI) have been used with success for thoracic evaluation in dogs. Normal anatomic structure has been reported, and CT has been used to evaluate questionable pulmonary and non-pulmonary conditions identified radiographically. Questionable radiographic and ultrasonographic findings should be evaluated with CT to localize and determine the extent of the abnormality. CT has also been used to guide fine needle aspirates (FNA) and percutaneous biopsies of pulmonary and nonpulmonary mass lesions. The complication rate associated with FNA or transcutaneuos biopsy with CT guidance was 43% in one study, and the diagnostic accuracy was 65% for FNA and 83% for biopsy. The main disadvantage of CT and MRI is the need for and risk of general anesthesia in compromised patients. CT and MRI are becoming more available to practitioners, but the cost benefit ratio must be considered prior to their use.

Laboratory Findings

Thoracocentesis with fluid analysis is imperative in every case of pleural effusion. Fluid should be placed in an ethylenediaminetetraacetic acid (EDTA) tube for cell counts and cytological examination. Fluid should also be saved in a serum tube (*i.e.* "clot tube") for biochemical analysis and aerobic and anaerobic culture. Chylous effusion is grossly opaque white or white with a red or pink tinge (Table 43-2).[11,12] The fluid is high in lipid, which may interfere with refractometric quantification of protein. The total nucleated cell count is usually less than 10,000/µL, consisting mainly of small lymphocytes.[4] Lower numbers of macrophages may be present and filled with lipid. With chronicity, lymphocytes may be depleted due to decreased production in the face of continued cell loss to the effusion, nondegenerate neutrophils then become the primary cell type in the effusion. Neutrophils may also be the primary cell type in patients that have undergone multiple thoracocentesis, which may induce pleural inflammation. If the repeated aspirates of pleural fluid result in secondary bacterial colonization and sepsis, degenerate neutrophils appear in the fluid.

Table 43-2. Characterization of Chylous Pleural Fluid in Dogs and Cats

	Dogs	Cats
Specific gravity	1.022-1.037	1.019-1.038
Total Protein (g/dl)	2.5-6.2	3.5-7.8
Average nucleated cells/µL	6,127	11,919

The definitive diagnosis of chylous effusion relies on biochemical testing of the pleural fluid and serum. With chylothorax, triglyceride content of the pleural fluid is higher than that of the serum and cholesterol levels in the pleural fluid is less than that in the serum. Other tests, (*e.g.* ether clearance and Sudan staining for fat) may also be used to diagnose chylous effusion. Concurrent aerobic and anaerobic culture of the fluid are recommended. Psuedochylous effusion, opaque, white fluid devoid of chyle, has been associated with tuberculosis and rheumatoid pleurisy in man but has not been identified in dogs or cats.

Complete blood count, biochemical profile analysis, and urinalysis should be done and may aid in the identification of a primary cause of chylothorax. They may also be useful in monitoring for lymphopenia, hyponatremia, and hyperkalemia, which have been associated with repeated thoracocentesis in the medical management of the condition.[13] Significant protein and fluid loss due to chronic chylous effusion may also be reflected in the patient's biochemical profile and urinalysis. Feline leukemia virus (FeLV), Feline immunodeficiency virus (FIV), and heartworm tests are also recommended to rule out primary disease processes.

Differential Diagnoses

Other causes of cough should be included in the initial differential list if cough is present; however, pleural effusion should be identified early in the evaluation of the patient with chylothorax. Other types of pleural effusion (*e.g.* hemorrhage, transudate, exudate) are ruled out upon fluid analysis. Chylous effusion

may be classified as either a modified transudate or exudate, depending on the reference used to characterize pleural fluid types (See Table 43-2). Primary disease processes that cause chylothorax (See Table 43-1) should be ruled out by diagnostic evaluation including thoracic radiography and ultrasound examination, echocardiography, CBC, biochemical analysis, urinalysis, FeLV, FIV, and heartworm testing, and abdominal radiography and ultrasound. If primary disease conditions are eliminated, the diagnosis of idiopathic chylothorax, which is the most common form of chylothorax, is made.

Medical Management

Any primary condition associated with secondary chylothorax should be treated or the effusion may persist. Treatment of the underlying condition may not, however, guarantee diminution of chyle. Resolution may also take time (*e.g.* months), depending on the primary condition. While treating the primary condition, the accumulation of chyle within the pleural space may be managed with intermittent thoracocentesis as dictated by clinical signs (*e.g.* dyspnea associated with a restrictive breathing pattern). Fluid balance and electrolytes should be monitored for significant alterations secondary to repeated thoracocentesis (described in laboratory findings) and is of more concern in patients requiring frequent fluid removal.[13] Fat soluble vitamins should be added to the diet of patients undergoing prolonged medical management of chylothorax due to the continued loss into the pleural space.[3] Recurrent thoracocentesis may also result in secondary bacterial infection of the fluid, despite the high lecithin content, which is thought to have a bacteriostatic effect.[9] Immunodeficiency has also been hypothesized with the removal of protein and cells by repeated thoracocentesis.

Concurrent dietary changes may alter the fat content of the effusion and improve fluid absorption from the pleural space, thereby decreasing the frequency of thoracocentesis. Low fat diets are therefore recommended in the treatment of idiopathic chylothorax. The fat content of commercially available low fat diets is approximately 6%.[4] Medium chain triglyceride supplementation may not result in improved nutritional status; they may not be directly absorbed into the intestinal venous system as previously hypothesized. Dietary management and fluid removal rarely result in resolution of cases of spontaneous, idiopathic chylothorax.

The addition of different medications has been attempted in an effort to increase the rate of resolution of idiopathic chylothorax. Benzopyrones are compounds extracted from the Brazilian Fava D'anto tree.[14] They have been used to treat lymphedema in people and have been used to treat idiopathic chylothorax in dogs and cats. Their action may decrease vascular leakage, increase protein lysis and absorption, stimulate macrophage function, and increase tissue macrophage numbers. Rutin, a benzopyrone agent (Rutin, Nature's Plus, Melville, NY), resulted in improvement in two of four cats treated, and has been reportedly associated with resolution of the disease in two other case reports.[14-16] The empiric dose of rutin ranges from 50 to 100 mg/kg PO q 8 h.[14] A large clinical trial of its use in dogs and cats with idiopathic chylothorax has not yet been reported, but it is commonly used as part of the medical treatment of chylothorax.

Octreotide (Sandostatin®, Novartis Pharma B.V., Arnhem, the Netherlands) is an experimental agent for the treatment of idiopathic chylothorax. The somatostatin analog has been used to treat chylothorax in people and was associated with a more rapid decline in the amount of pleural chyle following experimental transection of the thoracic duct in dogs.[17] The response to octreotide may be due to inhibition of pancreatic, biliary, and gastric secretions, decreased gastric blood flow, decreased intestinal transit time, and constriction of lymphatic vessels.[17,18] A small therapeutic trial of 10 mg/kg SC q 8 h therapy for 10 to 28 days resulted in resolution of signs in two of three cats. Neither of two dogs treated with octreotide showed a response to therapy.[18] Side effects occurred in two patients and consisted of diarrhea and loose stools.[18] The response of dogs and cats to octreotide has not been investigated investigated in a clinical trial.

Corticosteroid treatment to combat fibrosing pleuritis and furosemide administration to decrease chylous effusion have not been evaluated. Furosemide has not been shown to alter the accumulation of chyle in the pleural space. Its use could result in further fluid loss and dehydration, so it is not recommended for treating chylothorax. Likewise, corticosteroids have not been shown to have any beneficial effect in the treatment of chylothorax, and their use should be reserved for underlying conditions requiring corticosteroid therapy.

It is, however, important to monitor any patient undergoing prolonged medical management for the occurrence of fibrosing pleuritis. Chronic exposure of mesothelial cells to chyle may result in altered fibrin production and degradation.[9] An imbalance of fibrin may result, leading to the deposition of fibrin on the visceral pleura. Fibrosis of the visceral pleura can result in severe lung lobe atelectasis. Radiographic evidence of failure of complete pulmonary expansion following thoracocentesis or dyspnea in the face of minimal pleural effusion should alert the clinician to this problem, which may decrease the prognosis associated with further therapy. Due to the risk of nutritional and fluid imbalance and fibrosing pleuritis, prolonged medical management (beyond 4 to 8 weeks) is not recommended.[3]

Surgical Management

Many surgical techniques have been developed in an attempt to improve the resolution rate of idiopathic chylothorax in dogs and cats, which indicates that the definitive therapy has not been established. Surgical treatment is usually sought in animals with chronic chylothorax despite proper medical management and in cases in which medical therapy becomes impractical. Surgical techniques include mesenteric lymphangiography in conjunction with thoracic duct ligation and pericardectomy, passive or active pleuroperitoneal or pleurovenous shunting, omentalization, and ablation of the cisterna chyli.[19-22] Resolution rates associated with thoracic duct ligation alone range from 53% to 20 to 53% in dogs and cats, respectively.[11,12,23] Concurrent or subsequent pericardectomy may dramatically improve the success rate of thoracic duct ligation to 90%.[2] Both thoracic duct ligation and pericardectomy may be performed with video-assisted thoracoscopic surgery (i.e. thoracoscopy).

Chylothorax resolution rates with omentalization and ablation of the cisterna chyli have not been reported in large numbers of dogs, but these procedures may offer future alternatives for therapy. Redistribution of the effusion into the abdominal cavity or directly into the venous system may be required in cases of persistent chylous or non-chylous effusion after surgery has been attempted and has failed.

Surgical Techniques

Mesenteric Lymphangiography

Mesenteric lymphangiography is recommended prior to ligation of the thoracic duct to provide the surgeon with the number and location of thoracic duct branches. Lymphangiography is repeated after thoracic duct ligation to ensure that all branches have been ligated. If patent branches remain, ligation and lymphangiography should be repeated. An abdominal approach is required, and lymphatic catheterization may be difficult, especially in cats and small dogs. The main disadvantage of lymphangiography is prolongation of surgery time. The other disadvantage is that small thoracic duct branches may remain patent but not fill with contrast material during lymphangiography. The small remaining branches could be a cause for the high failure rate associated with thoracic duct ligation.

Cream (1 to 2 mL/kg) may be fed once an hour for 3 to 4 hours prior to surgery to opacify the lymphatics, making them easier to identify. A right paracostal approach to the abdomen is made in dogs; a ventral midline approach may be made in cats in conjunction with a transdiaphragmatic approach to the thoracic duct.[7] The ileocecocolic region is exteriorized, and the lymphatics evaluated (Figure 43-1). If necessary, a small volume (0.25 to 0.5 mL) of dilute methylene blue dye may be injected into a lymph node to aid in the visualization of efferent lymphatics. Repeated injection of the dye is not recommended, as Heinz body anemia or renal failure may occur.

A 22 to 20-gauge over-the-needle catheter is placed in a lymphatic, secured to the mesentery with suture, and connected to extension tubing preloaded with heparinized saline. The catheter and extension tubing is then sutured to the adjacent segment of intestine to decrease the risk of catheter dislodgement. A three-way stopcock is placed on the end of the extension tubing for contrast injection. Water soluble contrast (1 mL/kg) is diluted 1:1 or 1:0.5 with sterile saline to decrease the viscosity of the solution and ease injection.[2,7,9] Lateral and ventrodorsal radiographs are recommended after injection. Ventrodorsal radiographs should allow visualization of a larger number of thoracic duct branches than lateral views. Alternatively, computed tomography may be done, which allows visualization of the thoracic duct and its branches without superimposition of adjacent structures or further manipulation of the patient.[24] Unfortunately, CT is not available within the surgical suite, making re-evaluation after thoracic duct ligation more difficult. The risk of catheter dislodgement is increased if the patient must be moved to an imaging suite for lymphangiography.

The indwelling lymphatic catheter may also be used for embolization of the thoracic duct with cyanoacrylate.[25] The advantage of embolization is the lack of a thoracic approach and the use of a simple approach to the abdomen. The disadvantages of embolization include thrombosis of the cranial vena cava and embolization of pulmonary artery branches.[25] Positive pressure ventilation may stop migration of cyanoacrylate during its polymerization phase and decrease the risk of embolization of structures other than the thoracic duct.[25] The efficacy of embolization can be evaluated with lymphangiography and repeated if necessary. Thoracic duct embolization, however, has not been studied in a large number of clinical cases.

Standard lymphangiography requires laparotomy and prolongs operative time. A simpler method of injection of the mesenteric lymph nodes with 0.22 mL/kg of aqueous contrast did result in a readable lymphangiogram in four of five dogs if images were made within one to two minutes.[26] The difference between a pressurized lymphatic injection by a catheter and mesenteric lymph node injection is not known.

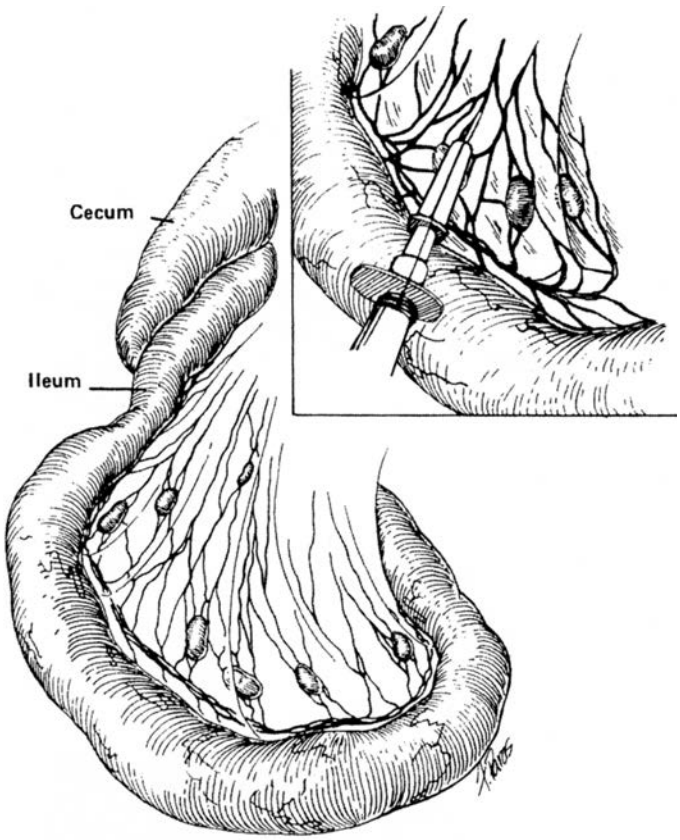


Figure 43-1. Anatomy of the lymphatics adjacent to the cecum and placement of a lymphatic catheter (inset).

Thoracic Duct Ligation

Ligation of the thoracic duct causes new lymphaticovenous anastomoses to form, resolving the effusion and its associated clinical signs.[2-4,7,11-12,23] The thoracic duct should be ligated in the caudal thorax where the fewest number of branches are located. An intercostal thoracotomy is performed on the right side in dogs and on the left side in cats, located at the eighth, ninth, or tenth intercostal space (Figure 43-2). The duct and its branches are located dorsal to the descending aorta and ventral to the azygous vein and sympathetic trunk. The surgeon ligates all branches of

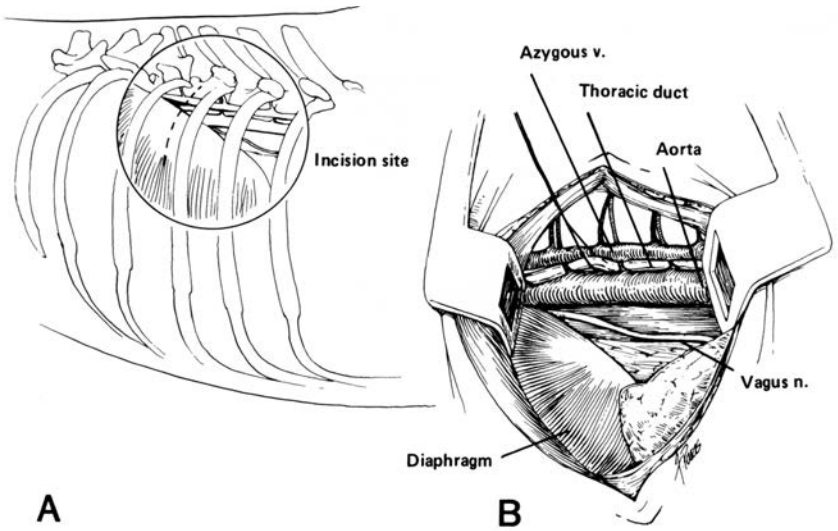


Figure 43-2. Ligation of the thoracic duct. **A.** Right, tenth, lateral intercostal thoracotomy **B.** Anatomy of the structures at the site of ligation.

the thoracic duct with silk (2-0 or 3-0) or hemostatic clips. As with mesenteric lymphangiography, the thoracic duct may be colored by injecting methylene blue dye into the lymphatic catheter or directly into a mesenteric lymph node. Mesenteric lymph node injection reliably colored the canine thoracic duct within ten minutes and lasted up to one hour in one experimental study.[27]

An alternative approach to thoracic duct ligation is to ligate all structures dorsal to the aorta and ventral to the sympathetic trunk, including the azygous vein.[28] Thoracoscopic ligation of the thoracic duct has also been developed in dogs.[29] Portals are placed in the middle of the chest at the ninth intercostal space and at the junction of the dorsal and middle thirds of the chest at the eighth and tenth intercostal spaces.[29] Hemostatic clips are applied to the thoracic duct ventral to the cranial lumbar or caudal thoracic vertebrae, prior to the emergence of the azygous vein into the thorax.[29] With any method of ligation, the area dorsal to the aorta should be completely evaluated for branches of the thoracic duct, some of which may lie further lateral than previously described.

Pericardectomy

Conditions that result in increased hydrostatic pressure may contribute to the accumulation of chyle in the thorax by two mechanisms. Increased hydrostatic pressure may increase the production of lymph in the viscera and caudal body, which will increase the flow of chyle in the thoracic duct.[2] Concurrently, the increased hydrostatic pressure in the cranial vena cava will impede drainage of lymph from the thoracic duct into the venous system. Pericardectomy may decrease venous hydrostatic pressure, decreasing both causes of fluid accumulation.[2] Pericardectomy was described in 20 patients (10 dogs and 10 cats) with idiopathic chylothorax.[2] It was a primary treatment (n=2) or was done in conjunction with thoracic duct ligation in cases with persistent chylous or nonchylous effusion following thoracic duct ligation.[2]

Pericardectomy with thoracic duct ligation resulted in a 90% rate of resolution of effusion in the clinical cases reported.[2] All dogs and eight of ten cats were successfully treated with the combination of the two procedures, which is rapidly becoming the mainstay of therapy for idiopathic chylothorax.[2] Pericardectomy was done by retracting the pericardium into the intercostal thoracotomy used for thoracic duct ligation or by an additional intercostal thoracotomy.[2] Pericardectomy is described in Chapter 42.

Ablation of the Cysterna Chyli

Ablation of the cisterna chyli was developed in an attempt to force lymphaticovenous anastomosis formation within the peritoneal cavity, rather than in the thoracic cavity.[22,30] Ablation of the cisterna chyli was theorized to relieve the increase in lymphatic hydrostatic pressure caudal to the site of thoracic duct ligation, which is a proposed mechanism for collateral lymphatic formation and persistence of pleural effusion following thoracic duct ligation. Thoracic duct ligation alone allows new lymphaticovenous anastomoses to form with the azygous vein, but in dogs that underwent ablation of the cisterna chyli with thoracic duct ligation, the anastomoses formed with the caudal vena cava or phrenicoabdominal vein, mesenteric root, or azygous vein.[30]

Thoracic duct ligation is performed as described above. The cisterna chyli is approached through the abdominal ventral midline.[22,30] The peritoneum adjacent to the left kidney is incised, and perirenal fat dissected until the cisterna is identified ventral to the aorta. Sharp excision of all cisternal membranes is recommended. Seven of eight clinical cases responded to the combination of thoracic duct ligation and ablation of the cisterna chyli.[22] Pancreatitis complicated one case but no other significant complications were noted.[22]

Omentalization of the Thorax

The omentum is an organ that has been used in the treatment of chronic wounds, abscesses, cystic structures. Omentum provides a rich network of blood and lymphatic vessels for healing and presumably a large surface area for the absorption of fluid and obstruction of vascular leakage. The function of the omentum in the treatment of chylothorax is unknown; its lymphatic drainage is via the thoracic duct. Omental advancement through the

diaphragm has been associated with a positive outcome in one dog and one cat with idiopathic chylothorax.[20,21]

Pleuroperitoneal or Pleurovenous Shunting

Persistent chylous or nonchylous effusion following surgical treatment for idiopathic chylothorax may respond to pleuroperitoneal or pleurovenous shunt placement. (Figure 43-3) A commercially available shunt utilizes a one-way, manually compressed pump to move fluid from the pleural space into the peritoneal cavity or the venous system.[19] Although seemingly more physiologically sound, pleurovenous shunting can cause major venous, right atrial, or right ventricular thrombus formation. Peritoneal fluid accumulation is well tolerated by veterinary patients, so pleuroperitoneal shunt placement is more commonly performed.[4] Pre-existing peritoneal conditions that could prevent fluid absorption are a contraindication for pleuroperitoneal shunt placement.

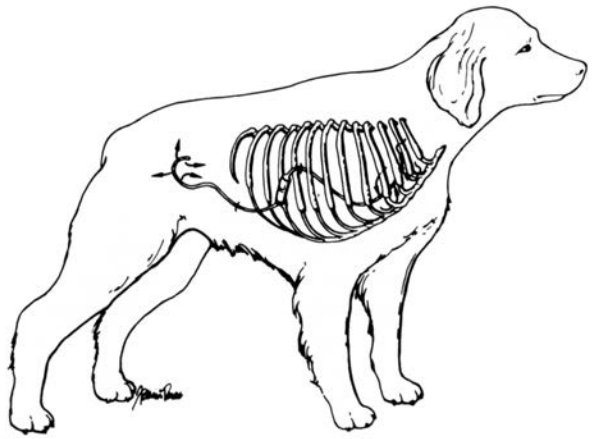


Figure 43-3. Placement of a pleuroperitoneal shunt. (From Smeak DD, et al. Management of intractable pleural effusions in the dog with pleuroperitoneal shunt. Vet Surg 1987;16:212.)

The shunt catheter consists of an afferent portion, pump chamber, and efferent limb. The entire system is placed in heparinized saline and filled until no air bubbles are present. A small thoracotomy incision is made over the sixth, seventh, or eighth intercostal space.[4] The afferent limb is placed in the chest, and a tunnel is made in the subcutis through which the efferent limb is passed, allowing the pump chamber to lie over and be secured to the ribs.[4] Securing the chamber to the adjacent ribs allows postoperative compression of the chamber for pleural evacuation. The efferent limb is introduced into the peritoneal cavity through a small skin incision and pursestring suture in the abdominal musculature.[4] Alternatively, the efferent limb is tunneled over the shoulder and into the caudal cervical region, and the efferent limb is introduced into the jugular vein. The efferent limb should be inserted no further than the cranial vena cava. Alternate venous insertion sites include the caudal vena cava or azygous vein.

Unfortunately, many complications have been associated with shunting of pleural fluid including obstruction of the catheter by clot or kink formation, dislodgement of the pump chamber from the thorax, severe abdominal distention, pyothorax, peritonitis, and pleural compartmentalization.[19] The pump chamber moves 1mL of fluid with each compression and may cause patient discomfort and poor client compliance due to the amount of care required to maintain pleural evacuation. These complications may result in shunt removal, replacement, or patient euthanasia.[19]

Postoperative Care

Patients should be monitored closely for complications associated with thoracotomy and or laparotomy. The need for fluid evacuation postoperatively is dependent on clinical signs and laboratory evaluation of ventilation. Resolution of pleural fluid accumulation following surgery should be monitored, as recurrent chyle accumulation or accumulation of a modified transudate may complicate recovery. Lung lobe torsion has also been associated with chylothorax or other pleural effusions.[31] Chronic chylous effusion may also result in fibrosing pleuritis and dyspnea despite evacuation of fluid.

References

1. Bezuidenhout AJ: The lymphatic system In Evans HE, ed.: Miller's Anatomy of the Dog. Philadelphia: WB Saunders Co., 1993, p 717.

2. Fossum TW, Mertens MM, Miller MW, et al.: Thoracic duct ligation and pericardectomy for treatment of idiopathic chylothorax. J Vet Intern Med 18:307, 2004.

3. Birchard SJ, Smeak DD, McLoughlin MA. Treatment of idiopathic chylothorax in dogs and cats. J Amer Vet Med Assoc 212:652, 1998.

4. Fossum TW: Small Animal Surgery. St. Louis: Mosby, Inc., 2002, 788.

5. Holt JC. A review of traumatic chylothorax with a case report of spontaneous remission in a dog. Aust Vet Pract 8:135, 1978.

6. Hodges CC, Fossum TW, Evering W. Evaluation of thoracic duct healing after experimental laceration and transaction. Vet Surg 22:431, 1993.

7. Birchard SJ, Cantwell HD, Bright RMI. Lymphangiography and ligation of the canine thoracic duct: a study in normal dogs and three dogs with chylothorax. J Amer Anim Hosp Assoc 18:769, 1982.

8. Bilbrey SA, Birchard SJ. Pulmonary lymphatics in dogs with experimentally induced chylothorax. J Amer Anim Hosp Assoc 30:86, 1994.

9. Fossum TW. Feline chylothorax. Comp Cont Ed Pract Vet 15:549, 1993.

10. Suter PF. Thoracic Radiography: A Text Atlas of Thoracic Diseases of the Dog and Cat, With Contributions by Peter F. Lord. Wettswil, Switzerland : P.F. Suter, 1984, 683.

11. Birchard SJ, Smeak DD, Fossum TW. Results of thoracic duct ligation in dogs with chylothorax. J Amer Vet Med Assoc 193:68, 1988.

12. Fossum TW, Forrester SD, Swenson CL, et al. Chylothorax in cats: 37 cases (19691989). J Amer Vet Med Assoc 198:672, 1991.

13. Willard MD, Fossum TW, Torrance A, et al. Hyponatremia and hyperkalemia associated with idiopathic or experimentally induced chylothorax in four dogs. J Am Vet Med Assoc. 199:353, 1991.

14. Thompson MS, Cohn LA, Jordan RC. Use of rutin for medical management of idiopathic chylothorax in four cats. J Am Vet Med Assoc 215:345, 1999.

15. Gould L. The medical management of idiopathic chylothorax in a domestic long-haired cat. Can Vet J. 45:51, 2004.

16. Kopko SH. The use of rutin in a cat with idiopathic chylothorax. Can Vet J. 46:72, 2005.

17. Markham KM, Glover JL, Welsh RJ, et al. Octreotide in the treatment of thoracic duct injuries. Am Surg. 66:1165, 2000.

18. Sicard GK, Hardie RJ, Hayashi K, et al. The use of a somatostatin analogue (Octreotide) for the treatment of idiopathic chylothorax in dogs and cats. Vet Surg 32:496, 2003.

19. Smeak DD, Birchard SJ, McLoughlin MA, et al. Treatment of chronic pleural effusion with pleuroperitoneal shunts in dogs: 14 cases (1985-1999). J Am Vet Med Assoc. 219:1590, 2001.

20. Lafond E, Weirich WE, Salisbury SK. Omentalization of the thorax for treatment of idiopathic chylothorax with constrictive pleuritis in a cat. J Am Anim Hosp Assoc. 38:74, 2002.

21. Williams JM, Niles JD. Use of omentum as a physiologic drain for treatment of chylothorax in a dog. Vet Surg. 28:61, 1999.

22. Hayashi K, Sicard G, Gellasch K, et al. Cisterna chyli ablation with thoracic duct ligation for chylothorax: results in eight dogs. Vet Surg. 34:519, 2005.

23. Kerpsack SJ, McLoughlin MA, Birchard SJ, Smeak DD, Biller DS. Evaluation of mesenteric lymphangiography and thoracic duct ligation in cats with chylothorax: 19 cases (1987-1992). J Am Vet Med Assoc. 205:711, 1994.

24. Esterline ML, Radlinsky MG, Biller DS, et al. Comparison of radiographic and computed tomography lymphangiography for identification of the canine thoracic duct. Vet Radiol Ultrasound. 46:391, 2005.

25. Pardo AD, Bright RM, Walker MA, Patton CS. Transcatheter thoracic duct embolization in the dog. An experimental study. Vet Surg. 18:279. 1989.

26. Brisson BA, Holmberg DL, House M. Comparison of mesenteric lymphadenography performed via surgical and laparoscopic approaches in dogs. Am J Vet Res 67:168, 2006.

27. Enwiller TM, Radlinsky MG, Mason DE, Roush JK. Popliteal and mesenteric lymph node injection with methylene blue for coloration of the thoracic duct in dogs. Vet Surg. 32:359, 2003.

28. Orton EC. Small Animal Thoracic Surgery. Baltimore: Williams & Wilkins, 1995, 95.

29. Radlinsky MG, Mason DE, Biller DS, et al. Thoracoscopic visualization and ligation of the thoracic duct in dogs. Vet Surg. 31:138, 2002.

30. Sicard GK, Waller KR, McAnulty JF. The effect of cisterna chyli ablation combined with thoracic duct ligation on abdominal lymphatic drainage. Vet Surg. 34:64, 2005.

31. Neath PJ, Brockman DJ, King LG. Lung lobe torsion in dogs: 22 cases (1981-1999). J Am Vet Med Assoc. 217:1041, 2000.

Transdiaphragmatic Approach to Thoracic Duct Ligation in Cats

Robert A. Martin

This technique is one of several surgical procedures used in an attempt to disrupt the flow of abdominal lymph drainage through the thoracic duct system in cats; it is specifically aimed at resolving chylothorax when no identified underlying cause can be found. Occlusion of the thoracic duct system results in the formation of alternate abdominal lymphaticovenous communications to return chyle to the circulation.[1] After a ventral midline celiotomy, a left transdiaphragmatic thoracotomy exposes the thoracic duct system for occlusion with hemostatic clips.[1] The procedure allows vital staining and immediate ligation of the thoracic duct system through a single body wall incision. The technical description of the procedure follows.

Surgical Technique

The cat is placed in dorsal recumbency, and the abdomen is prepared for aseptic surgery. A ventral midline incision is made from the xiphoid cartilage caudal to the umbilicus. The jejunum, ileum, and ascending co-Ion are identified and are exteriorized to locate the mesenteric lymph nodes. A more caudal lymph node is selected, usually the right colic, for injection of 1% Evans blue solution (Sigma Chemical Co., St. Louis, MO). Direct puncture with a 25-gauge needle on a 1-mL syringe is used to deliver 0.1 to 0.2 mL of dye into the selected node. A dry surgical sponge is used to contain any leakage of dye on removal of the needle, thus minimizing abdominal contamination. Lymphatic

drainage of the injected dye is immediate. By retracting the descending duodenum ventrally and to the left, the stained intestinal lymphatic trunk is easily visualized as it courses through the duodenal mesentery dorsally toward the cisterna chyli. The transparent wall of the intestinal trunk is covered by visceral peritoneum, which can be delicately dissected away to improve the ease of cannulation of the intestinal trunk with a 22-gauge, over-the-needle catheter (Jelco intravenous catheter x 1 inch, Johnson & Johnson, Inc., Arlington, TX). After stylet removal, spillage of dye from the catheter should be contained by capping the catheter either with an injection cap (PRN Adapter, Becton Dickinson Vascular Access, Sandy, UT) or by attaching the 1-mL syringe containing the Evans blue solution. The catheter is fixed to the mesoduodenum with circumferential ligatures of small-diameter suture material (4-0 or 5-0), and the viscera are returned to the abdomen. Gentle manipulation of viscera minimizes disruption of the catheter.

The left side of the diaphragm is identified by retracting the stomach and left liver lobes caudomedi-ally. A left transdiaphragmatic thoracotomy is performed by incising the diaphragm from a point 2 cm dorsolateral to the xiphoid cartilage dorsally toward the left diaphragmatic crus until adequate exposure of the caudal thoracic aorta is achieved. By curving the diaphragmatic incision to parallel the costal arch, the medial portion of the incised diaphragm can more readily be used as a retractor to contain and displace the abdominal viscera caudomedially. Several stay sutures in the medial margin of the diaphragmatic incision are used for retraction.

The left caudal lung lobe is displaced cranially with a moistened sponge to expose the caudal thoracic aorta. The thoracic duct system should be identified in the areolar tissues surrounding the aorta by its staining from the previously injected Evans blue solution. An additional injection through the catheter in the intestinal trunk may be necessary to improve visualization of the thoracic duct branches. The thoracic aorta is dissected from the thoracic duct system just cranial to the aortic hiatus of the diaphragm. The least number of branches of the thoracic duct system is present for ligation at this location.[2] The aortic dissection is performed by beginning directly along its ventral ad-ventitia to minimize disruption of any of the thoracic duct branches, which are incorporated in areolar tissue dorsally and laterally. A moistened umbilical tape is passed around the aorta, which is then retracted ventrally to expose the stained thoracic duct

system completely within the mediastinal tissues. Contraction of aorta occurs during dissection and retraction. Without immobilization of the thoracic aorta by complete circumferential dissection and isolation, complete exposure to the thoracic duct system cannot be achieved consistently.

Multiple hemostatic clips (Hemoclip [medium], Edward Week, Inc., Research Triangle Park, NC) are used to mass ligate any visible thoracic duct branches, without an attempt to isolate individual ducts before ligation. Usually, a single duct arising from the cranial pole of the cisterna chyli abdominally passes through the diaphragm and gives rise to one or two main thoracic branches, which can be identified at this site along with occasional minor collateral branches.[2] A major thoracic duct branch courses on the left dorsolateral aspect of the thoracic aorta. Looping collateral branches or a major or minor thoracic duct may be identified along the right dorsolateral aspect of the thoracic aorta, and multiple cross-communications between longitudinal ducts usually exist more cranially. The number of cross-communications increases cranial to the preferred site of ligation (Figure 43-4), which is just cranial to the aortic hiatus of the diaphragm (ventral to T13). The paired sympathetic trunks that lie lateral to the thoracic duct system should not be included in the ligation.

After thoracic duct system ligation, a second injection of dye into the intestinal trunk catheter is performed to highlight any collateral branches at the site of ligation that may have been unidentified but require ligation. The moistened sponge on the left caudal lung lobe is removed, and the lobe is reinflated. The thorax is lavaged with warm balanced electrolyte solution, and all fluid is removed from the thorax with suction. The diaphragm is closed in a simple continuous suture pattern dorsally to ventrally with 3-0 monofilament absorbable suture material. Thoracentesis may be performed through diaphragmatic puncture or through a previously placed thoracostomy tube until negative intrathoracic pressure is established. The abdominal lymphatic catheter is removed, and two-layer or three-layer abdominal closure is performed.

Postoperative Care

Postoperatively, a thoracostomy tube is maintained for 24 hours or until thoracic effusion becomes minimal. The success of the procedure is determined by resolution of the chylothorax without recurrence. Perioperative antibiotics are indicated and should be continued until after the thoracostomy tube is removed. Frequent short-term follow-up evaluations are indicated to monitor the cat for recurrent thoracic effusion.

References

1. Martin RA, Richards DLS, Barber DL, et al. Sunt E. Transdiaphragmatic approach to thoracic duct ligation in the cat. Vet Surg 1988;17:22-26.

2. Martin RA, Barber DL, Richards DLS, et al. A technique for direct lymphangiography of the thoracic duct system in the cat. Vet Radiol 1988;29:116-121.

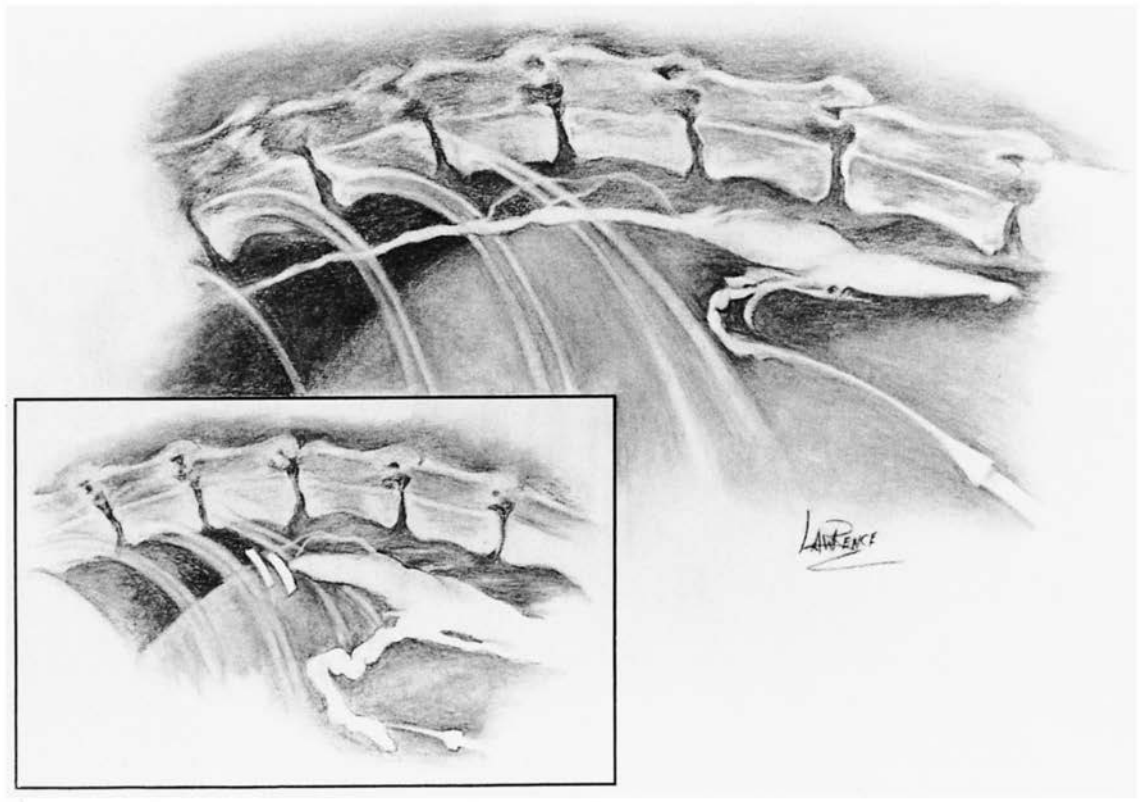


Figure 43-4. A lymphangiogram of the cisterna chyli and thoracic duct system in the caudal thorax. Note the possible small collateral branches coursing through the diaphragm dorsal to the major duct. Inset: the correct location of hemostatic clip mass ligation at a point immediately below thoracic vertebra 13.

Lymph Node Biopsy

MaryAnn Radlinsky

Indications

Lymph node biopsy is indicated to evaluate persistent lymphadenopathy, determine if a neoplastic process is present, and to aid in the diagnosis of vague clinical signs associated with systemic disease. Lymphadenopathy may or may not be present; normal sized lymph nodes may still be involved in a disease process. The presence of metastasis for staging of disease or for definitive diagnosis of the type of neoplasia, as in lymphosarcoma, are common reasons for lymph node biopsy. Lymph nodes may also be sampled for the diagnosis of infectious disease or immune mediated conditions.[1-3] Non-diagnostic lymph node fine-needle aspirates (FNA) are also an indication for node biopsy. Peripheral lymph node biopsy is a simple and quick procedure with few complications. The information gained outweighs the risk of the procedure, which can be performed by needle, incision, or excision. Lymph node biopsy during open procedures such as laparotomy or thoracotomy rarely increases the risk associated with the approach or primary disease process. The information obtained may be extremely important for cancer staging and providing an accurate prognosis for the owner. For example, the survival time in dogs with bronchogenic carcinoma of the lung is markedly decreased for patients with lymph node metastasis at the time of surgery.[4] Excisional lymph node biopsy may be indicated to decrease tumor burden prior to adjuvant chemotherapy, (*e.g.* malignant melanoma), to decrease tumor activity (*e.g.* insulinoma, mast cell tumor), or if the nodes are causing clinical signs because of their size (*e.g.* colorectal compression caused by medial iliac lyphadenopaty).

Contraindications and Complications

Contraindications to lymph node biopsy are rare. A complete evaluation of the patient should be performed prior to sedation or general anesthesia for lymph node sampling. Hemorrhage is one potential complication of lymph node biopsy with needle, incisional, or excisional techniques. Animals with coagulopathies should have the disorder corrected by administration of plasma, a blood transfusion, or vitamin K therapy prior to surgery.

Lymph nodes may have a generous blood supply, and vessels should be carefully ligated as necessary during the procedure. Specific lymph nodes such as the medial iliac, hypogastric, and hepatic lymph nodes are anatomically associated with large blood vessels. The external and internal iliac vessels and the portal vein are adjacent to the lymph nodes and trauma to those vessels can lead to significant hemorrhage. Complete excision of the mesenteric lymph node(s) may be difficult due to the risk of compromise to the blood supply of the bowel. Edema is rarely a complication of lymph node biopsy.[5]

Biopsy Techniques

Selecting a Biopsy Site

Physical examination or the anatomic location of disease usually dictates which lymph nodes are selected for biopsy. The superficial lymph nodes are easiest to sample from patients with generalized lymphadenopathy or unexplained systemic illness (Figure 43-5). The popliteal and mandibular lymph nodes are easily palpated and sampled in patients with normal sized lymph nodes. The mandibular lymph nodes may display reactive hyperplasia due to constant exposure to exogenous antigens of the oral cavity and although they are readily palpated and approached for biopsy, they may not be representative of the condition present.[6] The same is true for lymph nodes draining the gastrointestinal tract. Normal inguinal and superficial cervical, or prescapular, lymph nodes may also be sampled if necessary, but are not as easily approached. A single approach for the lymph nodes draining the head, parotid, mandibular, retropharyngeal areas, has been described for the staging of maxillofacial neoplasms.

The lymph nodes draining an abnormal site or lesion should be sampled in any case requiring lymph node biopsy. Therefore, the regional lymphatic anatomy should be considered prior to biopsy. A detailed description of lymphatic anatomy should be consulted if the anatomy is not readily apparent. Alternative methods of determining lymph node drainage of a particular site include magnetic resonance imaging and computed tomography following injection of contrast material into the affected region.[7] Advanced imaging methods with coloration of the lymph nodes and scintigraphic identification of sentinel lymph nodes have not been widely used in veterinary patients.

The drainage areas for specific superficial lymph nodes should be considered prior to lymph node biopsy. The *parotid lymph nodes* drain the nasal planum, skin, and subcutis of the frontal and temporal regions and many of the muscles of the ear and head. Drainage from the parotid lymph nodes is to the retropharyngeal lymph nodes. The *mandibular nodes* drain the nose, lips, superficial muscles of the head, and parts of the tongue, oral cavity, and pharynx. Efferent lymphatics from the mandibular lymph nodes proceed to the retropharyngeal lymph nodes. The *superficial cervical lymph nodes* drain the skin and subcutis of the caudal head, thoracic cavity, neck, shoulder, and portions of the thoracic limb. Drainage from the superficial cervical lymph nodes is to the right lymphatic duct, thoracic duct, or directly into the jugular vein. The *axillary lymph nodes* drain an area similar to but extending more caudal to the drainage area of the superficial cervical lymph nodes. The axillary lymph nodes also drain portions of the thoracic limb and cranial mammary glands. Efferent lymphatics from the axillary lymph node drain to the right lymphatic duct, thoracic duct, tracheal duct, or external jugular vein. The *inguinal lymph nodes* drain the skin and subcutis of the ventrolateral trunk, pelvic and tail areas, medial and lateral thigh, perineum, and caudal mammary glands. The drainage from the inguinal lymph nodes proceeds to the external iliac lymph node. The *popliteal lymph nodes* drain the majority of the pelvic limb structures, mostly distal to the location of the lymph node. Efferent lymphatics go to the inguinal and external iliac lymph nodes.[8,9]

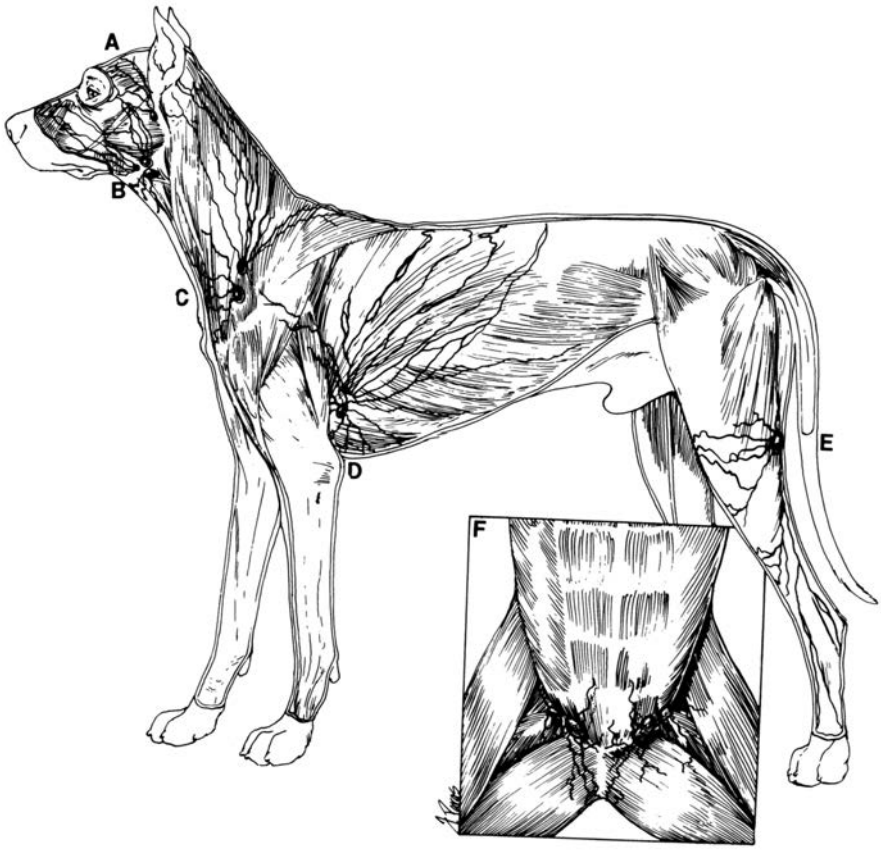


Figure 43-5. Superficial lymph nodes in the dog. *A.* Parotid lymph node *B.* Mandibular lymph node *C.* Superficial cervical lymph node *D.* Axillary lymph node *E.* Popliteal lymph node *F.* Inguinal lymph nodes.

Fine-Needle Aspiration (FNA)

Any of the superficial lymph nodes that can be palpated and stabilized can be aspirated. Sedation or anesthesia is usually not required, nor is skin preparation necessary. The only equipment needed is glass slides, a 10 or 12 cc syringe, and 22 to 25 gauge needle. Two methods of aspiration exist. One technique uses suction generated by the needle and syringe, the other does not. The lymph node is grasped, and the needle placed within the parenchyma. If suction is used, 8 to 10 cc of suction is generated. The needle is carefully redirected within the lymph node and suction reapplied. Discontinue the procedure if blood appears in the hub of the needle. Release suction prior to withdrawal of the needle from the lymph node. The needle should be removed from the syringe, and 5 cc of air is aspirated into the syringe, the needle is replaced on the syringe, and the material in the needle is immediately sprayed onto a clean glass slide.

If suction is not used, stabilize the lymph node by palpation and insert the needle into the parenchyma. The needle is redirected multiple times; discontinue the procedure if blood appears in the hub of the needle. Fivecc of air is aspirated into a 12 cc syringe, the needle is applied to the end of the syringe, and the material is sprayed onto a clean glass slide. With either procedure, the contents of the needle must be sprayed onto a clean glass slide immediately, and a vertical or horizontal squash preparation made. Only gentle pressure is used to make the smears, as lymph node tissue is extremely fragile; cellular and nuclear damage will interfere with interpretation of the cytology. Wright's stain is applied to evaluate the smears.[10]

Tru-Cut Biopsy

Enlarged lymph nodes can be biopsied with a 14 to 16 gauge Tru-Cut needle, which supplies a cylindrical core of tissue. This method may be used for sampling superficial lymph nodes in cases in which a diagnosis is not apparent on fine needle aspiration cytology and can often be performed under sedation. The lymph node is stabilized by hand, and a stab incision made in the skin over one end of the lymph node. The needle is introduced into the lymph node so that the sampling chamber will ideally remain in nodal tissue only during the biopsy process. Automated or manual biopsy needles are available.

Incisional Biopsy

An incisional biopsy requires a surgical approach to the lymph node and removal of a wedge of tissue for biopsy. Incisional biopsies are usually done on lymph nodes that are difficult to completely excise without consequences, as with mesenteric lymph nodes, and are achieved with stabilization of the lymph node. Superficial lymph nodes are approached by a skin and subcutaneous incision and muscular dissection as needed to expose the lymph node. A wedge of lymph node is excised using a number 15 scalpel blade. The wedge is oriented transverse to the long axis of the lymph node and is removed with minimal handling to avoid damaging the architecture of the specimen. The defect is closed with small (3-0 to 4-0) absorbable suture in a horizontal mattress pattern for hemostasis (Figure 43-6). The approach is closed routinely. Impression smears of the biopsy sample can be made prior to placing the sample in formalin.

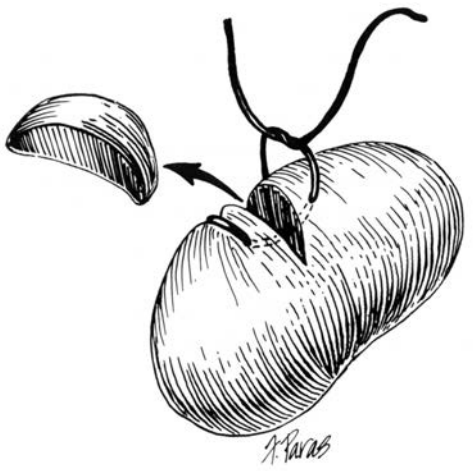


Figure 43-6. Incisional biopsy of a lymph node. The sample is oriented transverse to the longitudinal axis of the lymph node, and closure is achieved with a horizontal mattress suture.

Ideally, the surface is blotted dry with absorbent paper, and the cut surface is lightly pressed against a clean glass slide; care should be taken to not damage the biopsy specimen during any part of the process. Fungal or bacterial cultures may also be obtained prior to fixation.

Excisional Biopsy

Superficial lymph nodes may be excised with heavy sedation and local anesthetic depending on the patient's temperament and physical status. General anesthesia for superficial lymph node extirpation is recommended in most patients and is required for deep, abdominal, or thoracic lymph node excision. For superficial lymph nodes, the node is palpated and stabilized with external pressure toward the skin surface. An incision is made longitudinally over the lymph node, and blunt dissection is used to mobilize the node. Afferent vessels may or may not require ligation; more frequently hilar vessels are ligated.[8] Deep, abdominal, or thoracic lymph nodes are evaluated during surgical exploration. Care is taken when dissecting the lymph nodes from surrounding structures, particularly nerves and vessels. Hemostasis is achieved with ligation and electrocautery in most cases, however, collateral damage to the lymph node can occur if cautery is applied close to the nodal surface.

The lymph node should be handled carefully to avoid structural damage. Samples may be collected for fungal and bacterial culture, and the lymph node may be sectioned for impression smears. The sample should be placed in an adequate volume of 10% formalin for processing.

References

1. Manna L, Vitale F, Reale S, *et al.*: Comparison of different tissue sampling for PCR-based diagnosis and follow-up of canine visceral leishmaniosis. *Vet Parasitol* 125:251, 2004.

2. Barrouin-Melo SM, Larangeira DR, Trigo J, *et al.*: Comparison between splenic and lymph node aspirations as sampling methods for the parasitological detection of *Leishmania chagasi* infection in dogs. *Mem Inst Oswaldo Cruz* 99:195, 2004.

3. Mylonakis ME, Koutinas AF, Billinis C, *et al.*: Evaluation fo cytology in the diagnosis of acute canine ehrlichiosis *(Erlichia Canis)*: a comparison between five methods. *Vet Microbiol* 91:197, 2003.

4. McNiel EA, Ogilvie GK, Powers BE, *et al.*: Evaluation of prognostic factors for dogs with primary lung tumors: 67 cases (1985-1992). *J Am Vet Med Assoc* 211:1422, 1997.

5. Soran A, Aydin C, Harlak A, *et al.*: Impact of sentinel lymph node biopsy on lymphedema following breast cancer treatment. *The Breast* J 11:370, 2005.

6. Perman V, Stevens JB, Alsaker R, *et al.*: Lymph node biopsy. *Vet Clin North Amer* 4:281, 1974.

7. Suga K, Yuan Y, Ueda K, *et al.*: Computed tomography lymphography with intrapulmonary injection of iopamidol for sentinel lymph node localization. *Invest Radiol* 39:313, 2004.

8. Fossum TW. Lymph node biopsy *In* Bojrab MJ, ed.: Current Techniques in Small Animal Surgery. Philadelphia, Williams & Wilkins, 1998, p 703.

9. Rogers KS, Barton CL, Landis M. Canine and feline lymph nodes. Part I. Anatomy and function. *Comp Cont Ed Pract Vet* 15:397, 1993.

10. Rogers KS, Barton CL, Lnadis M. Canine and feline lymph nodes. Part II. Diagnostic evaluation of lymphadenopathy. *Comp Cont Ed Pract Vet* 15:1493, 1993.

Chapter 44

Spleen

Surgery of the Spleen

Dale E. Bjorling

Introduction

The spleen is suspended in a portion of the greater omentum (the gastrosplenic ligament) that extends from the diaphragm, fundus, and greater curvature of the stomach to the spleen.[1] The splenic artery arises from the celiac artery and supplies branches to the left lobe of the pancreas as it courses to the splenic hilus (Figure 44-1). The splenic artery divides into a dorsal and a ventral branch several centimeters from the spleen. The dorsal branch continues to the dorsal portion of the spleen, where it gives off the short gastric arteries. The left gastroepiploic artery arises from the ventral branch of the splenic artery before it contacts the spleen. Venous drainage from the spleen is through the portal vein.

The spleen contains smooth muscle and is innervated by both sympathetic (from the celiac plexus) and parasympathetic (from the vagus) nerve fibers. The spleen also has a considerable population of adrenergic receptors that control contraction and relaxation.[2]

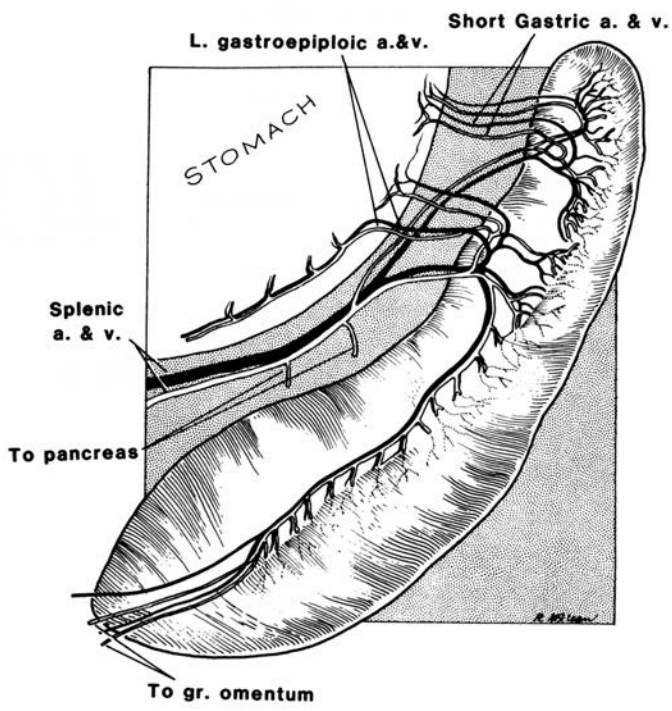


Figure 44-1. Vasculature of the spleen. The splenic artery and its branches give off vessels that supply the pancreas and the greater curvature of the stomach.

Multiple spleens are uncommon in dogs, but trauma may result in the widespread dissemination of splenic tissue throughout the abdomen. Such fragments of splenic tissue become revascularized, and the resultant condition (splenosis) may be confused with neoplasia. Intentional splenic reimplantation during surgery has been recommended as a means of salvaging splenic function,[3] but the mere presence of tissue of splenic origin does not ensure that normal splenic function will be maintained.[4,5]

The spleen may have white fibrin deposits or siderotic plaque on its surface. Siderotic plaque consists of iron and calcium deposits and is brown or rust colored. This appearance should not be considered abnormal. Similarly, splenic nodules (areas of benign hyperplasia) may be confused with neoplasia. Distinguishing splenic nodular hyperplasia from neoplasia may be difficult without a biopsy. The size of the spleen is variable, and the spleen may appear abnormally large during barbiturate anesthesia or when it is relaxed during minimal adrenergic stimulation. Anemia, blood loss and stress all cause the spleen to contract.

The spleen has several functions: blood storage, blood filtration and phagocytosis of particles, parasites, bacteria, and damaged or aged red blood cells; contributions to the body's immune defenses; hematopoiesis; and iron metabolism. The spleen may retain as much as 10% of the total red blood cell mass[6,7] that can be discharged into the general circulation in response to adrenergic stimulation during stress or blood loss. The structure of the spleen places red blood cells in close contact with macrophages; therefore, red cells that are damaged, contain parasites, or have immunoglobulins attached to the surface are removed from circulation in the spleen. The spleen also appears to remove blood-borne bacteria efficiently.[8] It produces immunoglobulins (particularly I gM) and opsonins, as well.[9] Although not reported in animals, overwhelming sepsis after splenectomy has occurred in human patients.[10] Hematopoiesis is not a significant function of the spleen in adult animals, unless it is necessitated by decreased function of the bone marrow. Iron is extracted from hemoglobin as red blood cells are broken down and is stored in the spleen for future transport to the bone marrow for production of more hemoglobin.

Indications

Indications for removal of the spleen include neoplasia, torsion of the splenic pedicle (isolated or in conjunction with gastric dilatation volvulus), and severe traumatic injuries. Splenectomy has been recommended as adjunctive treatment for immune mediated thrombocytopenia and hemolytic anemia unresponsive to medical therapy.[11] The spleen is often removed in dogs used as blood donors to prevent undetected infection with Haemobartonella canis or Babesia canis. Because the spleen has several functions, partial splenectomy should be considered (when feasible) to retain functional splenic tissue.

Hemangiosarcoma is the most common primary tumor of the spleen. Other tumors of the spleen include hemangioma, leiomyosarcoma, fibrosarcoma, lymphosarcoma, plasma cell sarcoma, mast cell sarcoma, and reticular cell sarcoma. Euthanasia of an

animal should not be recommended to an owner solely because of the presence of a splenic tumor. Splenectomy prevents intra abdominal bleeding subsequent to rupture of the tumor, and mean survival times of at least 4 to 6 months in the dog[12,13] and longer in the cat[14] may be expected after splenectomy for hemangiosarcoma. Removal of the spleen for treatment of splenic leiomyosarcoma in dogs resulted in a median survival of 10 months.[15] The spleen may also be enlarged because of infiltration with mast cells in association with feline systemic mastocytosis. Splenectomy appears to improve the duration of survival in affected cats.[16]

Determining when irreversible splenic injury has occurred after torsion of the splenic pedicle is difficult. The onset of clinical signs may be insidious or peracute, necessitating emergency surgery.[17] Occlusion of the splenic vein causes vascular stasis, and the vessels ultimately become thrombosed. If the spleen is engorged and blue black, or if thrombi are observed within the vasculature, the spleen should probably be removed. Untwisting the splenic pedicle to restore circulation may release toxic byproducts of anaerobic metabolism.

Preoperative Considerations

Intravenous fluid administration should begin before, and should continue during and after, splenectomy. The rate of administration and total volume given depend on the animal's condition. If the hematocrit is low (less than 18 to 20%), a transfusion of whole blood or packed red blood cells before surgery should be considered. Although a certain percentage of the red cell mass is removed with the spleen, this volume of cells does not contribute to the peripheral hematocrit at the time of the surgical procedure. Removal of the spleen, however, has a negative effect on the body's ability to compensate for subsequent blood loss. The presence of a splenic tumor is an indication that the patient should be evaluated thoroughly to detect primary tumors or other sites of metastasis that would diminish the animal's ability to tolerate anesthesia and surgery or would decrease its life span after surgery.

Surgical Techniques

Splenorrhaphy

Superficial lacerations of the capsule of the spleen may be closed with sutures. If hemorrhage from the splenic wound is brisk, the injured tissue can be devascularized by ligation of the arteries supplying the wounded area near their junction with the spleen (Figure 44-2A and B.). This tissue does not remain ischemic, and collateral circulation develops within 3 weeks.[18] Large isolated arteries within the splenic parenchyma that have been injured can be individually ligated. The splenic capsule is closed with 3-0 or 4-0 absorbable suture swaged onto an atraumatic needle in an interrupted or continuous pattern (Figure 44-2C). It may be necessary to close the defect in the spleen with an interrupted or continuous horizontal mattress suture pattern placed in the splenic parenchyma to control hemorrhage. Pressure may be applied to the surface of the spleen to control continued hemorrhage, or the omentum may be wrapped around the spleen. If complete hemostasis cannot be achieved, a partial or total splenectomy should be performed.

Partial Splenectomy

A portion of the spleen can be removed for biopsy purposes or to treat localized splenic trauma or abscessation. A partial splenectomy can be performed with sutures or a mechanical stapling device. The vascular supply of the area to be removed is isolated, ligated, and divided. The tissue to be removed soon assumes an ischemic appearance. The parenchyma is compressed between the fingers along the proposed line of excision. Two pairs of forceps are applied to the spleen approximately 1 to 2 cm apart (Figure 44-3A). Atraumatic forceps (large, straight vascular forceps or Doyen intestinal forceps) should be applied to the splenic remnant to be retained; crushing forceps may be applied to the portion to be excised. The spleen is completely incised between the two forceps approximately 3 to 5 mm from the atraumatic forceps. The capsule is closed with 3 0 or 4 0 absorbable suture in a simple continuous pattern, and the forceps are removed (Figure 44-3B). A second suture line is placed

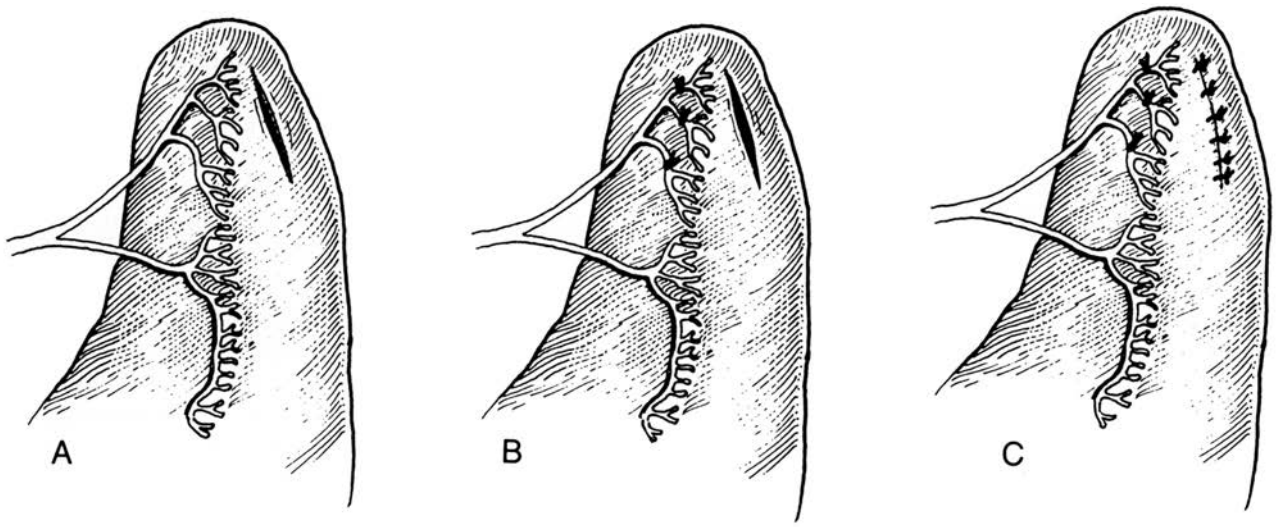


Figure 44-2. A. Laceration of the spleen. **B.** The vessels supplying the injured area of the spleen are ligated to control hemorrhage. **C.** The laceration in the capsule of the spleen is closed with absorbable sutures in a simple interrupted or continuous pattern.

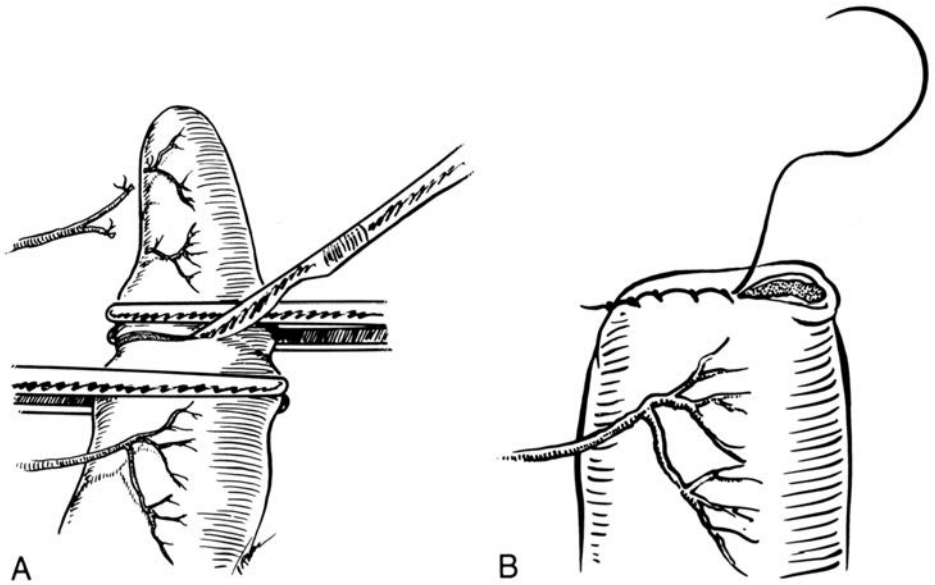


Figure 44-3. Partial splenectomy. **A.** After the vessels supplying the portion to be removed are ligated and divided, crushing forceps are applied to the tissues to be removed and atraumatic forceps are applied to the splenic remnant. The spleen is then divided between these forceps a few millimeters from the atraumatic forceps. **B.** The spleen is closed with absorbable suture in a simple continuous pattern. A second suture line is placed proximal to the first to control hemorrhage.

proximal to the first suture material in a continuous horizontal mattress pattern to ensure hemostasis. Partial splenectomy can be performed easily with stapling devices. Staples of a length sufficient to incorporate all tissue must be used. In most animals, staples at least 3.5 mm in length are adequate; if splenic tissue cannot be compressed to a width less than 2 mm, staples 4.8 mm in length should be used.[19] If hemorrhage is observed after application of staples and excision of a portion of the spleen, individual vessels can be ligated.

Splenectomy

Splenectomy is usually performed though a midline celiotomy. The incision should be of sufficient length to allow the spleen to be easily delivered from the abdomen. If an essentially normal spleen is being removed (e.g., to prevent hidden parasitemia or to treat an autoimmune disorder), 1 to 2 mL of 1:100,000 epinephrine can be applied to the surface to cause the spleen to contract. Use of larger volumes or higher concentrations of epinephrine may predispose the animal to cardiac arrhythmias, especially if anesthesia is maintained with halothane.

Vessels should be ligated as close to the hilus of the spleen as possible to minimize the potential for damage to the left gastroepiploic and short gastric vessels that supply the greater curvature of the stomach or the vessels passing to the left lobe of the pancreas. Ligation of vessels during splenectomy can be achieved with suture, metal clips, a mechanical stapling device or vessel sealing device. Although absorbable suture may be used for ligation of vessels, I prefer 2-0 or 3-0 silk. The vasculature of the spleen is usually isolated, ligated, and then divided. Alternatively, two rows of hemostatic forceps may be applied to the vasculature. The vasculature is divided, and vessels are ligated after the spleen has been removed. This technique often results in placement of ligatures some distance from the spleen, thereby increasing the potential for inadvertent ligation of vessels supplying the stomach and pancreas. As mentioned previously, when splenectomy is performed to treat splenic torsion, the splenic pedicle should not be untwisted. The vessels are usually adequately accessible to allow individual ligation near the spleen. If this is not possible, forceps can be applied, and the vessels can be ligated individually after the spleen has been removed.

The abdomen should be explored thoroughly after removal of the spleen. When the spleen has been removed to treat neoplastic disease, particular attention should be paid to the liver and lymph nodes, and biopsies should be obtained if these structures appear abnormal. The pancreas and stomach should be examined to be sure that these structures and their vasculature have not been damaged during surgery.

The splenic bed should be examined for hemorrhage before closure of the abdomen. Lavaging the abdomen with sterile saline or another balanced salt solution helps to remove blood clots and improves the surgeon's view of the splenic pedicle.

Postoperative Complications

Hemorrhage as a result of displacement of a ligature is the most common complication of splenectomy. Intraabdominal hemorrhage causes a progressive decline in the packed cell volume and plasma protein concentration when these values are measured repeatedly. Abdominal paracentesis and diagnostic peritoneal lavage also are useful for detecting hemorrhage after splenectomy. If tests support a diagnosis of intra abdominal hemorrhage after splenectomy, the abdominal incision should be reopened, and the splenic bed should be examined directly. A transfusion of whole blood may be required to compensate for blood loss. If a donor is not available, blood may be retrieved

from the patient's abdomen, mixed with an appropriate volume of anticoagulant, and given back to the patient (autotransfusion). This blood should be filtered as it is administered to remove microemboli and other debris. Blood should be removed from the abdomen using suction or sponges, and clots should be removed from the splenic bed to allow direct observation of the splenic vessels.

In the absence of continued hemorrhage, anemia after splenectomy is of limited duration if the bone marrow is functioning satisfactorily. Splenectomy does impair the capacity of the animal to maintain the circulating red blood cell volume during hemorrhage. Removal of the spleen 2 to 3 weeks before experimentation impaired the ability of anesthetized dogs to respond to hypoxemia.[20] Although this phenomenon may be transient, it does suggest that animals that have undergone splenectomy may be less able to maintain cardiovascular homeostasis during surgery, anesthesia, or other stressful situations.

Damage to the vasculature of the stomach or pancreas can cause ischemic necrosis of these organs. Pancreatitis may result from traumatic handling of the pancreas during surgery. These complications occur infrequently.

Ventricular arrhythmias have been reported to occur in as many as 44% of dogs after splenectomy, and it has been observed that these may not be detected in the absence of continuous electrocardiographic monitoring.[21] Not all dogs that develop ventricular arrhythmias after splenectomy require treatment, and treatment of arrhythmias often prolongs hospitalization. Treatment should be reserved for ventricular arrhythmias that result in significant pulse deficits or ventricular rates that exceed established standards.[22]

As mentioned previously, overwhelming septicemia (occasionally observed in humans after splenectomy) has not been reported after splenectomy in dogs and cats. However, splenectomy may render animals more susceptible to infection by blood borne organisms (Haemobartonella, Babesia). Other, as yet undetected immunologic abnormalities may also result from splenectomy in dogs and cats.

Editors Note: Reported survival times in dogs following splenectomy for malignent neoplasia vary considerably. Consultation with an oncologist regarding chemotherapy following surgery is recommended.

References

1. Evans HE. Miller's anatomy of the dog. 3rd ed. Philadelphia: WB Saunders, 1993; p 654.

2. Opdyke DF, Ward CJ. Spleen as an experimental model for the study of vascular capacitance. Am J Physiol 1973:225:1416.

3. Mililkan JS, et al. Alternatives to splenectomy in adults after trauma: repair, partial resection, and reimplantation of splenic tissue. Am J Surg 1982;144:711.

4. Cooney DR, Swanson SE, Dearth JC. Heterotopic splenic autotransplantation in prevention of overwhelming postsplenectomy infection. J Pediatr Surg 1979:14:337.

5. Cooney DR, et al. Relative merits of partial splenectomy, splenic reimplantation, and immunization in preventing postsplenectomy infection. Surgery 1979;86:56l.

6. Prankerd TAJ. The spleen and anemia. Br J Med l963;2:517

7. Song SH, Groom AC. Storage of blood cells in the spleen of the cat. Am J Physiol 1971;220:779.

8. Sullivan JL, et al. Immune response after splenectomy. Lancet 1978;1:178.

9. Andersen V, et al. Immunological studies in children before and after splènectomy. Acta Paediatr Scand 1976:65:409.

10. Krivit W. Overwhelming postsplenectomy infection. Am J Hematol 1977;2:193.

11. Feldman BF, Handagama P, Lubberink AAME. Splenectomy as adjunctive therapy for immune mediated thrombocytopenia and hemolytic anemia in the dog. J Am Vet Med Assoc 1985;187:617.

12. Fees DL, Withrow SJ. Canine hemangiosarcoma. Compen Contin Educ Pract Vet 1981;3:1047.

13. Frey AJ, Betts CW. A retrospective study of splenectomy in the dog. J Am Anim Hosp Assoc l977;13:730.

14. Scavelli TD, et al. Hemangiosarcoma in the cat: retrospective evaluation of 31 surgical cases. J Am Vet Med Assoc 1985;187:817.

15. Kapatkin AS, Mullen ITS, Matthiesen DT, et al. Leiomyosarcoma in dogs: 44 cases (1983 1988). J Am Vet Med Assoc 1992;201:1077.

16. Liska WD, et al. Feline systemic mastocystosis: a review and results of splenectomy in seven cases. J Am Anim Hosp Assoc 1979;15:589.

17. Montgomery RD, Henderson RA, Home RD, et al. Primary splenic torsion in dogs: literature review and report of five cases. Canine Pract l990;15:17.

18. Keramidas DC. Ligation of the splenic artery in the treatment of traumatic rupture of the spleen. Surgery 1979;85:530.

19. Bellah JR. Surgical stapling of the spleen, pancreas, liver, and urogenital tract. Vet Clin North Am Small Anim Pract 1994;24:375.

20. Ffoulkes Crabbe DJO, et al. The effect of splenectomy on circulatory adjustments to hypoxaemia in the anaesthetized dog. Br J Anaesth 1976;48:639.

21. Marino, DJ, Matthiesen DT, Fox PR, et al. Ventricular arrhythmias in dogs undergoing splenectomy: a prospective study. Vet Surg 1994;23:101.

22. Ettinger SJ, Le Bobinnec G, Cote E. Electrocardiography. In Textbook of veterinary internal medicine. 5th ed. Philadelphia: WB Saunders, 2000; pp 800-833.

Section J

Exotic Species

Chapter 45

Surgical Techniques in Small Exotic Animals

Surgery of Pet Ferrets

Neal L. Beeber

Introduction

In recent years, the domestic ferret has had a dramatic increase in popularity. In 1990, the number of pet ferrets in the United States was estimated to be more than 7 million.[1] As these animals have increased in Popularity, they have become more common in veterinary practices. This discussion deals with some of the more common surgical procedures in ferrets.

Preparation and Fasting

Healthy ferrets make excellent surgical candidates, are hardy, and with attention to certain parameters they do not present any unusual anesthetic risks. The intestinal tract is short, resulting in a gastrointestinal transit time of 3 to 4 hours.[2] For this reason, patients are only fasted for 4 to 5 hours before surgery, except in the case of insulinoma resection, for which the fast is 3 hours.

Sedation and Anesthesia

Isoflurane is the anesthetic of choice; however, halothane can also be used, except in critically ill patients. A nonrebreathing system is used with a flow rate of 0.6 to 1.0 L per minute. No premedication is required. In many cases, ferrets can be masked until they are sufficiently anesthetized to allow endotracheal intubation. This can usually be accomplished with a flow rate of 2 L and a 4 to 5% isoflurane concentration. The animal relaxes in 2 to 5 minutes. Because struggling or excitement is minimal, chamber induction is not usually necessary. Maintenance level of isoflurane is 1.75 to 2.5%. It is often necessary to use a small amount of lidocaine (0.1 mL) to paralyze the larynx to accomplish intubation, as in the feline species. All ferrets are intubated except for the most minor procedures. Use of 1.5 to 4.5 French endotracheal tubes is sufficient for most ferrets. If the tubes are allowed to become cold in a refrigerator, they will become stiff and more easily introduced into the trachea. Because ferrets vary in body size, several tube sizes should be available. Some breeding establishments have been importing European ferrets, which are generally larger than the American breeds and commonly weigh up to 5 to 6 lb. These ferrets need slightly larger endotracheal tubes. Whenever possible, a cuffed tube is recommended.

Ketamine and diazepam ketamine combinations can be used as a preanesthetic, for intubation, or for short procedures intramuscularly at a dose of 10 to 20 mg/kg for ketamine and 1 to 2 mg/kg for diazepam. In my opinion, acepromazine should not be used in ferrets because of this agent's vasodilatative properties and the possibility of heat loss. Ferrets should be placed on a warm water recirculating system to prevent heat loss, and any intravenous fluids to be administered should be warmed to 85 to 90° F. The patient's rectal temperature should be monitored during the surgical procedure. A simple and inexpensive way to accomplish this is to use a digital outdoor thermometer available commercially for under $15 (indoor outdoor thermometer, Radio Shack catalog No. 63 854). The probe can be inserted directly into the rectum or attached to a red rubber catheter as a stylet.

Except for a routine spay, neuter, or other minor procedure, a 24 gauge intravenous catheter (Baxter Quickcath 24 gauge 1.6 cm) should be placed for all surgical procedures. The cephalic vein is the most common site for placement, but lateral saphenous, jugular, and intraosseous catheters can also be used. When a jugular catheter is necessary, a 24 gauge cephalic catheter can be placed in the jugular vein. The types of fluids administered depend on the type of surgical procedure performed and are discussed under the appropriate section. Ferrets are monitored with a pulse oximeter, which works well in this species. Recovery time depends on the animal's condition and length of anesthesia; however, when isoflurane is used alone, recovery is remarkably fast and smooth.

General Surgical Considerations

Ferret skin is tougher than dog or cat skin, so slightly more pressure may need to be exerted. One often sees a thick subcutaneous fat layer, which should be dissected bluntly. The linea alba is readily apparent. A stab incision should be made into the abdominal cavity and extended. Care should be taken to avoid the spleen because it is often large in this species. Most common types of sutures can be used depending on the operation performed. I prefer to close the abdomen with 4-0 polydioxanone (PDS), polypropylene (Prolene), or nylon. Most nonabsorbable suture material with a cutting needle can be used for skin sutures. Ferrets rarely chew external sutures.

Ovariohysterectomy

Most ferrets sold as pets in the United States are neutered before 6 or 7 weeks of age, so ovariohysterectomy is not a common procedure, as in dogs and cats. Ferrets should be spayed by 6 months of age, however, if they are not to be used for breeding. Ferrets are induced ovulators. If they are allowed to remain in estrus, potentially fatal bone marrow suppression may result from estrogen toxicity. Medical treatments to terminate estrus are available;[3] however, spaying is recommended.

The surgical procedure is similar to that for cats. The ferret is placed in dorsal recumbency, and the abdomen is shaved and prepared. A 3 to 4 cm midline incision is made 1cm posterior to

the umbilicus. Blunt dissection is used to dissect through the fat layer and subcutaneous tissue to expose the linea alba. An incision is made through the linea and is extended. Usually, a layer of fat is encountered. The uterus of ferrets is bicornate, as in cats. The uterus can be elevated by using a spay hook, or sometimes it can be seen lying just under the incision by bluntly moving the fat. The uterus of the ferret is not nearly as friable as that of the rabbit. Ferrets have a high degree of body fat, and the ovarian tissue and vessels may be obscured. The surgeon must be certain to ligate the ovarian vessels completely using 2-0 or 3-0 gut. The uterus is easily exteriorized and the suspensory ligament is readily torn. The uterus is ligated with gut and is removed. The abdomen can be closed with any of several sUi types in a simple interrupted pattern using 4 U nlonl filament absorbable or nonabsorbable material. The same suture or gut can be used for the subcutaneous or subcuticular layer. The skin can be closed with 3-0 or 4-0 nylon. Chewing of sutures has not been a problem. If the surgical procedure is performed in the morning, the ferret is released the same day. Postoperative antibiotics are not necessary. Skin sutures are removed in 7 to 10 days.

Orchiectomy

Like ovariohysterectomy, orchiectomy (castration) is usually done in young ferrets before they are sold to pet stores. For this reason, the average practitioner is not called on to perform this operation routinely. If an intact male ferret is presented, the owners should be encouraged to have the ferret castrated. In some cases, intact male ferrets are more aggressive, especially if intact females are nearby. The main objection to intact males is the heavy musky odor they produce. Many times, castration alone is enough to control odor, making descenting unnecessary. Testicular tumors have been reported, but a true incidence is difficult to estimate because most domestic ferrets arc neutered.[4,5]

Castration in the ferret is similar to castration in the dog. The ferret is placed in dorsal recumbency, and the prescrotal area is shaved. One prescrotal incision is made through which both testicles may be exteriorized. An open or closed method can be used. The spermatic cord and vessels are ligated with 4-0 gut, are iricised, and allowed to retract into the incision. The subcutaneous tissue is closed with gut, and the skin is closed with 4-0 nonabsorbable suture, which is removed in 7 to 10 days. Chewing the sutures has not been a problem. Alternatively, two incisions can be made in the scrotum, and the vessels can be clamped and ligated with 4-0 chromic gut. With this method, the scrotal incisions are not closed, similar to the procedure in cats. The ferrets are released the same day.

Adrenalectomy

Adrenal tumors are among the most common neoplasms of ferrets. In our practice, adrenalectomy is the single most common surgical procedure performed in these animals, followed by insulinoma resection. In a retrospective study performed at our hospital and the Animal Medical Center from 1987 to 1991, the following types and frequency of biopsy results were recorded: adrenocortical adenoma, 64%; nodular adreno cortical hyperplasia, 26%; and adrenocortical carcinoma, 10%. In the patients with adreno cortical carcinoma, no gross or microscopic evidence of metastasis was seen. In addition, 70% of the cases occurred in females.[6] Since this study, I have had the opportunity to operate on many more cases and have found that the biopsy percentage has shifted to adrenocortical adenoma. Hyperplasia now accounts for 95% of the cases, and the ratio of males to females has equalized. In addition, the earlier study found that 64% of ferrets had disease of the left adrenal gland, 20% had disease of the right gland, and 16% had bilateral disease. In the years after the study, my colleagues and I have seen left sided disease in 75% of patients, right sided disease in 15%, and bilateral disease in 10%.

Clinical signs, in order of decreasing frequency, are vulvar swelling, alopecia, pruritus, polydipsia, and polyuria. The diagnosis is based on clinical signs and abdominal ultrasonography. The accuracy of the ultrasound diagnosis depends on the experience of the ultrasonagrapher. Recently, a study indicated that the concentrations of certain plasma steroid hormones can be used as a marker for the disease.[7] Even though the clinical signs may indicate the presence of an adrenal tumor, the clinician should obtain a presurgical ultrasound study whenever possible. This examination helps to rule out other causes of the clinical signs and indicates which adrenal gland is diseased. This distinction becomes important because removal of the right gland is technically more difficult, owing to its location under the caudate liver lobe and its proximity to the vena cava. The differential diagnosis of adrenal gland disease includes ovarian remnants, an intact female reproductive tract, pheochromocytoma, seasonal hair loss of ferrets, nutritional deficiencies,[8,9] mycosis fungoides,[10] and infestation by external parasites. I have also seen a ferret with cutaneous *Malassezia pachydermatis* infection that caused generalized hair loss. Adrenal disease in ferrets is not the same as Cushing's disease because the clinical signs and pathologic changes are not caused by an increase in plasma cortisol concentration.

Preparation

After the diagnosis is made, a complete blood screen and chemistry panel should be evaluated for each patient. Any abnormalities should be investigated and treated preoperatively. One of the most common abnormalities is hypoglycemia because many ferrets concurrently have insulin secreting tumors of the pancreas. Because these islet cell tumors are generally malignant, the prognosis should be discussed with the owners before proceeding. In addition, an in hospital blood glucose determination should be made immediately before anesthesia is induced, to make certain the blood sugar is still normal after the presurgical fasting period. Another important presurgical consideration is the possibility of underlying cardiac disease. Both hypertrophic and dilated forms of cardiomyopathy are seen in ferrets.[11] At this time, clients are advised that a presurgical echocardiogram should be performed if possible. If this is not feasible, chest radiographs and careful cardiac auscultation should be performed. Every patient undergoing adrenalectomy receives an intravenous catheter. Various fluid types may be used; however, if one has any question about the presence of

an insulinoma, 5% dextrose is the fluid of choice. Each patient receives a presurgical injection of antibiotics.

Left Adrenalectomy

The ferret is placed in dorsal recumbency, and the abdomen is shaved from the area of the xiphoid cartilage to the inguinal area. An incision is made starting 1 to 2 cm from the xiphoid and extending 4 to 5 cm caudally. After dissecting through the fat and subcuta¬neous tissue, a stab incision is made in the linea alba and is extended with scissors. A self retaining Gelpi retractor should be used for good exposure. As in other species, a complete abdominal exploratory operation should be performed. It is especially important to check the pancreas for the possibility of insulinoma nodules (see later). In addition, all male ferrets should be examined for the presence of paraurethral cysts (discussed later). The surgeon generally must retract the spleen and intestines toward the right side of the ferret's body. A laparotomy pad soaked in warm saline can be used to hold structures away from the surgical site. Alternately, the spleen and small intestines can be exteriorized through the incision and placed to the right. This maneuver pulls the mesentery away from the area of the adrenal gland and affords excellent exposure. Any exteriorized tissues should be covered with a warm moist lap pad to prevent tissue drying. The left adrenal gland is located just medial and proximal to the left kidney. This gland is located within a fat pad, and if diseased, it is usually irregular in shape and readily seen. In some cases, one sees a brownish-yellow discoloration. Digital palpation reveals the presence of borders on the mass. The dissection is begun on the medial side of the gland through the fat layer using Mayo scissors and is continued bluntly with mosquito forceps and sterile cotton tipped applicators. The gland is gently elevated as the dissection is continued. The small blood vessels in the fat generally do not have to be ligated. The adrenolumbar vein runs laterally and caudally from the ventral surface of the adrenal gland. It can be seen as the gland is elevated. This vessel is ligated using 4 0 chromic gut or a surgical clip (Hemoclip). The gland is continually elevated and dissected until a suture can be placed below it. The tissue is then incised, and the gland is removed. Closure is the same as for an ovariohysterectomy. Because this is a major abdominal procedure, patients are hospitalized for 1 to 2 days postoperatively. Amoxicillin oral suspension at a dose of 10 mg/lb is dispensed for 7 days.

Right Adrenalectomy

As mentioned previously, removal of the right adrenal gland is a technically more difficult procedure. After entry into the abdominal cavity, and a general exploratory operation, the spleen and intestines are moved to the left or are exteriorized. The right adrenal gland is located under the caudate liver lobe. The hepatorenal ligament must be incised to elevate the tip of the liver lobe. The lobe is then reflected cranially. The adrenal gland is usually directly adhered to the vena cava (Figure 45-1). One must be careful to avoid lacerating this major vessel. The surgeon begins shelling out the gland by sharp dissection of the surface furthest from the vena cava and continues around the gland using iris scissors, mosquito forceps, and sterile cotton swabs. When the gland is mostly peeled away, a Hemoclip or a ligature using 5-0 absorbable suture is placed between the gland and the vena cava. Any remaining glandular tissue is trimmed using the iris scissors. One should have available 5-0 and 7-0 suture as well as sterile sponges (Gelfoam) in the event that the vena cava is lacerated. When one is certain that all hemorrhage has been controlled, closure is as described earlier.

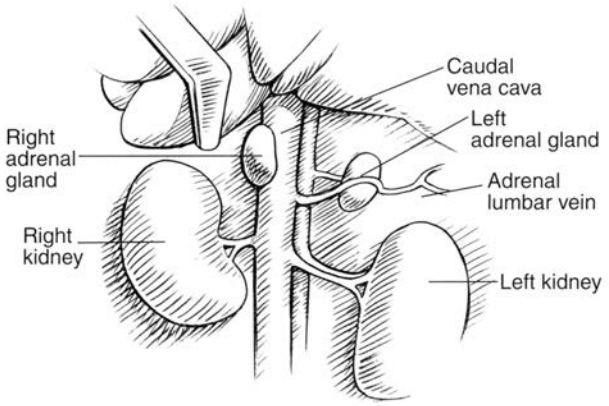


Figure 45-1. Appearance of the adrenal glands. The caudate lobe of the liver has been reflected cranially. The right adrenal gland usually adheres to the vena cava.

Bilateral Adrenal Disease

When both adrenal glands are abnormal, the surgeon removes the left entirely and debulks the right. If incised, the adrenal gland bleeds profusely. One begins Caudal venacava dissecting the gland and places a crushing suture around the part that has been freed, using 4-0 monofilament absorbable or nonabsorbable material. Iris scissors can then be used to cut above the suture. The surgeon removes 50 to 75% of the right adrenal tissue.

Complications

The most common complication of adrenalectomy is prolonged or difficult recovery resulting from hypogly cemia secondary to an undiagnosed insulin secreting tumor of the pancreas. In fact, when ferrets are referred to my practice for postsurgical problems blood glucose concentrations are frequently found. For this reason, a blood glucose determination is performed before the surgical procedure and 1 to 2 hours postoperatively. Many times, fluids containing dextrose are used as a precaution. Ferrets are encouragcd to eat after they are fully awake, and Deliver (Deliver I 2.0, Mead Johnson Nutritionals, Evansville, 'N) is often administered orally within 3 to 4 hours postoperatively. Vomiting has not been a problem.

Another problem commonly encountered is hypothermia. Intravenous fluids should be warmed before administration. We use a warm water heating pad and heat lamp during and after surgery. Ferrets are generally hardy and are good surgical candidates. Postoperative infections appear to be rare.

Even with the removal of the left adrenal gland and part of the right, most patients do not appear to require hormonal supplementation. Vital signs in these ferrets should be monitored closely in the immediate postoperative period. If recovery is prolonged or if the patient is dping poorly, a blood glucose

determination should be made. If the blood glucose level is normal, corticosteroids can be administered, and blood can be saved for a resting cortisol level to ascertain the need for continued cortisone supplementation.

Paraurethral Cysts

One problem encountered with male ferrets with adrenal disease is the presence of paraurethral cysts. Animals with this condition present with dysuria or total blockage along with other signs of adrenal disease. The cysts are thought to arise from prostatic tissue that has been stimulated by the hormones released from the adrenal gland. These cysts are present just caudal to the bladder and can usually be felt by external abdominal palpation (Figure 45-2). If the urinary tract is totally obstructed, the blockage must be relieved. This procedure can be challenging because the penis is difficult to catheterize as a result of the os penis. I have been most successful using a tomcat catheter or 3 French red rubber catheter. At the present time, the best treatment (Figure 45-2). A paraurethral cyst around the neck of the urinary bladder.) appears to be adrenalectomy. In addition, one should attempt to aspirate material from the cyst during the surgical procedure using a 22 gauge needle and a 3 mL syringe. The material in the cysts appears flocculent. Because the cysts are usually multiloculated, a few attempts should be made into different areas. Leakage from the cysts after this procedure has not been a problem. The cysts regress after the adrenal tumor has been removed. The ferret is kept on postoperative antibiotics for 14 days. In a few cases, cysts that have not regressed and that cause reobstruction need to be marsupialized. In severe cases, pre scrotal or perineal urethrostomies can be performed. In these patients, the cysts should regress after 3 to 4 weeks of antibiotic therapy.

Prognosis

The prognosis for patients undergoing adrenalectomy is excellent. It is the treatment of choice for this condition. In females, the swollen vulva may begin to shrink within 1 to 2 days. Hair loss takes longer to resolve. My impression is that the longer the interval between the onset of clinical signs and surgery (and usually the more extensive the alopecia), the longer the hair takes to regrow. Clinical signs return in some patients, and a second surgical procedure will be needed to remove the other gland, which has since become diseased.

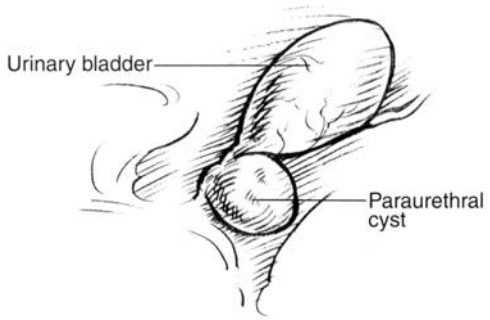


Figure 45-2. A paraurethral cyst around the neck of the urinary bladder.

Insulinoma

As previously mentioned, insulinoma surgery is the second most common procedure performed in my practice. Signs are due to hypoglycemia and range from ferrets who begin to sleep more and seem lethargic, act nauseated, and paw at their mouths, to episodes of "vacant expressions" and staring into space, to hind limb weakness and collapse, to seizures and coma. Signs can be intermittent and can resolve quickly. Because this disease is commonly seen in ferrets over 3 years of age, early signs may be interpreted as normal aging. Diagnosis is based on the demonstration of low blood glucose concentrations and hyperinsulinemia. After a 3 hour fast, normal blood glucose should be above 80 mg/dL. Levels below 65 mg/dL suggest the diagnosis. Prolonged anorexia or starvation can produce a blood glucose level this low, but the presence of an insulinoma is much more common. Many times, the blood glucose level is below 50 mg/dL. Blood glucose levels between 65 and 80 mg/dL are suggestive of this diagnosis, and the fast should be continued for another 1 to 2 hours and an insulin level checked. An abnormally high insulin level along with low blood glucose is diagnostic.

Often, treatment begins with medical intervention. It is effective in the early course of the disease and has been used for 3 months to 2 years. Therapy is begun with prednisone at a dose of 0.5 to 2 mg/kg. The dose can be increased over time to keep clinical signs under control. Diazoxide (Proglycem), at a dose of 5 to 10 mg/kg, can be added to the prednisone regimen. It inhibits insulin release and stimulates hepatic gluconeogenesis.[12] Sometimes, the dose of prednisone can be lowered when diazoxide is added. Side effects in other species include vomiting and anorexia, but these effects are rare in ferrets. The easiest form to adminis¬ter is the suspension, which is expensive.

Owners are instructed to, feed ferrets with insulinomas frequently. Owners are also instructed to avoid high sugar or carbohydrate containing supplements unless treating a hypoglycemic episode. These foods or treats can stimulate insulin secretion and can cause rebound hypoglycemia. These ferrets should be fed a high quality ferret or cat food containing an animal protein source. Brewer's yeast should be added to the diet at a rate of one quarter teaspoon twice daily because it is a good source of chromium, which helps to stabilize blood glucose and insulin levels in humans.[13] Deliver makes an excellent supplement because of its high fat content and acceptance by almost every ferret. Medical treatment is indicated in ferrets that are poor surgical 'candidates or whose owners decline surgery for their pet. Clients should be informed that the /3 cell tumors are almost always malignant, and surgical treatment appears to slow the progression of the disease. Many ferrets become normoglycemic at least for a time after surgery. Clinical impression is that ferrets seem to do better for longer with a combination of surgical and medical treatment. In dogs with insulinomas, surgical treatment prolongs life span over medical management alone.[14]

Surgery is generally recommended in ferrets younger than 5 or 6 years of age. All ferrets should be carefully screened for other diseases, especially cardiac disease. As mentioned in the discussion of adrenal surgery, a cardiac ultrasound study

is recommended as a presurgical screen. Often, surgery is performed concurrently for adrenal disease and insulinoma. Presurgical fasting is usually limited to 3 to 4 hours. An intravenous catheter is placed in all cases, and warmed 5% dextrose is administered during the surgical procedure.

As with adrenal surgery, a midline incision is made, and a standard exploratory operation is performed. I have seen metastasis of β cell carcinoma to the spleen and liver. In patients with splenic metastasis, splenectomy was performed. Most commonly multiple, and infrequently solitary, nodules are present. The entire pancreas should be inspected visually and also palpated. The nodules usually appear as raised areas that may be lighter in color. Sometimes, the nodules are not evident visually, yet they are firmer than the surrounding tissue, so careful digital palpation is imperative. In most cases, blunt dissection enables the surgeon to shell out the affected areas. Some minimal bleeding occurs, but it usually stops with pressure or Gelfoam application. In some cases, 5-0 or 6-0 polyglycolic acid (Dexon), polyglactin 910 (Vicryl), or polydioxanone (PDS) can be used to ligate larger vessels. If numerous nodules are present, a partial pancreatectomy can be performed. The previously listed absorbable suture can be used to ligate the pancreatic tissue in a crushing manner. If the area is small enough, one circumferential ligature can be placed around the area to be removed, or the suture can be placed in the center of the area and transfixed in both directions (Figure 45-3). In this manner, less tissue is included in each tie. Pancreatitis does not seem to be a problem after surgery.

Blood glucose should be measured postoperatively and at reasonable intervals during recovery. Some ferrets become normoglycemic 1 to 2 days postoperatively. In many cases, I observe only a slight increase in measured blood glucose, although the ferrets appear to improve clinically. Often, medical management must be continued. Some patients have Postoperative hyperglycemia, which is usually transient and reso1ves within 3 to 5 days.

The surgeon must inform clients that this is a maiignant neoplasm,[15] and a cure should not be expected. One should also be sure that clients understand that medical intervention may need to be continued or resumed as the disease progresses. Even with these caveats, I believe, based on many cases, that a combination of surgical and medical management yields the best results for the longest period.

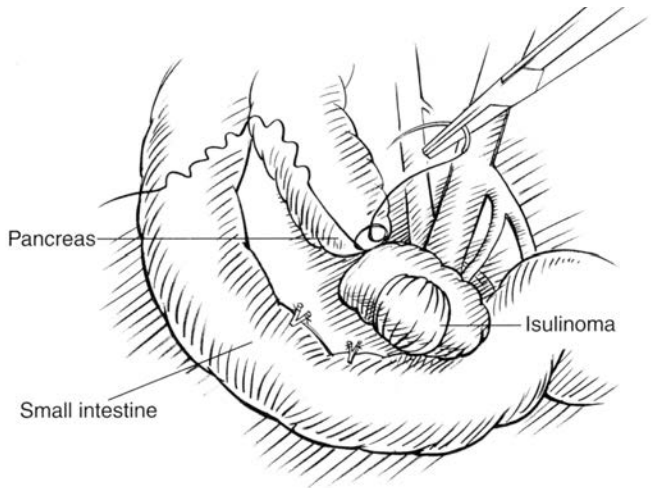


Figure 45-3. Transfixation and removal of a portion of the pancreas containing a nodule of moderate size.

Foreign Body Surgery

Foreign body ingestion by ferrets is common, especially in young animals. The most common materials are pieces of a ferret's plastic or rubber toys. For this reason, I recommend that owners do not provide ferrets with the soft squeaky toys commonly sold for use by ferrets or with toys made of any other material soft enough to be chewed apart. Hard nylon (Nylabone type) toys are acceptable. Other foreign bodies seen include trichobezoar, pieces of foam rubber, cork, the hard ends of shoe laces, and almost anything one could imagine.

Clinical signs include anorexia, vomiting, diarrhea, and weakness. In general, ferrets do not exhibit vomiting as often as dogs and cats, but they appear nauseated by stretching the neck and retching, salivating, and pawing at the mouth.

Diagnosis is made by history, abdominal palpation, and plain and contrast radiography. Ferrets often exhibit pain on abdominal palpation. In my experience, ferrets with trichobezoars exhibit less severe clinical signs. The most common location for foreign bodies is the small intestine, but they may also be located in the stomach or esophagus.[16,17]

In some cases, endoscopy may be helpful to remove esophageal and gastric'foreign bodies. I use a pediatric bronchoscope. The diameter is too large to be useful for the small intestine.

Surgical Procedure

In many cases, ferrets with foreign body ingestion exhibit anorexia and are dehydrated. Therefore, adequate rehydration is important. Surgery should be considered an emergency and performed as soon as possible. A standard midline approach is used, and a complete examination of the intestinal tract is performed to check for multiple foreign bodies. In patients with esophageal or proximal duodenal obstruction, the surgeon should retropulse the material into the stomach and perform a simple gastrotomy. Gastric surgery is similar to that in the dog or cat. Closure is accomlished with a double layer simple interrupted pattern using 4-0 absorbable material.

Because of the small diameter and fragility of the intestines, gentle tissue handling is important, to mini-ize stricture of the surgical site. The incision is made jn the antimesenteric border and is closed with 4-0 or 5-0 monofilament nonreactive suture in a simple interrupted pattern. Because of its handling characterstics, I prefer 5-0 polydioxanone (PDS). If the section:of intestine appears devitalized, an intestinal resection and anastomosis should be performed. The procedure is the same as in dogs and cats. The surgical site and abdomen should be flushed completely with warmed saline solution. The omentum should be placed over the area to aid healing. Closure is routine, and as in all gastrointestinal surgery, care must be taken to avoid contamination.

Ferrets are offered water and Deliver about 12 hours postoperatively, and they are encouraged to eat solid food within 24 hours. Intravenous fluids should be continued until the patient is eating well.

References

1. Rupprecht CE, Gilbert J, Pitts R, et al. Evaluation of an inactivated rabies virus vaccine in domestic ferrets. J Am Vet Med Assoc 1990;193:1614 1616.

2. An NQ, Evans HE. Anatomy of the ferret. In: Fox JG, ed. Biology and diseases of the ferret. Philadelphia: Lea & Febiger, 1988: 100 134.

3. Bernard, SL, Leathers, CW, Brobst, DF, et al. Estrogen induced bone marrow depression in ferrets. Am J Vet Res 1983;44:657.

4. Meschter CL. Interstitial cell adenoma in a ferret. Lab Anim So 1989;39:353-354.

5. Goad WP, Fox JG. Neoplasia in ferrets. In: Fox JG, ed. Biology and diseases of the ferret. Philadelphia: Lea & Febiger, 1988: 278 280.

6. Rosenthal KL, Peterson ME, Quesenberry KE, et al. Hyperadrenocorticism associated with adrenocortical tumor or nodular hyperplasia of the adrenal gland in ferrets: 50 cases (1987-1991). J Am Vet Med Assoc 1993;203:271 275.

7. Rosenthal KL, Peterson ME. Evaluation of plasma androgen and estrogen concentrations in ferrets with hyperadrenocorticism. J Am Vet Med Assoc 1996;209:1097 1102.

8. Ryland LM, Bernard SL. A clinical guide to the pet ferret. Corn pend Contin Educ Pract Vet 1983;5:25 32.

9. Ryland LM, Gorham JR. The ferret and its diseases. J Am Vet Med Assoc 1978;173:1154 1158.

10. Rosenbaum MR, Affolter YK, Usborne AL, et al. Cutaneous epitheliotropic lymphoma in a ferret. J Am Vet Med Assoc 1996;209:1441-1444.

11. Stamoulis ME, Miller MS. Cardiovascular diseases. In: Hillyer BY, Quisenberry KB, eds. Ferrets, rabbits, and rodents: clinical medicine and surgery. Philadelphia: WB Saunders, 1997:67-68.

12. Feldman EC, Nelson RW. Canine and feline endocrinology and reproduction. Philadelphia: WB Saunders, 1987:259, 304-327.

13. Baich JF, Balch PA. Prescription for nutritional healing. Garden Park City: Avery, NY. 1990:18 19, 211-213.

14. Leifer CE, Peterson ME, Matus RE. Insulin secreting tumor: diagnosis and medical and surgical management in 55 dogs. J Am Vet Med Assoc 1986;188:60-64.

15. Caplan ER, Peterson ME, Mullen HS, et a!. Surgical treatment of insulin secreting pancreatic islet cell tumors in 49 ferrets: ACVS abstract. Vet Surg l995;24:422.

16. Caligiuri R, Bellah JR, Collins BR, et a!. Medical and surgical management of esophageal foreign body in a ferret. J Am Vet Med Assoc 1989;195:969-971.

17. Mullen HS, Scavefli TD, Quesenberry ICE, et al. Gastrointestinal foreign body in ferrets: 25 cases (1986 1990). J Am Anim Hosp Assoc 1992;28:13-19.

Anal Sac Resection in the Ferret

James E. Creed

Introduction

The ferret is a popular house pet; however, odor emitted from the anal sacs of both sexes is often objectionable. Like nearly all carnivores[1] and all mustelids,[2] the ferret has an anal sac on each side of the anus. The ducts open at 4 o'clock and 8 o'clock positions on the inner cutaneous zone of the anus, adjacent to the mucocutaneous junction. The sacs are interposed between the internal and external anal sphincter muscles. Material stored within the sac is secreted by a glandular complex surrounding the neck of the sac and 3 to 4 mm of the duct. This complex is evident without magnification, but a binocular loupe enhances visualization. The sebaceous gland component surrounding the distal part of the duct is covered asymmetrically by an apocrine gland component.[3] Surgical removal of the anal sacs and their ducts eliminates the odor of anal sac secretions, but some odor from sebaceous and apocrine tubular glands in the perianal region typically persists.

Indications

Client request is the principal indication for performing this procedure. However, veterinarians should recommend this operation for all ferrets at 6 to 8 months of age to make them more acceptable pets. Neutering should be recommended at this age in ferrets of both sexes to reduce odor further. Neutering also prevents development of aplastic anemia in nonbreeding females, which can develop from hyperestrinism associated with prolonged estrus.[3,4] The client must be made aware that anal sac resection and neutering do not eliminate all "musky" odor, because of sebaceous and apocrine glands in the ferret's penrianal skin.

Preoperative Considerations

In addition to a complete physical examination, the patient's packed cell volume of blood and total serum protein level should be determined. One study of 11 healthy male ferrets reported an average packed cell volume of 52.4% and average total serum protein of 6.0 g/dL.[3] Food should be withheld for 12 hours. Anesthesia is induced with oxygen and an appropriate gaseous agent in an anesthesia chamber; it can be maintained with a mask or an endotracheal tube 2.5 mm in inner diameter (12 French outer diameter, Cole, Intermountain Veterinary Supply, N. Kansas City, MO). An alternate method is intramuscular injection of ketamine hydrochloride (26mg/kg) and acepromazine (0.2 to 0.3mg/kg).[5]

The ferret may be positioned for anal gland resection in dorsal or ventral recumbency. Because neutering is frequently performed and is best accomplished in dorsal recumbency, all ferrets should be positioned in this way, to provide consistent orientation of anatomic structures. The ferret is placed at the end of a table on a sandbag or similar pad to prevent loss of body heat, with its pelvic limbs pulled craniad and its tail dropped. The scrotal or ventral abdomen and perianal regions are prepared and draped

for the surgical procedure. Aseptic neutering is accomplished, and then the surgical drape is shifted to expose the anal region.

Surgical Technique

A binocular loupe should be used to locate the minute opening of each anal sac duct and to aid visualization throughout the procedure. The opening of each duct and the surrounding 2 mm of skin and mucous membrane are grasped with mosquito forceps. A circumferential incision is made with a No. 15 Bard Parker scalpel blade immediately distal to the forceps tip; one must be careful not to incise too deeply. Using a gentle scraping action with the blade, skin and mucosa are reflected from the duct (Figure 45-4). The glandular complex surrounding the terminal 3 to 4mm of the duct makes dissection difficult (Figure 45-4C). This complex has a nodular surface, with skeletal muscle fibers inserting into the glandular tissue. One should not attempt to find a fascial plane at this level, and dissection should be superficial with respect to overlying tissue. Shifting the mosquito forceps to clamp them across skin, mucous membrane, and terminal duct should prevent tearing the duct as caudal traction is applied with the forceps (Figure 45-4E). Applying another forceps parallel to the first provides even more support.

A fascial plane is encountered as dissection is carried beyond the glandular complex (Figure 45-4B). The anal sac can be removed readily by reflecting sphincter muscles off the sac wall with a scraping action of the scalpel blade. Staying on the proper fascial plane not only enhances sac removal, but also minimizes hemorrhage and damage to internal and external anal sphincters. If the fascial plane is followed, little muscle will be left on the sac wall. The wall appears yellowish white; it is thin, and glandular secretions are yellow. It is easy to rupture the duct and sac, particularly if the veterinary surgeon is inexperienced. Trying to establish a fascial plane before dissecting beyond the nodular glandular complex is futile and particularly hazardous, because it is easy to cut into the duct lumen. If the duct or sac is incised, surgical extirpation can still be accomplished, but the absence of a distended sac makes the operation more tedious. Odor from an incised or ruptured sac is obnoxious, but not overwhelming.

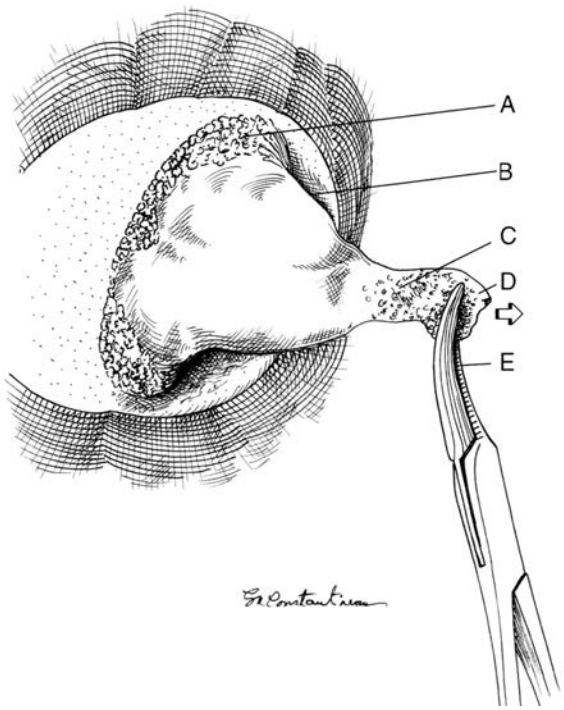


Figure 45-4. *A-C.* Resection of the anal sac. External anal sphincter muscle *A.* Wall of the anal sac *B.* Nodular glandular complex surrounding the duct *C.* End of the anal sac duct *D.* Tip of mosquito forceps grasping skin, mucous membrane, and terminal duct *E.*

Intraoperative hemorrhage is negligible, although sterile cotton tipped applicator sticks work well to clear oozing blood from the surgical field. Placement of sutures and administration of local or systemic antibiotics are not required.

Postoperative Care

The patient is normally discharged when recovery from anesthesia is complete. Although no serious postoperative sequelae have been observed, complications can occur. Persistent minor hemorrhage may develop postoperatively, but this ceases spontaneously. Potential complications include prolapsed rectum and fecal incontinence if trauma to the anal sphincter muscles is excessive. Staying on the proper fascial plane minimizes trauma and the possibility of these serious sequelae.

References

1. Ewer RF. The carnivores. Ithaca, NY: Cornell University Press, 1973:95.

2. Ryland LM, Gorham JR. The ferret and its diseases. J Am Vet Med Assoc 1978;173:l154.

3. Creed JE, Kainer RA. Surgical extirpation and related anatomy of anal sacs of the ferret. J Am Vet Med Assoc 1981;179:575.

4. Kociba GJ, Caputo CA. Aplastic anemia associated with estrus in pet ferrets. J Am Vet Med Assoc 198l;178:1293.

5. Muir WW III, Hubbell JAB. Handbook of veterinary anesthesia. 2nd ed. Philadelphia: Mosby, 1995:368.

Soft Tissue Surgery in Reptiles

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Introduction

In recent years reptiles have become increasingly popular as pets. Veterinarians are called upon to perform a variety of medical and surgical procedures on these animals.[1,2] The anatomy and physiology of reptiles differs from the more familiar mammalian patients and the surgeon must be familiar with these differences. Skin incisions are generally made between scales in the thin softer tissue between them. It is assumed that healing in this skin is more rapid than when an incision is made through the tough scales. A number 11 scalpel blade is particularly useful for skin incision as its fine tip allows the surgeon to incise with more precision in the zig-zag pattern required to cut between scales (Figure 45-5). In a retrospective report there was no difference in healing when the incision for celiotomy in snakes was made through the scutes (large ventral scales) on the midline compared with a lateral incision between scales.[3]

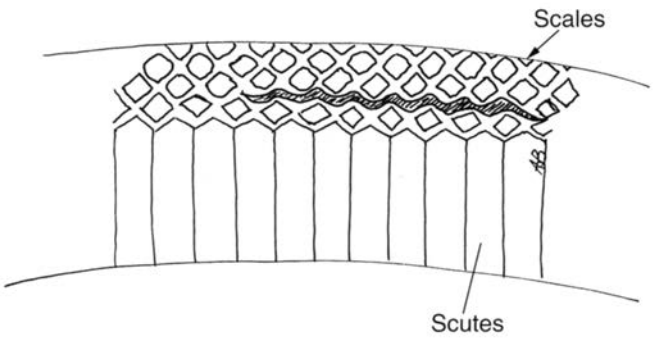


Figure 45-5. The skin incision for a lateral celiotomy in a snake is made between the first two rows of scales dorsal to the large ventral scales (scutes). The incision is made in the soft skin between the scales.

The incised skin of most reptiles has a tendency to invert. Because of this, an everting skin closure pattern, such as an interrupted horizontal mattress, is commonly used. Alternatively, skin staples are designed to slightly evert the skin edges when applied and serve nicely for skin closure in reptiles. Reptiles have very little subcutaneous tissue and most incisions are closed with sutures in the deep tissues and skin only. The skin of reptiles is very tough and is considered the holding layer for wound security. For example, when closing a celiotomy in an iguana, the body wall muscle is very thin and does not hold suture well. No distinct fascia is identified and the muscle does not easily separate from the skin. A two layer closure is used with a simple continuous pattern in the body wall and an everting pattern in the skin recognizing that the skin is the holding layer. Sutures are tightened to gently appose the skin edges. Sutures tightened excessively will cause necrosis of the skin within the suture and dehiscence of the incision. Reptiles do not traumatize their skin incisions or remove sutures.

The tissue reaction to 8 types of suture material and cyanoacrylate tissue adhesive placed between the skin edges in ball pythons (Python regis) has recently been reported. One centimeter skin incisions were made and a piece of suture placed in the wound. The same suture material was used to close the skin over each piece of implanted suture. One wound was left to heal by second intention and served as a control. Cyanoacrylate was not significantly different from the control wound. All suture materials induced an inflammatory response. No suture material was was absorbed at 90 days. In many instances, the inflammatory response progressed with time and in some wounds suture had been or was in the process of being extruded from the tissues. Materials that are more rapidly absorbed such as poligliecaprone 25 and chromic catgut were in the process of being absorbed at 90 days while other sutures with longer absorption times such as polydioxanone may take years to be completely absorbed. In another study polyglactin 910, poliglecaprone 25, and polyglyconate were evaluated in the skin of juvenile loggerhead sea turtles *(Caretta caretta)*. Polyglactin 910 induced statistically significant more panniculus inflammation in juvenile loggerhead sea turtles and poliglecaprone 25 and polyglyconate caused the least cutaneous tissue reaction.[5] Chromic catgut has been observed to induce granuloma formation and was not absorbed 12 weeks postoperative in some reptiles[6] but appears to be less inflammatory in some chelonians.[5]

Given the variety of suture materials on the market that induce less inflammation and have more predictable absorption rates, the use of chromic gut is not advised. Synthetic absorbable monofilament suture materials are preferred but absorption appears to be prolonged in reptiles compared to mammals. If absorbable suture materials are placed in the skin, it should be anticipated that they will require removal.

Skin suture removal is generally not attempted for at least 4 weeks postoperative. At that time incisional healing is assessed by gently teasing the incision edges to determine wound security. Often only every other suture is removed at 4 weeks and the remaining sutures removed 2 to 3 weeks later. Ecdysis (skin shedding) is considered to speed wound healing as during this time the epidermis is metabolically active. Because of this many surgeons prefer to wait for suture removal until after the subsequent ecdysis. Environmental temperature has been shown to have an effect on wound healing in reptiles.[7] The patient is maintained at the upper end of its preferred optimum temperature range during the recovery period to promote healing. Following suture removal, the skin will frequently stick to the incisional scar for several sheds (ecdysis) but this eventually resolves.

Anatomy

Prior to undertaking a surgical procedure in a reptile patient, the surgeon must become familiar with the unique anatomy of the particular family of reptiles to which the patient belongs.[1-3] There is variation in anatomy among families of reptiles; for example, crocodilians are considered to have a 4 chambered heart while squamates (lizards and snakes) and chelonians (turtles and tortoises) have a 3 chambered heart.[8-11] There is also variation within a family of reptiles. In green iguanas, the kidneys are normally located within the pelvic canal while in monitor lizards they are within the coelomic cavity.

Some features are relatively consistent across species of reptiles. In general, reptiles do not have a muscular diaphragm and, as such, have a ceolomic cavity rather than thoracic and abdominal cavities; however, crocodilians do have a relatively well developed septum between the thoracic viscera and the abdominal viscera. Reptiles do not have lymph nodes. They do not store fat in the subcutaneous tissue but have discrete fat bodies within the coelom. In some species the spleen and pancreas are intimately associated with each other forming a splenopancreas.

The urinary system of reptiles is substantially different from mammals. Reptiles have a renal portal system such that, when the portal vein is open, blood from the caudal half of the body passes through the kidney prior to reaching the systemic circulation. Urine leaves the kidneys through the ureters which empty into the cloaca, not the urinary bladder. Urine then travels from the cloaca into the bladder of those species with a urinary bladder (chelonians and some lizards) or into the colon in those species without a bladder (snakes, crocodilians, and some lizards) where water absorption and ion exchange occur.[8-11] Urine does not flow through the reproductive system and the short urethra only connects the bladder to the cloaca.

The cloaca receives excretions from the ureters, colon and urinary bladder in those species with a bladder, and the reproductive system. Chelonians and crocodilians have a single copulatory organ (penis) while squamates have paired copulatory organs called hemipenes (hemipenis, singular). The copulatory organs do not contain tubular structures such as a urethra. Semen travels along a groove in the hemipenis into the cloaca of the female. The female reproductive tract is bilateral in reptiles with each oviduct having a separate opening into the cloaca.

Celiotomy

The approach for celiotomy in reptiles varies with the family of reptile. Because reptiles lack a diaphragm celiotomy can allow access to both thoracic and abdominal viscera.

Lizards and **crocodilians** have a body structure more similar to mammals than chelonians and snakes. A paramedian incision is recommended in these species because of the ventral abdominal vein. This vein receives blood from the caudal abdominal wall and courses along the ventral midline 2 to 3 mm inside the body wall. It is located between the umbilical scar and the pubic bones and is suspended by a short mesovasorum. Some surgeons prefer a midline approach using meticulous dissection to avoid damaging this rather large vein.[3] Making a paramedian incision 2 to 4 mm lateral to midline minimizes the risk of lacerating this vessel. It has been reported that this vein may be ligated without consequence.[2,3]

Closure is accomplished using a simple continuous pattern with a synthetic absorbable material on a fine, atraumatic swaged-on needle. Because the muscle of the body wall is thin and tightly adhered to the skin, care must be taken with suture placement and tension on the suture or tearing through the muscle will occur. Suturing the body wall will pull the skin edges into apposition. Skin staples or an everting pattern of a nonabsorbable material maintain skin apposition.

In laterally compressed lizards, such as chameleons, an intercostal or paracostal approach is more appropriate. The ribs in the species extend caudally close to the hip and femur so there is little space to enter through this approach alone. Exposure can be improved by combining the intercostal or paracostal approach with a ventral midline approach creating a flap on one side or the other. For closure, suture the apex of the triangle of body wall created to the cranial aspect of the ventral midline incision. Then suture the paracostal or intercostal body wall followed by closure of the ventral midline incision. The skin is closed routinely.

Snakes have organs arranged in a linear configuration. In most cases, the specific organ being approached must be identified preoperative as celiotomy will not allow access to all of the viscera. It is essential to know the location of the specific organ being approached.[12]

The coelomic membrane may be closed as a separate layer or incorporated in the body wall closure. The body wall is a thin pale muscle that is tightly adhered to the skin. The coelomic membrane is not attached to the skin. The muscle of the body wall is closed with a simple continous pattern using a synthetic absorbable material on a fine atraumatic needle which will also approximate the skin edges. The skin is closed with either skin staples or an everting pattern such as a horizontal mattress.

Chelonians present a unique challenge for celiotomy because of their shell. For most procedures a plastron osteotomy is required. In species with a small plastron, such as snapping turtles and sea turtles, some procedures can be accomplished through a flank incision. Some procedures, such as cystotomy, can be accomplished through this approach in other chelonians.[3]

The pelvic bones are avoided during plastron osteotomy to avoid injury to the appendicular skeleton. Radiographs are helpful in assessing the location and extent of the pelvic bones. In most species, osteotomy through the femoral and abdominal epidermal shields (Figure 45-6) will allow access to coelomic viscera while avoiding injury to the appendicular skeleton and heart. The osteotomy must be large enough to allow the procedure to be accomplished and located in a position to allow access to the target organ.

Plastron osteotomy is performed using a power or pneumatic bone saw, or a sterile motorized wood working tool with a fine circular saw blade. Standard bur bits are not recommended because they cut an excessively wide osteotomy which will delay bone healing. Standard surgical preparation is performed and the surface of the plastron must be completely free of keratin

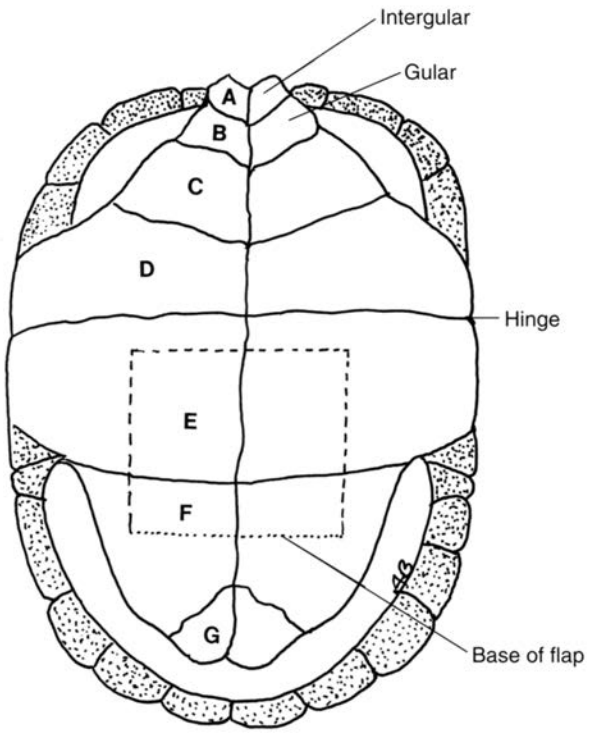


Figure 45-6. The plastron osteotomy for celiotomy in chelonians is generally made in the femoral *F.* and abdominal *E.* epidermal shields. If the osteotomy is made too cranial the heart can be injured and if too caudal the pelvic bones can be damaged. *A.* intergular, *B.* gular, *C.* humeral, *D.* pectoral, *E.* abdominal, *F.* femoral, *G.* anal.

debris and soil. This requires a surgical scrub brush. Alcohol, ether, or acetone is used to remove grease from the surface of the plastron to allow a better bond to form between the keratin and the epoxy resin that will be used to stabilize the plastron osteotomy postoperative.

The plastron is dermal bone and efforts are made to improve the environment for bone healing. The osteotomy cut is beveled slightly and the blade should be as thin as possible so when the segment of plastron is replaced, bone-to-bone contact will be achieved (Figure 45-7). The blade is irrigated while performing the osteotomy to dissipate heat and control bone dust. It is best to make a 3 sided osteotomy in species with a hinge (e.g. box turtles). An osteotomy is made on both sides as well as the caudal margin of the proposed flap. The segment of plastron is then reflected craniad based on the intact hinge which will provide blood supply to the segment of bone. For those species without a hinge (most tortoises), the segment is cut along the cranial or caudal border and the two sides. The fourth side is partially cut with the saw and then, as the section of bone is elevated, it is cracked along the remaining border to preserve some blood supply as well as some stability.

After the bone has been osteotomized, a periosteal elevator is used to dissect the body wall off the plastron preserving the attachments of the pelvic or pectoral musculature. It may be difficult to bend the segment beyond 90 degrees and it may require an assistant to hold the segment up and out of the surgeon's field while the procedure is performed. There are two large venous sinuses within the coelomic membrane located paramedian on each side between the midline and the bridge (junction of the plastron with the carapace). These are generally obvious during the intial approach but once manipulated, undergo vasospasm and become relatively imperceptible. Care is taken not to damage these vessels so when they dilate following closure, hemorrhage does not occur. It has been reported that they can be ligated without consequences.[2,3] The incision into the coelom is made along the ventral midline. The membrane is thin and transparent in the central region where there is no muscle.

Closure is accomplished using a synthetic absorbable material in the coelomic membrane and body wall. The bone flap is replaced and secured using epoxy resin and fiberglass cloth.

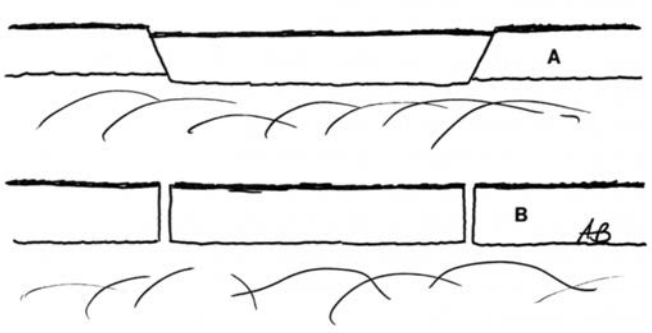


Figure 45-7. A bevel cut is recommended for plastron osteotomy to achieve postoperative bone-to-bone contact for more rapid bone healing. *A.* When the flap is replaced after a bevel cut, the bone contacts bone. *B.* With a vertical cut, a gap is created.

Epoxy is mixed and applied 2 to 3 cm around the periphery of the plastron osteotomy and over the entire bone segment leaving a 3 to 4 mm border around the osteotomy on both sides to prevent the resin from flowing into the osteotomy which would delay healing. A sterile autoclaved piece of fiberglass cloth is placed over the plastron flap with a 2 to 3 cm border extending over the osteotomy onto the plastron. The epoxy already on the plastron is gently worked into the cloth being careful not to allow the resin to seep into the osteotomy. The epoxy is allowed to cure and a second layer is applied over the entire patch. This layer should be thin enough that the resin does not soak through the cloth and into the osteotomy. Enough layers of epoxy are applied to create a completely smooth surface with no texture from the cloth remaining. During the final curing process, a piece of plastic sheeting or wax paper is applied to the patch to prevent paper or soil from adhering to the resin. This will not stick to the epoxy and is removed the following day. Within 24 hrs the resin is completely cured and the turtle can resume normal activity, including swimming. Some surgeons prefer to apply a thin layer of antibiotic cream along the osteotomy site to prevent resin from entering and provide some antibacterial activity.

Healing of a plastron ostetomy requires 1 to 2 years.[3] Patches have remained viable for over 5 years and are generally not removed. Often, the patch will fall off on its own; however if the borders become elevated from the plastron, the patch can be pried off. In young growing chelonians, the patch is cut at the growth rings after bone healing is complete to allow for shell growth. Because the epoxy is potentially carcinogenic, the cuts are best made under a hood or, at least, in a well-ventilated area using a respirator mask. Copious irrigation will help prevent aerosolization of the toxic dust.

Flank celiotomy is used in chelonians with a small plastron or in tortoises with small cystic calculi or a small intestinal foreign body.[3] With the animal in dorsal recumbency, the left hindlimb is pulled caudally exposing the inguinal depression. The skin is incised in either a longitudinal or transverse manner and the muscles are bluntly separated until the coelomic membrane is identified. The membrane is grasped with tissue forceps and incised to allow access to the coelomic cavity. Through this approach the left lobe of the bladder can be accessed and with a digital exploratory, small intestinal foreign bodies can be exteriorized. This approach has not been adequate for access to the entire female reproductive tract for ovariosalpingectomy; however, focal oviductal lesions may be approached through the flank. A two or three layer closure is performed with the coelomic membrane and muscle sutured either as separate layers or together.

Surgery of the Female Reproductive Tract

Female reptiles have a bilateral reproductive tract but their reproductive physiology varies considerably. Some reptiles lay eggs (crocodilians, chelonians, and some squamates) while others deliver live babies (some lizards and some snakes). Dystocia and prevention of reproduction are the major indications for surgery of the female reproductive tract. Surgical management of dystocia is indicated when husbandry changes and medical

management have failed to relieve the dystocia or if there is evidence (such as radiographic) that the eggs are unable to pass because they are too large or of an abnormal shape. Ovariosalpingectomy is performed to treat dystocia or to prevent future problems related to the reproductive tract such as yolk coelomitis, dystocia, and salpingitis.

Preovulatory egg stasis is characterized by the development of yolks on the ovary that are not subsequently released. Postovulatory stasis occurs when the eggs or feti are within the oviduct but do not pass normally. In either case, it is recommended that the ovaries as well as the oviducts be removed.[3] It appears that if the oviduct is removed without removing the ovary, yolks will be released into the coelom potentially inducing yolk coelomitis. If the ovaries are removed and the oviducts left, they simply atrophy and are unlikey to cause problems in the future. Removal of one side of the reproductive tract (unilateral ovariosalpingectomy) for treatment of reproductive disease allows the patient to remain reproductively viable which may be important for herpetoculturists.

The female reproductive tract is relatively mobile within the coelom. In lizards and chelonians it is readily accessible through a standard celiotomy approach. In snakes, the tract is very long and if the entire oviduct contains eggs or feti that must be removed, it is often necessary to make several celiotomy approaches. Generally, 3-5 eggs can be manipulated out of a single salpingotomy incision.

When reproductively active, the blood vessels supplying the ovary and oviduct become engorged and hypertrophied making surgical removal more challenging. For this reason, in pet reptile species with a high incidence of dystocia, prepubertal elective ovariosalpingectomy should be considered. The procedure is much easier when the vessels, ovaries and oviducts are small and the patient is in good metabolic condition.

The oviduct wall is very thin and transparent. When there is salpingitis the wall becomes thicker but more friable making it a challenge to suture closed. Cultures and biopsies should be obtained from the oviduct for diagnostic purposes to guide the postoperative management of the case and determine the prognosis for future reproductive capability. Once the oviduct is identified, an incision is made over an egg or fetus approximately the length of the egg/fetus. If the salpingotomy incision is too small the oviduct will tear while the eggs/feti are manipulated through the incision. The first egg/fetus is generally removed without much effort. Eggs/feti that have been in place a long period of time adhere to the oviduct wall. A 20 ga catheter on a 20 cc syringe filled with saline is inserted between the egg/fetus and oviduct wall and saline is injected to separate the wall from the egg/fetus. This will not only free the egg/fetus from its adhesions to the oviduct but also provide some lubrication. After the first egg/fetus is removed, adjacent eggs/feti are massaged toward the salpingotomy using saline injection, finger dilation, and digital manipulation to separate adhesions between the egg/fetus and oviduct, and to extrude the egg/fetus from the salpingotomy. Once all the eggs/feti have been removed the salpingotomy is closed using a fine (6-0 to 8-0) monofilament, synthetic absorbable material on a fine atraumatic needle in a two layer inverting pattern or a simple continuous oversewn with an inverting pattern. Following a properly performed salpingotomy the prognosis for reproductive viability is good.

In cases where there is irreparable damage to the reproductive tract or where the owner desires to prevent future episodes of dystocia, ovariosalpingectomy is performed. The following discussion applies primarily to green iguanas. Other lizards and chelonians will have some variation in anatomy but the procedure is similar. In snakes with their longitudinal configuration, the ovary is cranial to the oviduct and must be approached through a separate incision or by extending the celiotomy craniad until the ovary is identified.

In iguanas, the right ovary is very close to the right external iliac vein, while the left is more loosely attached with the left adrenal gland interposed between the left external iliac vein and the ovary (Figure 45-8). When the ovary is active, as with preovulatory egg stasis, the ligament is stretched out and it is easy to apply hemostatic clips to the vessels supplying the ovary. Two clips are applied to each vessel and the vessel is transected between the clips. The process is continued until all vessels are clipped and the ovary with its multitude of yolk follicles is removed.

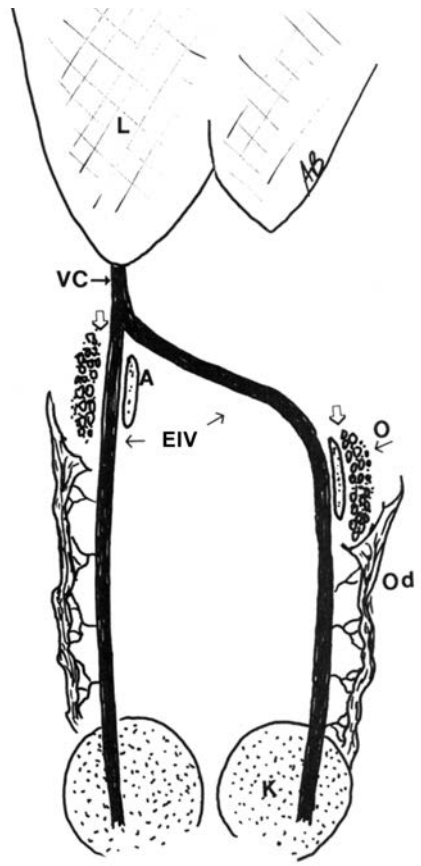


Figure 45-8. Anatomy of the female reproductive tract of a green iguana. Hemostatic clips are applied between the right ovary and the right external iliac vein, and the left ovary and left adrenal gland (*open arrows*). The tissue distal to the clip is incised allowing the ovaries to be removed. *L.* liver, *VC.* vena cava, *EIV.* external iliac vein, *O.* ovary, *Od.* oviduct, *K.* kidney, *A.* adrenal gland.

When the ovary is not active, removal is more challenging. Removal of the right ovary is accomplished by gently elevating the ovary, applying one or two clips between the right ovary and the right external iliac vein, then transecting the tissue distal to the clip to allow removal of the ovary. The left ovary is removed in a similar manner with the clips applied between the ovary and the left adrenal gland. The tissue distal to the clips is transected allowing removal of the ovary without damaging the adjacent adrenal gland.

Following removal of the ovaries, the oviducts are removed. Dissection is initiated at the infundibulum and continued to the cloaca. With preovulatory egg binding, the oviduct is empty and vessels are easily controlled either with hemostatic clips or bipolar cautery. One or two clips are applied to the base of each oviduct at the cloaca prior to their transection and removal.

In cases of postovulatory egg binding where the oviducts are full of eggs, the ovaries are relatively small and inactive as they have already released their yolks. The oviducts full of eggs will obscure visualization of the ovaries and are removed prior to ovariectomy. The vessels to the oviducts are generally engorged and numerous. Each vessel is identified, two hemostatic clips are applied, and the vessel is transected between them. Dissection is initiated at the ovaries and continued caudad until the oviducts can be ligated or clipped at the cloaca prior to transection. After the oviducts are removed the ovaries are visualized as described above. The ovaries are removed as described previously. Closure is routine.

Postoperative care is supportive. Most patients will have been anorectic for 2 to 4 weeks prior to surgical intervention. Fluid therapy is administered through an intravenous or intraosseous catheter. Antibiotics are indicated in the management of bacterial salpingitis. Again, the patient should be maintained at the upper end of its preferred temperature range for proper function of the immune system and the digestive system.

Orchidectomy

Castration is primarily performed in male green iguanas that have become aggressive toward their owner.[3] Castration has been shown to decrease testosterone levels and sexually aggressive behaviors in other lizard species.[13-15] Most commonly, orchidectomy is performed in iguanas after the aggressive behavior has developed and it may be more appropriate to perform the procedure in prepubertal iguanas before the inappropriate behaviors have developed. When performed in an aggressive animal, it appears that the aggression is not ameliorated until the following breeding season. The prognosis for attenuation of the behavior has anecdotally been reported to be around 50% following orchidectomy.[3]

Orchidectomy is performed through a standard celiotomy. As with the ovaries, the right testicle is more closely attached to the right external iliac vein by its short, vascular mesorchium. The right adrenal gland is located on the other side of the external iliac vein. The left testicle is more loosely attached to the left external iliac vein and the left adrenal gland is located between the left testicle and the external iliac vein (Figure 45-9). The adrenals are elongated, granular, pink glands easily distinguished from the smooth, white testicles. The testicles are covered by a capsule that can be ruptured during aggressive manipulation. Rupture of the capsule does not result in hemorrhage but the contents flow out making it difficult to continue with the dissection.

The testicles are removed in a manner similar to that described for removal of inactive ovaries. The right testicle is gently elevated and one or two hemostatic clips are applied between the testicle and the external iliac vein. The tissue distal to the clips is transected allowing removal of the testicle. The left testicle is removed following application of hemostatic clips between the left adrenal gland and the testicle. If hemorrhage from the external iliac vein occurs, one or two hemostatic clip are applied longitudinally along the damaged side of the vessel to control hemorrhage (Figure 45-10). Partial occlusion of the external iliac vein has not been associated with clinical disease; however, if over half of the diameter of the external iliac vein is attenuated, signs of vascular obstruction might be anticipated.

Cystotomy

Urinary calculi can develop in any species of reptile that has a urinary bladder but seem to occur most frequently in desert tortoises (**Gopherus agassizzii**) and green iguanas. Improper nutrition and inadequate access to water or dehydration have been suggested as initiating causes.[3] Clinical signs of

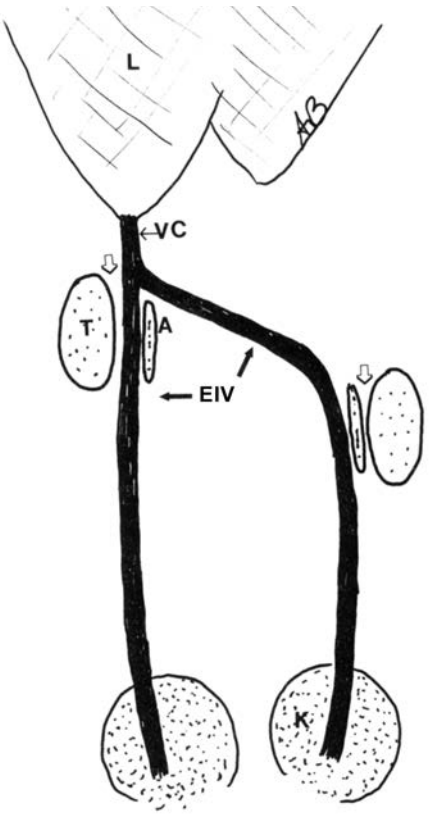


Figure 45-9. Anatomy of the male reproductive tract of a green iguana. The testicles are removed as described for ovariectomy in figure 45-8. *Open arrows* demonstrate the location where clips are applied. *L.* liver, *VC.* vena cava, *EIV.* external iliac vein, *T.* testis, *K.* kidney, *A.* adrenal gland.

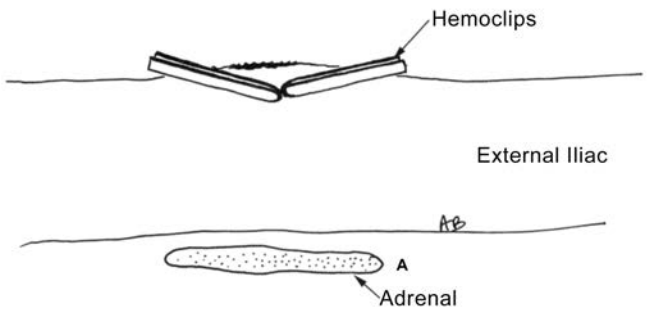


Figure 45-10. Hemostatic clips are applied to the external iliac if there is damage to the vein. Partial occlusion does not generally cause clinical problems. *A.* adrenal gland.

cystic calculi include anorexia, depression, constipation from occlusion of the colon, dystocia from occlusion of the oviduct, cloacal prolapse from tenesmus, and paraparesis secondary to compressive injury to the pelvic nerves.[3] A definitive diagnosis is made based on radiographs or palpation. Calcium urate calculi are radiopaque while ammonium urate calculi can be very difficult to visualize radiographically.

In chelonians, cystic calculi are palpated in the left inguinal fossa. The urinary bladder of chelonians is bilobed and the right liver lobe lays over the right lobe of the urinary bladder. Because the right portion of the bladder is compressed by the right liver lobe, most cystic calculi are present in the left lobe of the bladder. A finger is inserted into the fossa with the chelonian in a sternal recumbency. With the finger left in place, the tortoise is tipped to verticle (90 degrees) and the stone is felt hitting the finger as it falls to the dependent portion of the bladder. In lizards, cystic calculi are easily identified by abdominal palpation.

Cystotomy is performed through a standard celiotomy approach. The bladder is large and easily identified when a calculus is present. The bladder wall is very thin and transparent but becomes somewhat thicker because of the cystitis usually associated with a calculus. The bladder is isolated with moist gauze sponges or laparotomy pads prior to making the cystotomy to minimize coelomic contamination. The urine of reptiles contains mucus and urates giving it a thick, cloudy appearance which may not be easily aspirated through small suction tips. Following removal of the calculus, the bladder is irrigated to remove residual debris. Closure is accomplished using a fine (5-0 to 7-0) monofilament, absorbable material on a small, swaged-on, atraumatic needle in a simple continuous appositional pattern oversewn with an inverting pattern. Celiotomy closure is routine.

Because dehydration may cause dessication of urates within the bladder initiating calculus formation attention must be paid to maintaining adequate hydration. Antibiotics are indicated if bacterial cystitis is present. Husbandry changes (nutrition, temperature, access to water) are made where appropriate.

Reproductive Organ Prolapse

The cloaca of reptiles consists of three compartments: the coprodeum, the urodeum, and the proctodeum. Each of these compartments and their associated structures can, theoretically, prolapse; however, this has never been reported. The coprodeum is the most cranial compartment of the cloaca and is where the rectum enters.[13] This compartment receives urinary and fecal wastes from the terminal colon. The urodeum is the middle section of the cloaca and is where the ureters and the reproductive systems terminate. Urinary wastes of reptiles pass into the urodeum and then into the urinary bladder (chelonians and most lizards), or into the terminal cloaca (snakes and some lizards) where water absorption occurs.[13,14] The proctodeum is the caudal compartment of the cloaca and is a reservoir for fecal and urinary wastes prior to their excretion.

The anatomy and location of the male copulatory organ varies among reptile orders. Squamate reptiles (most lizards and snakes) have hemipenes (paired copulatory organs). Hemipenes in these reptiles are hollow organs that are inverted within the tail. Crocodilians, chelonians, and some lizards have a single phallus or penis. The penis of these reptiles is within the cloaca or coelomic cavity and is a solid organ. It is directed cranially within the cloaca and is everted during copulation. Neither the reptile penis or hemipenis contains a urethra. These organs are not for urination but strictly for the transport of semen.[14]

Paraphimosis occurs more commonly in chelonians than in squamate reptiles. Causes include excitement, stress, infection or inflammation, neurologic deficits, cloacal impaction, trauma to the exposed organ from cage mates or the enclosure substrate, forced separation during copulation, and iatrogenic trauma secondary to probing for sex determination.[13,15]

The prolapsed organ is often edematous from venous engorgement, lacerations from cage mates or the substrate, and may be infected, necrotic, and covered with inflammatory exudates.[13,15] If the tissue is very edematous and necrotic it may be difficult to determine if the prolapsed tissue is penis/hemipenes or another structure. It is simple to ascertain the nature of the tissue in most squamates. If the base of the prolapsed tissue is coming from the caudal aspect of the vent (i.e. coming from the tail) it is most likely a hemipenis or hemipenes. In crocodilians and chelonians, with severely damaged prolapsed tissue, it may be difficult to determine the origin of the tissue without entering the coelomic cavity. The penis/hemipenis is solid and has no lumen, while prolapsed intestine is hollow and has a lumen. If the sex is unknown, the oviduct is also hollow and often contains striations, unlike the intestine.

The reptile is sedated or placed under general anesthesia and the prolapsed organ is cleaned and lubricated. If lacerations are present, attempts are made to suture them, but usually edematous tissues will not hold sutures well. The tissue is then replaced into the tail in squamate reptiles or into the cloaca in chelonians and crocodilians. Moistened cotton-tip applicators are useful in reducing the prolapsed tissue.[13] If the prolapase does not reduce, application of a cold compress or hygroscopic fluids (glycerin or concentrated sugar solution) may help. In addition, stay sutures can be placed in the center of the vent (the opening of the cloaca), both proximal and distal, to help with traction. The vent can also be incised laterally on one or both

sides. Once the prolapse is reduced it is kept in place with a purse string or transverse sutures in the vent. Transverse vent sutures have the benefit of allowing fecal and urinary wastes to be passed more easily than through a purse string suture. In squamate reptiles, a purse string can be placed in the vent at the base of the tail (Figure 45-11). It is best to place a stent into the vent to prevent over-tightening allowing urine and feces to pass while keeping the tissue in place. This technique allows for normal cloacal function.[13] Regardless of the technique used the sutures are removed in 2 to 3 weeks.

If the tissue is necrotic or infected it should be amputated. Amputation of the penis, hemipenis or both hemipenes will not compromise urination. In snakes and lizards, amputation of one hemipenis still allows reproductive viability.[13] Mattress sutures or encircling sutures are placed around the base of the prolapsed tissue, and the organ is amputated distal to the suture (Figure 45-12). The mucosa of the stump is sutured with a simple continuous pattern, and the stump is replaced into its normal anatomic location.

Prolapse of the oviducts has occurred in female reptiles.[15] In some cases it is possible to reduce the prolapsed tissue; however, the viability of the tissue and assessment of damage to the suspensory ligament of the oviduct is limited.[13] Amputation of the exposed tissue has been performed but celiotomy for complete assessment of the prolapsed tissue and repair or removal of the reproductive tract is recommended. If only one side of the reproductive tract is removed, the contralateral side allows for reproductive viability.

Other Procedures

A variety of surgical procedures such as enterotomy for removal of foreign bodies may be performed in reptile patients once the surgeon is familiar with the unique anatomy of and surgical approaches used in reptile patients. Once the approach to the celomic cavity is made, most procedures are analogous to those performed in domestic animal surgery.

References

1. Bennett RA: Reptilian surgery. Part I. Basic principles. Compendium on Continuing Education Pract Vet 1989;11:10-20.

2. Bennett RA: Reptilian Surgery. Part II. Management of surgical diseases. Compendium on Continuing Education Pract Vet 1989;11:122-133.

3. Mader DR, Bennett RA, Funk RS, Fitzgerald KT, et al. Surgery. In: Mader DR. Reptile Medicine and Surgery 2nd edition. Elsevier, St. Louis, Missouri; 581-630, 2006.

4. McFadden MS, Bennett, RA, Kinsel MJ, Mitchell MA. Evaluation of the histologic reactions to commonly used suture materials in the skin and muscle of ball pythons (Python regis). Am J Vet Res 72 (10); 1397-1406, 2011.

5. Govett PD, Harms CA, Linder KE, et al. Effects of four different suture materials on the surgical wound healing of loggerhead sea turtles,Caretta







Figure 45-11. A. Hemipenis prolapse in an Eastern Diamondback Rattlesnake *(Crotalus adamanteus).* **B.** The hemipenis is replaced into its normal anatomic position with sterile lube and gentle manipulation with a sex probe. **C.** A mattress suture is placed in a portion of the vent to prevent the hemipenis from everting but still allowing for passage of cloacla contents through the vent.



Figure 45-12. A. and **B.** A common boa constrictor *(Constrictor constrictor)* with a chronic, healed, traumatic tail amputation and hemipenis prolapse. Because the hemipenis prolapse was likely associated with the tail injury, a decision was made to amputate the hemipenis. **A.** The hemipenis from the snake is being sutured with an encircling suture of 3-0 PDS. **B.** The hemipenis has been transected.

caretta. Journal of Herpetological Medicine and Surgery;14,6-10, 2004.

6. Millichamp NJ, Lawrence K, Jacobson ER, et al: Egg retention in snakes. Journal of the American Veterinary Medical Association 1983;183:1213-1218.

7. Smith DA, Barker IK: Preliminary observations on the effects of ambient temperature on cutaneous wound healing in snakes. Proceedings of the American Association of Zoo Veterinarians. 1983, 210-211.

8. Funk RS. Snakes. In: Mader DR. Reptile Medicine and Surgery 2nd edition. Elsevier, St. Louis, Missouri; 42-58, 2006.

9. Barten SL. Lizards. In: Mader DR. Reptile Medicine and Surgery 2nd edition. Elsevier, St. Louis, Missouri; 59-77, 2006.

10. Boyer TH, Boyer DM. Turtles, tortoises, and terrapins. In: Mader DR. Reptile Medicine and Surgery 2nd edition. Elsevier, St. Louis, Missouri; 78-99, 2006.

11. Lane T. Crocodilians. In: Mader DR. Reptile Medicine and Surgery 2nd edition. Elsevier, St. Louis, Missouri;100-117, 2006.

12. McCracken HE. Organ location in snakes for diagnostic and surgical evaluation. In: Fowler ME, Miller RE, editors. Zoo and Wild Animal Medicine Current Therapy 4. WB Saunders, Philadelphia; 243-248,1999

13. Moore MC: Castration affects territorial and sexual behavior of free-living male lizards, *Sceloporus jarrovi.* Animal Behavior 1987;35:1193-1199.

14. Cooper WE, Mendonca MT, Vitt LJ: Induction of orange head coloration and activation of courtship and aggression by testosterone in the male broad-headed skink *(Eumeces laticeps).* Journal of Herpetology 21:96-101, 1987.

15. Mason P, Adkins EK: Hormones and social behavior in the lizard, *Anolis carolinesis.* Hormone Behavior 1976;7:75-86.

16. Lock BA. Reproductive surgery in reptiles. In: Bennett RA. Soft Tissue Surgery. Veterinary Clinics of North America: Exotic Animal Practice:3, 733-752, 2000.

17. Bennett RA, Mader DR. Cloacal prolapse. In: Mader DR. Reptile Medicine and Surgery 2nd edition. Elsevier, St. Louis, Missouri; 751-755, 2006.

18. Barten SL. Penile prolapse. In: Mader DR. Reptile Medicine and Surgery 2nd edition. Elsevier, St. Louis, Missouri; 862-864, 2006.

Abdominal Surgery of Pet Rabbits

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Introduction

Because of their relative ease of care and their docile dispositions, rabbits are becoming more and more popular as pets in today's transient society. They are now estimated to be found in more than 1% of households in the United States, and represent some 4 million animals. As such, requests to small animal practitioners to provide rabbits with both medical and surgical care are increasing. In many areas, practitioners are responding to the increase in popularity of this animal species, with resulting supplemental income to many practices. In some cases, rabbits comprise a significant percentage of the total number of patients, and the result is that some practices are devoted exclusively to exotic animals. Unfortunately, some clinicians are failing to take advantage of emerging "pocket pet" clientele and to incorporate these patients into their practices. Practitioners' reluctance to provide such veterinary care, especially surgery on rabbits, may, in part, be due to a lack of formal training in the species during their veterinary education and training. It may also be due to a lack of confidence based on clinical experience with the species; no mentor may have been available for guidance. Reference texts recommended for practitioners considering treating rabbits in their practices should include Ferrets, Rabbits, and Rodents Clinical Medicine and Surgery, Quesenberry K and Carpenter J editors, 3rd edition, Elsdevier, 2012, BSAVA Manual of Rabbit Surgery, Dentistry, and Imaging. Francis Harcourt-Brown and John Citty editors. 2013, the current edition of James W. Carpenter's Exotic Animal Formulary, and the 3rd edition of Ferrets, Rabbits, and Rodents by Drs Quesenberry and Carpenter.

The intent of this chapter is to provide veterinary practitioners with basic information necessary to safely perform common abdominal surgical procedures in rabbits. Included are a general overview of anatomy, indications for each type

of surgical procedure, and detailed descriptions of commonly performed procedures: gastrotomy, cystotomy, ovariohysterectomy, orchiectomy (castration), and vasectomy. Because each procedure occurs within the abdominal cavity (castration may also be performed outside the abdominal cavity), several areas are common to all and warrant discussion beforehand: a review of the unique properties of rabbit skin, preoperative considerations, guidelines for preparation of the surgical area, general surgical principles particular to the rabbit, and useful suture patterns for closure.

Anatomy of the Skin

Except for some of the heavy skinned rabbit breeds whose pelts are used in the fur trade, a rabbit's skin is thin relative to body size.[1] The full thickness of the skin, including the hypodermis and panniculus carnosus, is generally only 1.0 to 2.0 mm thick. Except for the tip of the nose and the inguinal region (in both sexes) and a small area on the scrotum in bucks, a rabbit's skin is covered with fine textured hair, and both underfur and guard hairs are present. Rabbits generally molt their hair coats annually, with hair loss starting on the shoulders and moving caudally. Frequently, patterns and rates of hair growth and regrowth (where the hair has been clipped for a surgical procedure) do not appear uniform; this is often a concern of clients. After the rabbit's hair has been clipped, it may not begin to grow back uniformly and may look patchy, with some areas of hair longer and appearing to grow faster than others. This unusual, seemingly abnormal skin coat can be more pronounced in young, white animals when the hair on the animal's flank has been removed. It does, however, represent normal skin responses to variations in rabbit hair growth cycles. The raised, blotchy patches are areas of active hair growth. Beginning with the second coat of hair, waves of hair growth periodically move caudally and ventrally from the neck region. These "growth waves" occur in areas of the skin where all the hair follicles are simultaneously in an active growth cycle. Owners should be informed of this when the rabbit is discharged from the veterinary clinic.

The hair growth cycle has been divided into three main phases: anagen, catagen, and telogen. The anagen, or growing, phase, is the time when the germ cells undergo a burst of mitotic activity, leading to the formation of the sheathed hair bulb and papillary cavity and emergence from the skin surface. The catagen, or transition, phase is a brief period in which mitotic activity slows and the follicle shortens. The hair then passes into the telogen phase, which is a resting period. Changes in the vascularity and thickness of the skin are associated with these phases of the hair growth cycle. The skin thickness is approximately 1.0 mm during the telogen phase and may become 2.0 mm thick during the anagen period. As rabbits become older, the waves become less frequent and more patchy in their distribution.

Preoperative Considerations

Normal rabbit behavior and activity are typically sedentary, and stoic, but nervous or wary of their environment when compared with dogs and cats. As such, they may have preexisting health problems that may not manifest themselves clinically to their owners and can be easily overlooked preoperatively in today's busy veterinary practices. This is typical of species that are prey and they will hold off showing illness. The rabbit should be examined in a quiet setting and therefore, each animal must have a complete presurgical workup including physical examination, history, and, if possible, complete blood count and urinalysis. Diet, eating habits, and volume or consistency of fecal production are important items to be addressed. Clinical or subclinical problems, such as dehydration or emerging septicemia, should be corrected before any surgical procedure, to maximize the potential for a successful outcome. Because rabbits cannot vomit, withholding of food and water before the surgical procedure is not necessary, although 2 to 3 hours of fasting will clear the oral cavity, and may decrease the ingesta within the stomach, intestines, and in particular, the cecum. Assessment of pain requires astute observation. Signs of pain include reluctance to move, sitting in a stiff, hunched posture, rapid, shallow respiration, and tensing upon palpation. An elevated rectal temperature may indicate pain, stress, inflammation or infection.

As in other species, prophylactic antibiotics may be used in rabbits undergoing surgical procedures. Because of the predominance of gram-positive bacterial flora in the rabbit gastrointestinal tract, especially the cecum, any antibiotic that affects those populations, such as oral penicillins, cephalasporins, macrolides, and tylosin, should be avoided. Antibiotics, such as trimethoprim sulfa combinations, or fluorinated quinolones such as enrofloxacin, given either individually or together, can be used effectively with minimal side effects. These drugs are generally started the day before surgery, or they are administered at induction of anesthesia and are maintained for 3 days to ensure adequate blood levels should unexpected contamination occur during the surgical procedure. Clostridial overgrowths can occur in rabbit ceca and large intestine if the diet has been high in carbohydrates and sugars when using fluoroquinolone antibiotics alone. Fluoroquinolones are not effective against clostridial infections. If clostridial populations are suspected due to diet or detection of spores on fecal gram stains, metronidazole may be added to the antibiotic regimen. In the healthy rabbit, cecoliths are ingested and a few make it through the acidic stomach to the cecum to replenish the cecal flora. During illness or antibiotic therapy, this process is interrupted. Orally administered probiotics may not survive transit through the stomach and small intestine. The colon and large intestine of the rabbit sorts materials by particle size. Particles greater than 2 mm are passed into the colon and rectum to form fecal pellets. Smaller particles are moved back to the cecum via retroperistalsis. Thus probiotics administered in small quantities rectally may actually be moved back to the cecum to enable the rabbit to reestablish normal flora. An enema of healthy rabbit cecoliths is advantageous when administered to rabbits with anorexia and diarrhea post operatively. In addition, administration of fluids and gastrointestinal motility stimulants such as metoclopromide may be indicated to enhance intestinal tract motility postoperatively. Since anesthesia and opiate analgesics may slow gastrointestinal motility, use of motility stimulants will often speed recovery of normal intestinal motility. The rabbit should be encouraged to eat soon after surgery.

Preparation of the Surgical Site

For all procedures described in this chapter, the rabbit is placed in dorsal recumbency on heated water blankets with all four limbs fully extended. The animals are preanesthetized with a combination of ketamine hydrochloride (35 mg/kg intramuscularly), xylazine (5 mg/kg intramuscularly), and glycopyrrolate (0.1 mg/kg subcutaneously); they are carefully intubated and maintained on isoflurane and oxygen during the procedure. Alternative regimens include the use of glycopyrrolate, and ketamine at 20 to 30mg/kg IM with diazepam at 1 to 3 mg/kg IM. A number of different anesthetic regimens have been published and should be considered depending on the procedure to be performed. It is important to minimize stress to the rabbit during drug administration and the anesthetic induction phase. The reader is referred to the literature for additional information on anesthetic protocols used in rabbits.[2,3] Intravenous access is established with a 24 gauge catheter (Angiocath) placed in the marginal ear or cephalic vein and maintained by the slow administration of an isotonic crystalloid fluid. As the rabbit has a large and heavy abdomen in comparison with the thoracic cavity, care should be taken to slightly elevate the thorax during surgery and to not tilt the rabbit's head and thorax downward as is sometimes performed with carnivore abdominal surgery. The reader is referred to the literature for additional information on anesthetic protocols used in rabbits.[2,3]

Preparing the rabbit's skin for surgery can be a challenge to a practitioner inexperienced with the species. Removing hair at and around the incision site without damaging the skin can be frustrating. Although many clinicians use traditional clinic clippers with a No. 40 dipper clipper blade to remove hair, variable high speed clippers (e.g., Double K Industries, Inc., Model 401) specifically designed for animals with fine hair, such as rabbits and rodents are recommended. These clippers make hair removal easier and reduce the incidence of accidental cutting or burning of the skin. If possible, hair should be removed at least 5 to 10 cm in every direction from the incision site.

Rabbit skin can be sensitive to alcohol. Care should be taken to avoid excessive scrubbing when preparing the skin for surgery. After clipping the hair, the surgical site is vacuumed to remove any remaining hair and is wiped with a saline soaked gauze. The skin is then surgically prepared using alternating applications of povidone iodine soap and either alcohol or sterile saline for a total of three applications each. Each application begins at the center of the surgical site and works outward in larger and increasing sized circles. Povidone iodine solution should be sprayed over the entire surgical site and allowed to dry. Chlorhexidine surgical scrub has also been used rather than povidone iodine. The author has found that using cosmetic-grade soft cotton rather than gauze sponges causes less irritation to sensitive rabbit skin, particularly the scrotum when preparing the site for castrations. The author performs local blocks of all incisional sites using 2% lidocaine 1:10 dilution with sterile water prior to skin incisions.

General Surgical Principles

The rabbit intestine occupies most of the abdominal cavity. Handling and manipulating the intestinal tract must be minimized as the tissue is fragile. Injury to the intestine may precipitate bacterial migration which may lead to fatal peritonitis and clostridial toxicosis. Rabbits also are highly prone to form adhesions and generous lavage with warm saline should be performed prior to closure of the abdominal wall. Adhesions occur due to multiple microhemorrhages which may occur during tissue handling. Postoperative ileus or intestinal gas formation may be fatal to the rabbit because the intestinal flora is disrupted.

Taking steps to minimize inclusion of foreign materials such as gauze lint, surgical glove powder, and talc also decreases the opportunity for adhesion formation. After donning a surgical gown and gloves and before beginning the procedure, the surgeon should wash the powder and talc off surgical gloves with sterile saline soaked gauze sponges. In addition, any gauze sponges with frayed ends should be removed from the surgical tray because these sponge fragments may fall into the rabbit's abdomen and become a nidus for adhesion formation.[5]

Another important practice for avoiding adhesion formation is performed during closure of the abdomen. The two cut peritoneal surfaces from the incision must be brought into apposition when closing the muscle fascia layer. This maneuver reestablishes continuity of the nonadherent peritoneal surface, which directly contacts the underlying organs. Failure to restore the peritoneal barrier often results in adhesions involving the muscle fascia layer with one or more abdominal organs, often with adverse outcomes.

Wound Closure

Various suture materials can be used to close wounds in rabbits, including absorbable and nonabsorbable materials. Chromic or plain catgut or suture material that increases the inflammatory response should not be used in rabbits. Long-acting synthetic absorbable suture material that is broken down by enzymatic hydrolysis such as polyglactin 910 or polydioxanone suture are preferred. Nonabsorbable sutures for skin include monofilament synthetics and stainless steel. As many rabbits will remove externally placed sutures, it is recommended that skin closure be performed using a subcuticular pattern. Elizabethan collars may be necessary short-term to prevent the rabbit from opening the surgical site, however with adequate post-operative analgesia, the use of physical barriers to the incision site may be minimized. Closure of the abdomen in most rabbits is difficult in more than two layers. The muscle-fascia layer (with underlying peritoneum) is the primary strength layer of the abdomen. As such, this layer should be closed using a tapered swaged on needle and a simple interrupted suture pattern. These sutures should be placed close together. Elevating the muscle fascia layer with towel clamps placed at each end of the incision during the closure is useful and reduces suturing time. The added visualization helps to avoid accidental suturing of an underlying organs and at the same time ensures approximation of the two edges of "glistening" peritoneum with each stitch. When completed, the suture line

should be evaluated for potential herniation using Brown Adson thumb forceps. The tips of the forceps are held together, and the surgeon gently probes between each suture. If the forceps can easily enter the abdomen, a potential for abdominal organ herniation exists, and additional sutures should be placed. This process is continued until sufficient sutures are placed to prevent forcep entry.

The skin may be closed using various different suture patterns and materials. I prefer to close the skin using either absorbable suture material, as mentioned earlier, on a swaged on, reverse cutting needle in a subcuticular pattern or by using surgical staples. Surgical staples are usually reserved for linear skin incisions on flat surfaces. The site and nature of the skin lesion generally dictate which method to use. Surgical glue can be used to close any gaps remaining in the skin after subcuticular closure.

Adjustable Cervical Collars ("Scratch Guards")

Rabbits have an almost compulsive desire to keep themselves well groomed. This behavior is often exaggerated by surgery to a level which, unless they are inhibited, the animals literally lick and bite themselves down to muscle and bone, removing skin, sutures, and anything else in an attempt to eliminate the incision site pain. Post-operative pain control using a combination of opiate and an NSAID, will help to decrease self-trauma to the surgical site. Unfortunately, rabbits usually do not tolerate the traditional Elizabethan collar well postoperatively. Although this device does keep them from removing the sutures or traumatizing the incision, the animals seem frightened and frequently do not eat, drink, or move around. Often, they just stay in one location with their heads down. One soft, adjustable type of cervical collar overcomes many of the problems associated with Elizabethan collars.[6] It can be easily constructed using available clinic materials and is reusable. Preparation begins with an initial circular ring made from a roll of gauze or flexible anesthetic gas tubing approximately 14 inches in circumference. Four by four gauze sponges are next wrapped around the ring to provide both padding to the animal's neck and external diameter enlargement to the collar. The gauze is secured in place by wrapping over it with both surgical adhesive tape and Vetwrap (3M, Minneapolis, MN) applied sequentially. This not only reinforces the gauze ring, but provides for a consistent collar diameter and water resistance. The finished collar is simply placed over the animal's head, and the slack in the ring is compressed until it's snug. The collar can then be secured by adhesive tape so it resembles a yoke (Figure 45-13). It was coined "scratch guard" by staff members because the animals did not scratch the surgical site. When this collar is used, the affected animals seem distracted from surgical site discomfort and appear to resume normal activity and eating and drinking.

In a report of more than 1500 abdominal surgical procedures using the scratch-guard only 2.5% of animals exhibited self mutilation episodes, and those episodes occurred primarily because of the rabbit's ability to remove the scratch guard,[6] Some rabbits however will be depressed with any type of collar restraint. A belly-band wrap using Vetwrap, and taped circumferentially

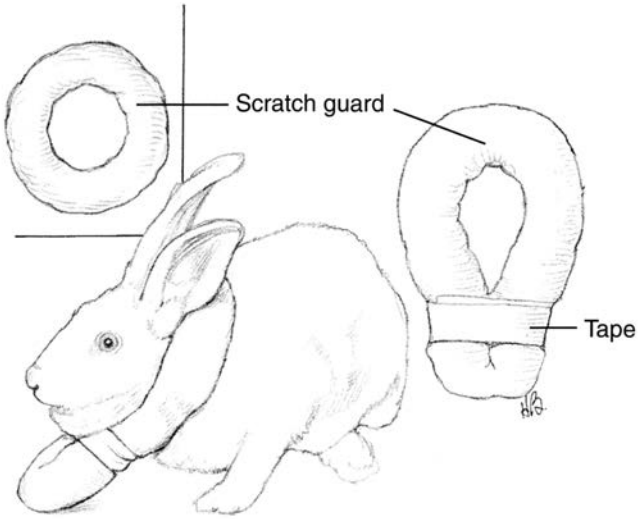


Figure 45-13. Adjustable cervical collar ("scratch guard").

cranially and caudally may be needed for several days. A gauze sponge with a topical anesthetic cream or gel can be placed over the incision. A layer of gauze bandage is wrapped loosely around the rabbit's mid-section, and finished with 2 to 4 layers of Vetwrap, then taped. The bandage needs to be loose enough to not constrict the abdomen, but layered enough to prevent the rabbit from chewing through it.

Postoperative Considerations

Postoperative care plays an important part in successful surgery in rabbits. Postoperative care can be broken down into two time periods: the first 24 hours after the surgical procedure and the next 13 days. After surgery, the animal is allowed to recover in a warmed, intensive care cage where the endotracheal tube is removed (on return of the animal's gag reflex). Once the rabbit is fully conscious, a scratch guard cervical collar is fitted, and food and water are offered. Close monitoring of the animal is important during the first 24 hours postoperatively, and, therefore; the animal should remain where it can be observed frequently by staff members. During this period, the animals should have complete health checks a minimum of twice a day. This examination includes rectal temperature, pulse count, thoracic auscultation, monitoring of fluid and water intake, monitoring of urination (volume) and defecation (amount and consistency), and monitoring of the incision line and the animal's behavior (activity and body language). In addition, the animals are continually evaluated for signs of pain, which may be obvious, such as vocalizations, to subtle, including reluctance to move, abnormal (hunched) postures, anorexia, grinding of teeth, elevated body temperature, increased respiratory rate, and unexpected aggression. If pain is present, pain relief can be provided (buprenorpbine, 0.05 mg/kg subcutaneously twice daily) as needed. NSAIDS such as meloxicam (Metacam, Boerhinger Ingleheim) at 0.2 to 0.5 mg/kg SQ or PO q 24 h or Carprofen (Rimadyl, Pfizer) at 2 mg/kg PO or SQ q 12 h or 4 mg/kg SQ q 24 h can be used with the opiate and greatly enhance the rabbit's return to normal activity. Minimal to no fecal production suggests potential cecal stasis. A "cow patty" stool may indicate bacterial enteritis. The rabbit must resume eating and drinking

as soon as possible following surgery. Rabbits normally have a small amount of ileus in the postoperative period, and the return to voluntary food and water consumption helps to prevent this occurrence from becoming deleterious. Offering the animals hay, either grass or timothy, usually stimulates reluctant animals to eat immediately. Critical Care (Oxbow Pet Products, Murdock NE) can be used to encourage eating, by assist-feeding it directly orally. Many pet rabbits will begin to eat when hand-fed and encouraged by nursing care. If the animal returns to near normal behavior, especially regarding food and water consumption, and normal urination, and defecation within 24 hours of the procedure the surgeon can send it home. To help facilitate a successful outcome, the owner should perform as many health monitoring techniques as possible, especially monitoring body temperature, incision site, food and water intake, urination and defecation (volume and consistency), movement, and overall attitude. Owners appreciate participating in the rabbit's postoperative care and in becoming more aware of their pet's health. A return progress visit should be scheduled for 3 to 5 days following major surgery.

Common Surgical Procedures

The common surgical procedures performed in the peritoneal cavity are discussed in this section. The techniques presented focus on procedures that I believe can be easily learned and are usually successful. No attempt is made to discuss all available surgical techniques. In addition, the description of each technique begins as if the surgeon had already opened the abdomen as discussed previously.

Gastrotomy

Rabbits are hindgut fermenters and have a simple, glandular stomach. The stomach serves as a reservoir for most of the ingested food, and it is never completely empty in a healthy animal. The stomach acids in the rabbit are among the most acidic of those of any species, with a pH of 1.2 to 1.5. This high acidity enables rabbits to use plant proteins more efficiently than most mammals and normally minimizes problems with ingested hair.

Unlike other species with incessant grooming behaviors, such as cats, rabbits physiologically cannot vomit.Consequently, ingested foreign materials, especially hair, which would normally induce a protective emetic reflex in other species, have the potential to become life threatening obstructions, unless sufficient roughage is present from the diet, and the rabbit is active, continually well-hydrated, and maintains normal gut motility. Additional predisposing factors in creating an obstructing trichobezoar may include boredom-associated over-grooming or ingestion of carpet/clothing fibers or other linear-type fabric strings, inadequate dietary roughage, anorexia because of off flavor or off odor feed, inability to smell from rhinitis, pain from sore hocks, malocclusion, lack of fresh water, or other stress factors. Once gastrointestinal motility is altered the rabbit may stop eating and drinking, and critical metabolic problems can result if this problem is not corrected.[4,7-13]

Common presenting complaints include anorexia, lethargy, weight loss, oligodipsia, diarrhea, or conversely, small or scant, dry feces. Other frequent clinical signs are dehydration, depression, hunched posture, tense abdomen, hypothermia, and bloating. Although definitive diagnosis of trichobezoar cannot be made without surgical exploration, a tentative diagnosis can be made based on history, clinical signs, palpation of an abdominal mass in the vicinity of the stomach, and contrast radiography, especially with fluoroscopy. Care should be taken when palpating the upper abdomen because the liver in these animals is often friable.

Rabbits with trichobezoars are frequently dehydrated and cachectic and should be treated as medical emergencies. Initial efforts should be directed at reestablishing normal homeostasis, including aggressive parenteral fluid administration before definitive therapy is pursued. Initial medical therapy involves the administration of intravenous or subcutaneous fluids, oral electrolyte fluids, and assist-feeding of a fiber-rich formula such as Oxbow's Critical Care. Fluids such as fresh pineapple juice or crushed papain tablets in water are promoted in many publications, but other than the fluid content, and possibly the sugar content of the pineapple juice, these have not been shown to dissolve or break-up a trichobezoar. These fluids should be given in small amounts (10 to 20 mL) four to six times a day for up to 3 to 4 days. Often, this oral fluid administration both "refloats" the hair mass in the stomach and aids in quickly rehydrating the animal. Refloating allows the proteolytic enzymes and stomach acids to penetrate the trichobezoar and to begin digesting the hair. The fiber-rich roughage is necessary to encourage gut motility. A valuable tool in assessing the efficacy of medical treatment is the production of fecal pellets in increased quantities. Radiographs are useful in assessing the size of the trichobezoar and its movement. Barium as a contrast agent must be used cautiously in animals that depend on cecal digestion. If the cecum becomes coated with barium, crucial metabolism and gut flora will be altered. Because of this, the author does not utilize contrast studies in rabbits with gastrointestinal motility disorders.

Other medical treatment strategies for treating trichobezoars, formerly a strictly surgical condition, have been successful in recent years, including the use of metoclopramide.[4,8-10] These newer regimens have reduced the number of animals that ultimately require surgical treatment. As a general rule, if no improvement is seen with medical therapy for trichobezoars after 3 days, these animals become surgical candidates for an exploratory gastrotomy. Animals presented for gastric foreign bodies other than trichobezoar are surgical candidates for gastrotomy (Figure 45-14). All animals having a gastrotomy are given prophylactic antibiotics, as previously mentioned, which are generally maintained for 5 to 7 days. Postoperatively, these rabbits resume food and water consumption as soon as possible. I recommend maintaining these rabbits in the hospital for several days until they return to normal eating, drinking, and defecating.

Orchiectomy (Castration)

Orchiectomy (castration) is one of the most common surgical procedures performed in companion rabbits. The usual indications for removing testicles are for birth control or to modify or eliminate certain offensive behaviors intact male rabbits (bucks) often develop when they reach sexual maturity. These behaviors include: urine spraying, territory marking with both urine and feces, and aggression toward their owners or other rabbits.

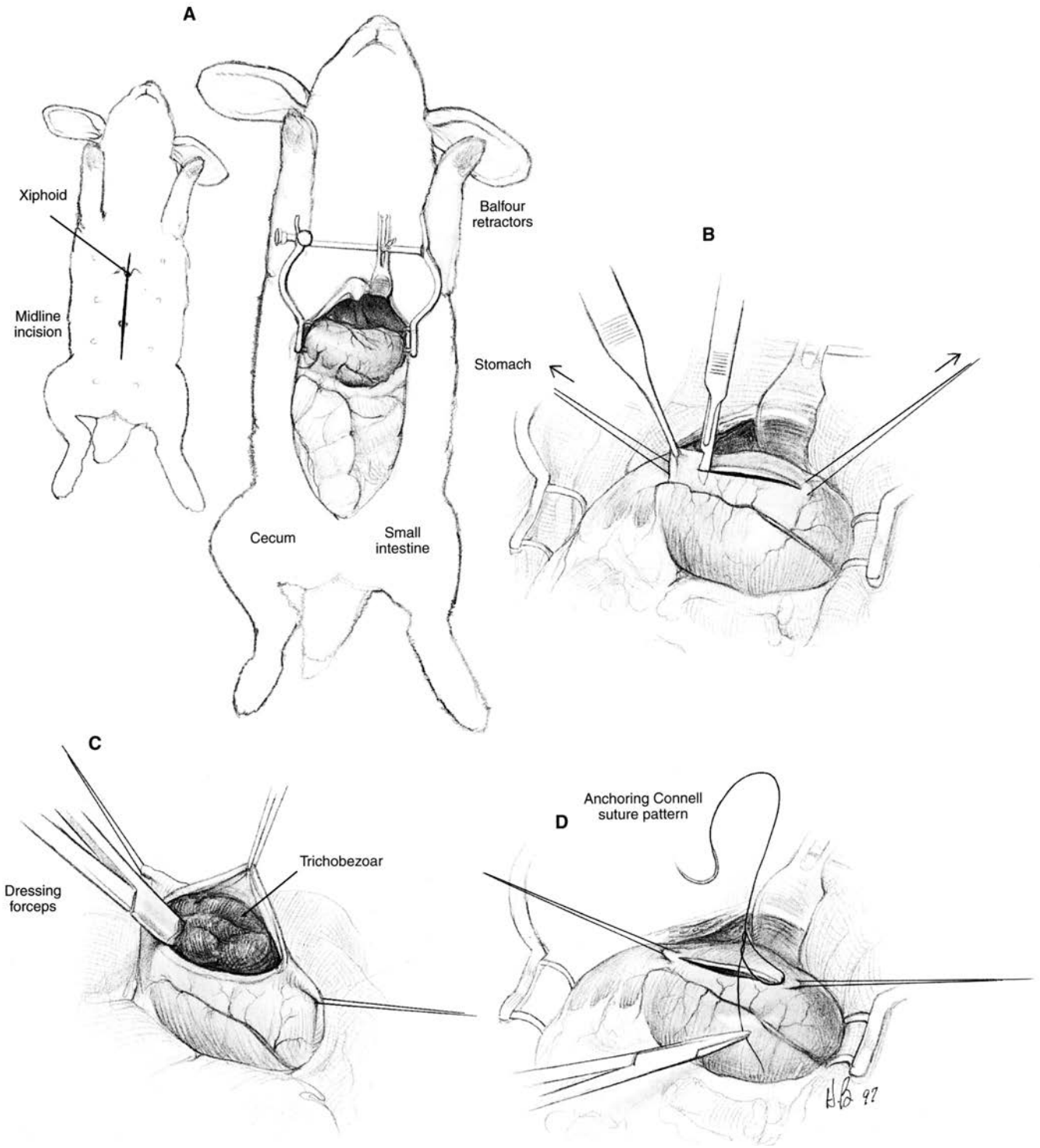


Figure 45-14. A. The animal is placed in dorsal recumbency, and the surgical site draped from 4 cm anterior to the xiphoid cartilage to 5 cm caudal to the umbilicus. A midline skin incision is made extending from 2 cm cranial to the xiphoid cartilage to 3 cm caudal to the umbilicus. Using thumb forceps and Metzenbaum scissors, the incision is continued through the linea alba through the muscle fascia layer into the abdomen. The surgeon must identify and avoid cutting the xiphoid cartilage when cutting the muscle cranially. When reaching the caudal edge of the xiphoid, the surgeon redirects the scissors and continues cutting the muscle along the edge of the cartilage for the remaining 2 cm. Both sides of the abdominal incision are lined with moistened laparotomy sponges. Exposure is maximized by placing pediatric self retracting Balfour abdominal retractors just caudal to the xiphoid. The two fenestrated retractor blades are spread laterally, and the xiphoid cartilage is elevated gently with the center Balfour blade to visualize the stomach, the cecum, and portions of the small intestine. **B.** Two stay sutures are placed 5 to 6 cm apart midway between the greater and lesser curvature of the stomach in a visibly avascular area. The sutures are lifted in opposite directions to elevate the stomach out of the abdomen and to provide a taut area for entering the stomach. The surgeon packs off the elevated portion of the stomach from the rest of the abdomen with moistened laparotomy sponges. Waterproof drapes are placed over the laparotomy sponges to prevent abdominal contamination from gastric contents when the stomach is opened. In addition, separate instruments should be available for entering and closing the stomach. A stab incision is made with a scalpel into the stomach.

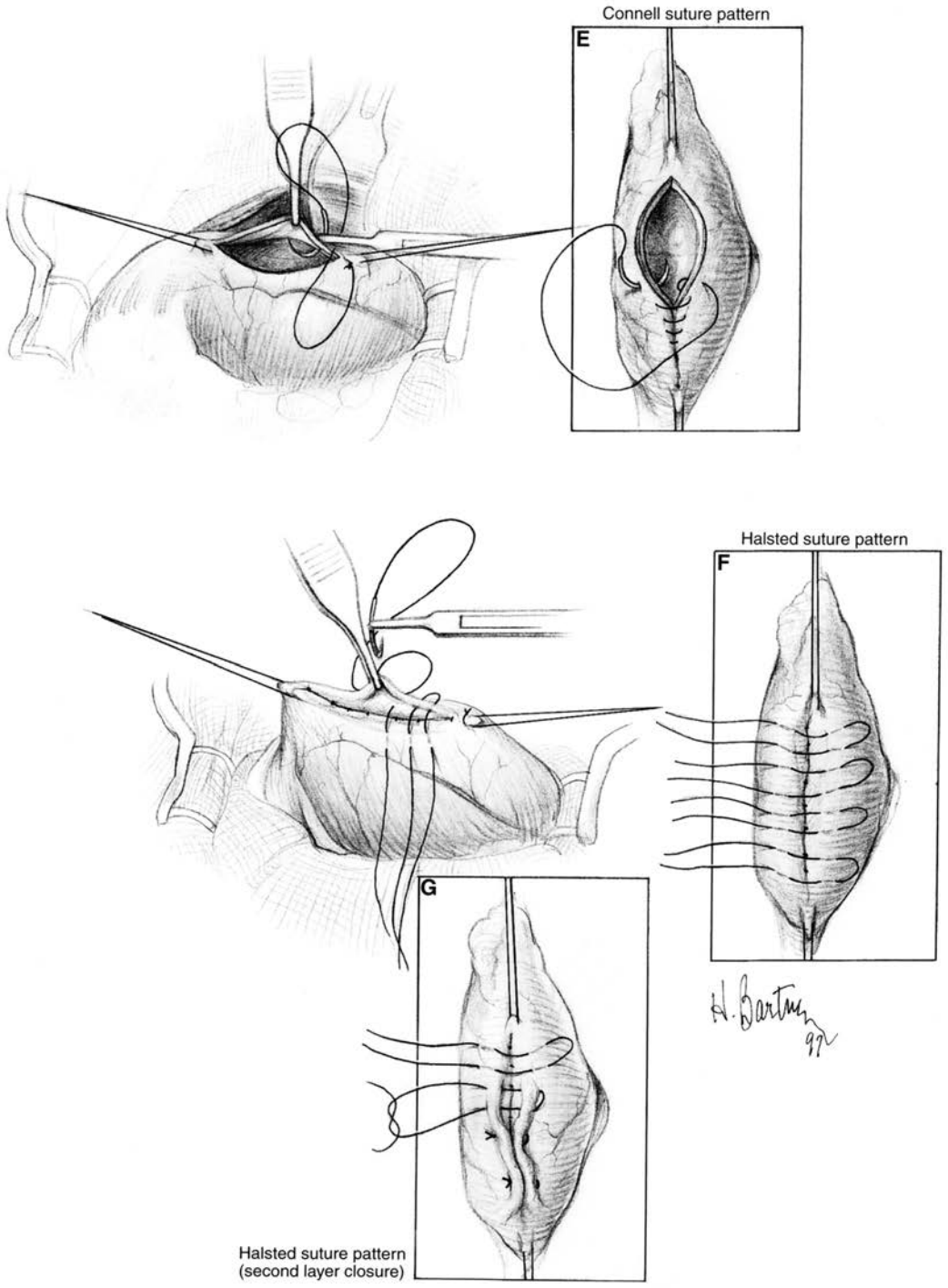


Figure 45-14 (continued). Suction is used to prevent accidental spillage of gastric juices onto the stomach serosal surface. This incision is extended as needed with a scalpel or with Metzenbaum scissors until a desired opening is achieved. **C.** The stomach contents are examined. If a trichobezoar is present, the hair mass is broken up and is removed with a pair of dressing forceps. The stomach is lavaged with warm saline solution and is suctioned. All instruments involved with entering the stomach are discarded. The surgeon should reglove, change or discard drapes, and begin closing the stomach with clean instruments. **D** and **E.** Closure of the stomach is accomplished with two inverting suture patterns using 3-0 polyglactin 910 or polydioxanone on a tapered needle. The first layer is a Connell pattern followed by a Halsted oversew. When performing the Connell pattern, full thickness bites should be placed from the edges of the incision, and the anchoring knots should be placed 2 to 3 mm from the incision at both ends. **F** and **C.** The second layer is closed using a Halsted suture pattern, which further inverts the incision and helps to ensure a complete seal. Each suture should be preplaced before being tied, to provide for even tissue inversion and tension distribution. Once the second layer is completed, the closure is checked for any leakage. The abdominal cavity should be lavaged with warm saline and suctioned if one sees evidence of gastric spillage. The stomach is returned to its normal anatomic position, and the abdomen is closed routinely.

Although not a panacea, castrating bucks generally makes them more docile, reduces fighting, and diminishes urine spraying. Other indications for castration are related to scrotal injury, including trauma from fighting or severe urine scalding.[4]

Male rabbits have two separate scrotal sacs, rather than one, as found in other placental mammals. These hairless structures lie slightly cranial to the penis. The testes are found in the abdomen at birth and descend into the scrotal sacs at approximately 3 months of age. Bucks reach sexual maturity between 4 and 5 months of age, depending on the breed of rabbit. Dwarf breeds mature more quickly than giant breeds. Castration is usually performed after the testicles descend. In addition to their peculiar scrotal anatomy, rabbits have open inguinal canals that allow the testicles to move easily between the scrotal sacs and the abdomen.[8] In intact bucks, epididymal fat, which lies cranial and medial to the inguinal canal on each side is normally inhibited from entering the scrotal sac by each testicle. Because this fat lies on the abdominal side of the inguinal ring, it, in turn, inhibits intestinal herniation through the canal. Castration techniques involving incision of the scrotal sac and removal of the testicle could potentially lead initially to epididymal fat herniation and, subsequently, herniation of the intestine into the scrotum unless the inguinal canal is closed surgically following castration.

Most of the techniques described for castrating male rabbits are adaptations of techniques used in dogs and cats: scrotal approach open castration with incised tunica albuginea and preservation of the epididymal fat; scrotal approach closed castration without incising the tunica albuginea; and the prescrotal approach over the inguinal rings with inguinal ring closure.[4,6,10,12] From experience, each technique is easily learned and has minimal complications. However, the scrotal perineal area can be traumatized or irritated either by the surgical procedure or by surgical preparation using any of these techniques. This trauma or irritation potentiates iatrogenic injury and the opportunity for subsequent bowel herniation or infection. Pre-surgical scrubbing should be gentle and the author prefers the use of chlorhexidine-based surgical scrubs delivered with cotton rather than gauze, and irrigated with sterile saline rather than scrubbed. The rabbit is positioned in dorsal recumbency with the thorax elevated. The incision is made on the midline just cranial to the scrotal sacs and penis. The incision should be as small as feasible (1-2 cm in length) to allow protrusion of the testicle. Ligation of the testicular vasculature is the same as in other species. For most bucks, a single suture applied through the inguinal ring and through the spermatic cord is adequate for hemostasis and closure of the inguinal ring. In this manner, the inguinal ring is closed, and no herniation can occur. The incision in the scrotum can be closed with a drop of tissue adhesive. The procedure is repeated on the opposite side. The use of manual pressure to elevate each testicle may cause bruising of the scrotal tissue, and therefore is not recommended. After both testicles have been removed, and the incisions glued, the author applies a topical anesthetic lidocaine gel to the scrotal tissue. Recently, the author has been applying Penetran ointment to the surgical area. This is an organic ammonia-based ointment that decreases pain and inflammation. It is absorbed into the skin completely so there is no residue for the rabbit to ingest. Healx Soother (Harrison's Pet Products, West Plam Beach, Fl). Post-operative analgesics and NSAIDS are continued for 2 to 4 days. With gentle tissue handling, the scrotum is not bruised or irritated, and with systemic pain control, most bucks seem unaware of the surgery.

An abdominal castration technique has also been described, and although it avoids the potential trauma to the scrotal or penile area, it does require post-operative use of a cervical collar and is more invasive. This method must be used in cryptorchid bucks (Figure 45-15).

When the animal is discharged from the clinic the owners must be advised that the desired effects of castration are not instantaneous. Although the animal's testicles have been surgically removed, male hormone levels have not been eliminated. Urine spraying, territory marking, and aggression may continue for a few weeks. In addition, libido and probably viable sperm (remaining in the vas deferens) are present for a month, and thus the potential for impregnating intact females does exists during that time.

Cystotomy

Urinary calculi (urolithiasis) are commonly encountered in clinical practice in pet rabbits, particularly in rabbits on an alfalfa-based pelleted diet. A healthy adult rabbit produces an average of 130 mL/kg of urine each day; this urine is usually turbid and varies in color from white to yellow to brown to orange to bright red.[8-11,14-16] The turbidity of the urine is due primarily to mineral precipitates. Because urine is the primary route for calcium and magnesium excretion in rabbits, various crystals, including ammonium magnesium phosphate, calcium carbonate monohydrate, and anhydrous calcium carbonate precipitates, are normally found on urinalysis.[8] The wide spectrum of colors and intensity is related to dietary pigments and the animal's hydration status; higher alkalinity and dehydration are usually associated with brighter, more intense colors.[8] The etiology of urolithiasis is still not clear, but several predisposing factors have been proposed, including urine stasis, genetic predisposition, dietary imbalances or diets high in calcium such as alfalfa-based diets and concurrent hypercalcemia), chronic urinary tract infections, and inadequate water intake.[8,9,14] Normal urine pH in rabbits is around 8.2, but at 8.5, calcium carbonate and phosphate crystals precipitate. Urine sludge is frequently seen and may or may not exacerbate the formation of calculi. The sludge itself can be irritating to the mucosa of the bladder and urethra, and add to the discomfort of the rabbit, reluctance to urinate, and with urine retention, increase the probability of ascending infection and stone formation. The most common presenting complaint in rabbits with urolithiasis is hematuria. As mentioned previously, rabbit urine may be any of several colors, depending on urine pH and diet. Diets high in calcium, such as alfalfa, can cause the urine to become bright red orange to red. Hematuria should, therefore, be confirmed by urinalysis or urine dipstick. This condition is often diagnosed after the animal has been presented for other problems. Hematuria was reported as the chief complaint in only one of seven rabbits with urinary calculi.[10] Other signs may include polyuria, perineal irritation from urine scalding, stranguria, lethargy, anorexia, hunched posture, abdominal distension, and chronic or intermittent

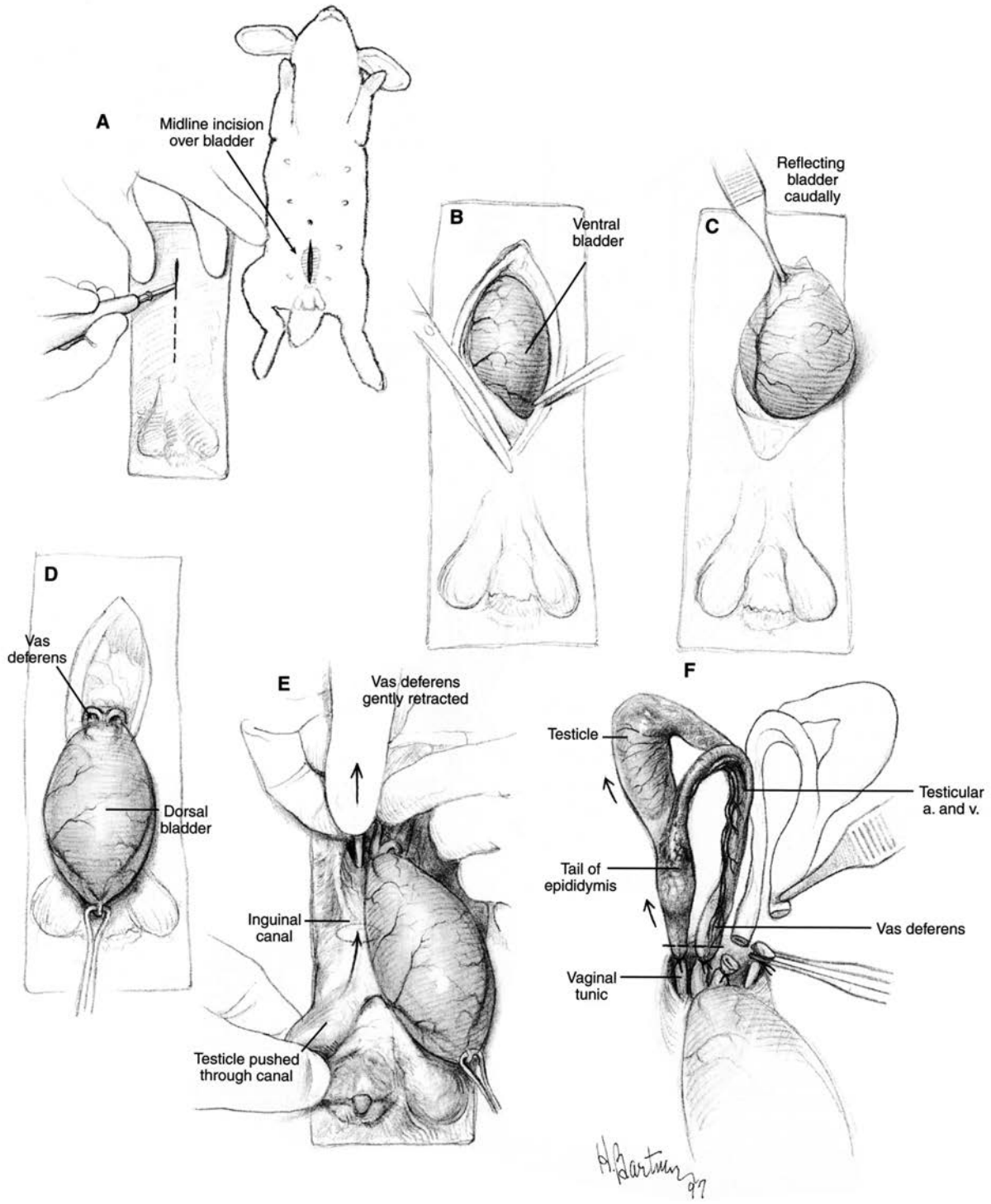


Figure 45-15. Abdominal orchiectomy (castration). **A.** The animal is placed in dorsal recumbency, and the surgical site is draped off to include the scrotum and penis. A midline skin incision is made extending from 5 cm caudal to the umbilicus to the level of the pelvis or 2.5 cm anterior to the genitalia or to the level of the last set of nipples. **B.** Using a pair of thumb forceps and Metzenbaum scissors, the incision is continued through the linea alba through the muscle fascia layer into the abdomen, exposing the ventral surface of the bladder. **C.** The apex of the bladder is grasped with a pair of Babcock (or other atraumatic) forceps and is reflected caudally, exposing the dorsal aspect of the bladder. **D.** Further gentle caudal retraction of bladder with Babcock forceps exposes the two vasa deferentia emerging near the base of the bladder. **E.** Removing the testicle involves performing the two procedures almost simultaneously: each vas deferens is gently retracted cranially (either with a spay hook or manually) while one gently pushes the testicle (often located within the scrotal sac) through the inguinal canal into the abdomen. **F.** This retraction continues until the entire testicle and blood supply are removed from the scrotal sac. These procedures are repeated for the other testicle. A ligature is placed around both vasa deferentia and their associated blood supply near the base of bladder. A second ligature is then placed between the head of the epididymis and its scrota attachment (at the vaginal tunic). The testicle can now be removed by cutting above both ligatures. After removal of both testicles, each side of the invaginated scrotal sac and its associated epididymal fat is pushed back to its normal position. The bladder is returned to its anatomic position, and the abdomen is closed routinely.

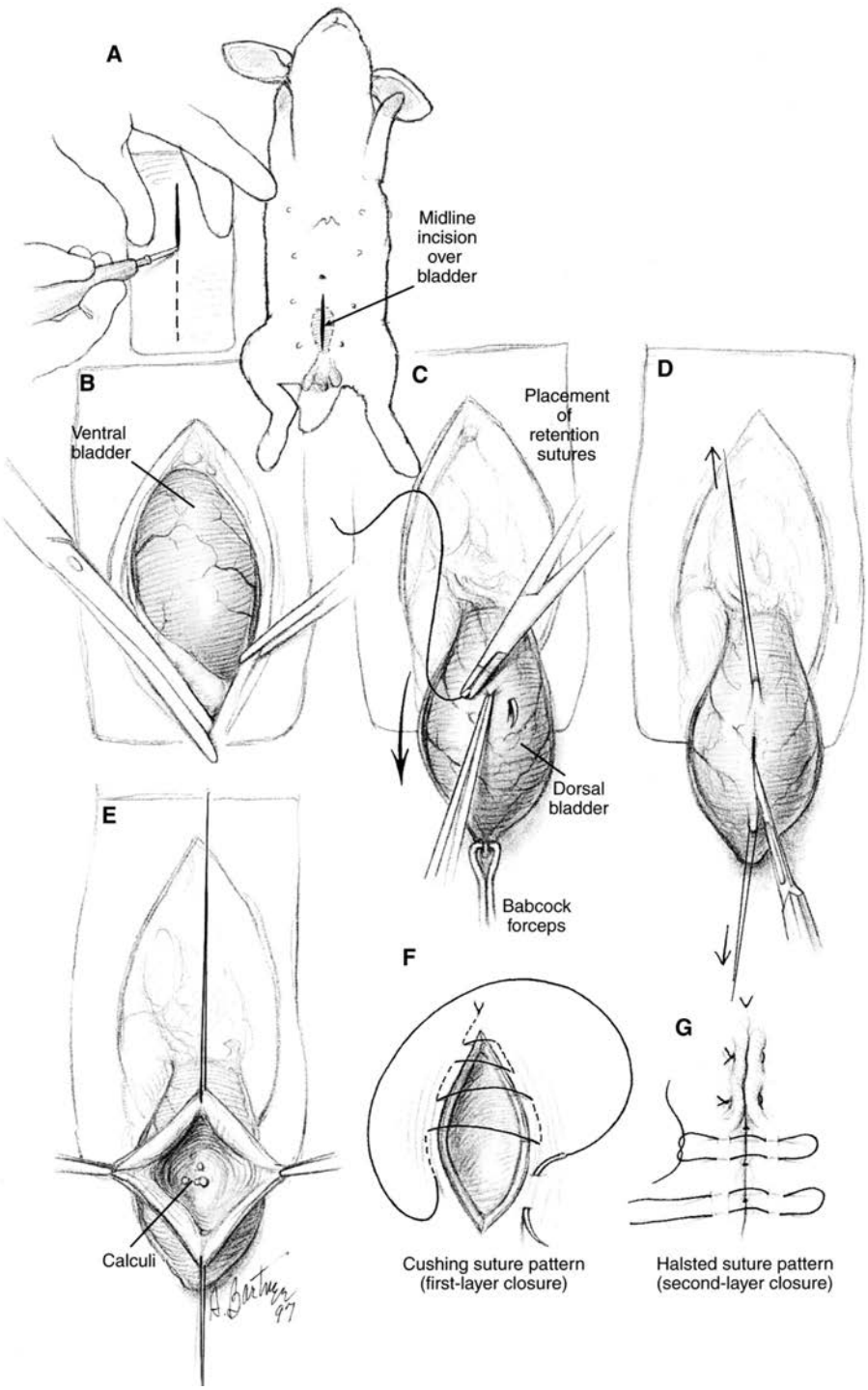


Figure 45-16. Cystotomy. **A.** With the animal placed in dorsal recumbency, a midline skin incision is made extending from a point 5 cm caudal to the umbilicus to the level of the pelvic brim. **B.** Using Metzenbaum scissors and forceps, the incision is continued through the thin linea alba and through the muscle fascia layer into the abdomen, exposing the ventral surface of the bladder. **C.** The apex of the bladder is grasped with a pair of Babcock (or other atraumatic) forceps and is reflected caudally, exposing the dorsal side of the bladder. The bladder is then isolated from the abdomen with moistened laparotomy pads. Then, using 3-0 polyglactin 910 or polydioxane suture on a taper needle, two retention sutures are placed 3 cm apart in an avascular location of the bladder. The bladder is then emptied by cystocentesis using a 25 gauge needle on a 20 mL syringe in a visibly avascular area of the fundus of the bladder. **D.** Lifting both retention sutures in opposite directions further elevates the bladder out of the abdomen and provides a taut area between them for entering the bladder. A stab incision is then made into this taut area with a scalpel. This incision is then extended cranially and caudally with Metzenbaum scissors. **E.** The bladder incision is then spread to allow inspection of the bladder contents. Any urinary calculi are removed with forceps or irrigation and suction. A specimen of bladder mucosa may be obtained for culture. **F.** The bladder is then closed in two layers using 3-0 polyglactin 910 or polydioxanone suture on a taper needle. The first layer is a Cushing suture pattern which inverts the suture line when completed. The suture should not penetrate the lumen of the bladder. **G.** The second layer is closed using a Halsted suture pattern, which further inverts the incision and helps to ensure a complete seal. Each suture should be preplaced before being tied, to provide for even tissue inversion and tension distribution. Once the second layer is completed, the closure is checked for any leakage. The bladder is returned to its normal anatomic position, and the abdomen is closed routinely.

cystitis.[4,9-11] Diagnosis can be confirmed through physical examination, palpation, and radiography.

The treatment of choice for urinary calculi is cystotomy (Figure 45-16). A urine culture should be taken by cystocentesis during the surgical procedure, before entering the bladder, and submitted for culture and antibiotic sensitivity testing. Any calculi removed should also be analyzed for possible dietary adjustment as part of the postoperative treatment.

The animals should undergo diuresis for 2 to 3 days postoperatively with either intravenous or subcutaneous fluids, and appropriate antibiotic therapy should be instituted, if indicated. An opiate analgesic along with an NSAID should be used for 3 to 5 days post surgery. The opiate is usually used for 24 to 48 hours, but the NSAID may be continued for 5 to 7 days, depending on the degree of inflammation noted in the bladder wall during the surgery. Acidifying the urine as is done with carnivorous animals is not indicated. Changing the rabbit's diet to one based

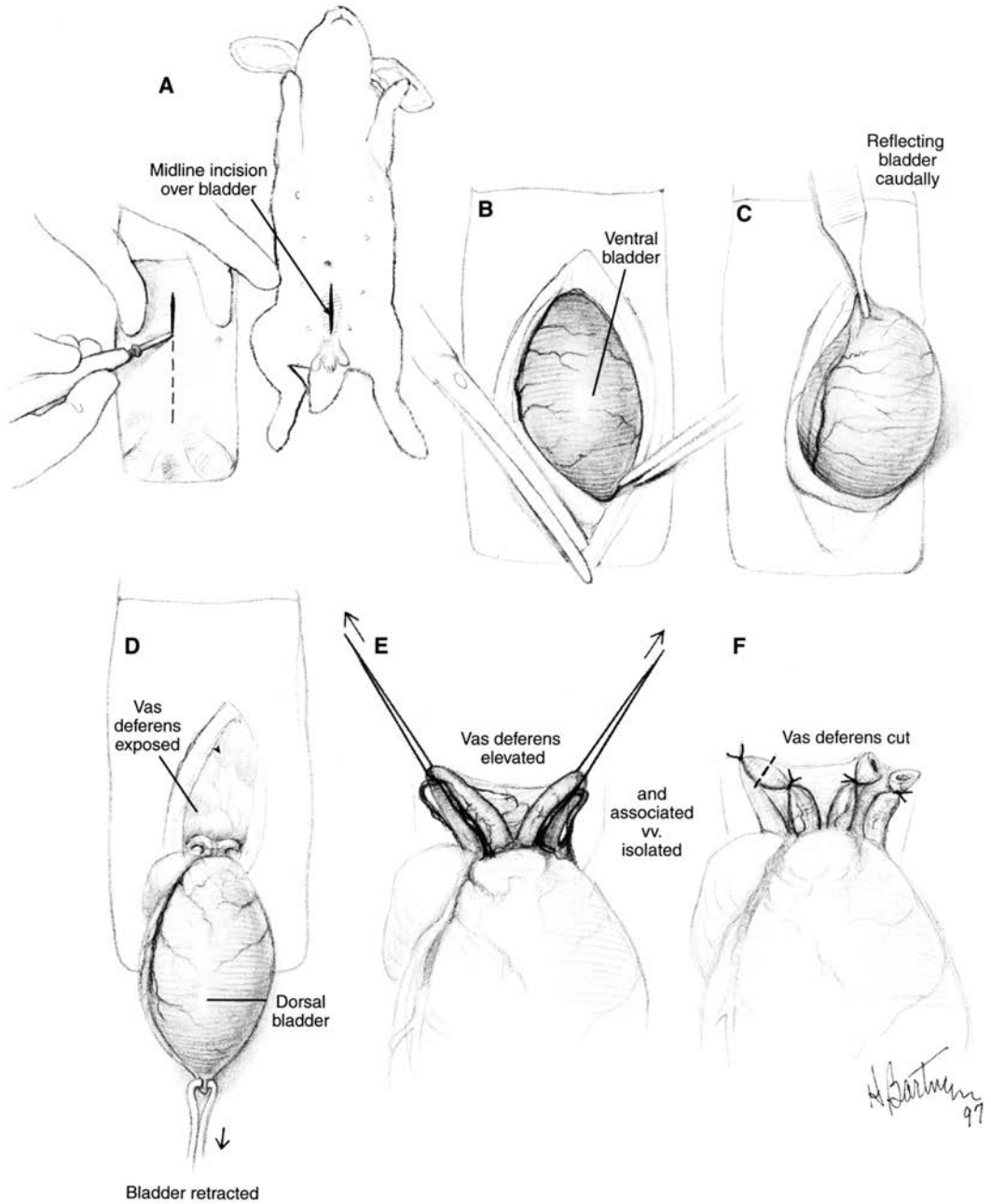


Figure 45-17. Vasectomy. **A.** With the animal placed in dorsal recumbency, a midline skin incision is made extending from 5 cm caudal 9 to the umbilicus to the level of the pelvis or 2.5 cm cranial to the genitalia or to the level of the last set of nipples. **B.** Using a pair of Metzenbaum scissors and forceps, the incision is continued on the linea alba through the muscle fascia layer into the abdomen exposing the ventral surface of the bladder. **C.** The apex of the bladder is grasped with a pair of Babcock (or other atraumatic) Orceps forceps and is reflected caudally, exposing the dorsal aspect of the bladder. **D.** Further gentle caudal retraction of the bladder with the Babcock forceps exposes the two vasa deferentia emerging near the base of the bladder. **E.** A ligature is placed around each vas deferens with care taken not to include the adjacent associated blood vessels. Each ligature is retracted to allow more exposure of each vas deferens for placement of second ligatures approximately 3 mm from the first **F.** Each vas deferens is divided between the two ligatures with Metzenbaum scissors to complete the vasectomy. The bladder is returned to its normal anatomic position, and the abdomen is closed routinely.

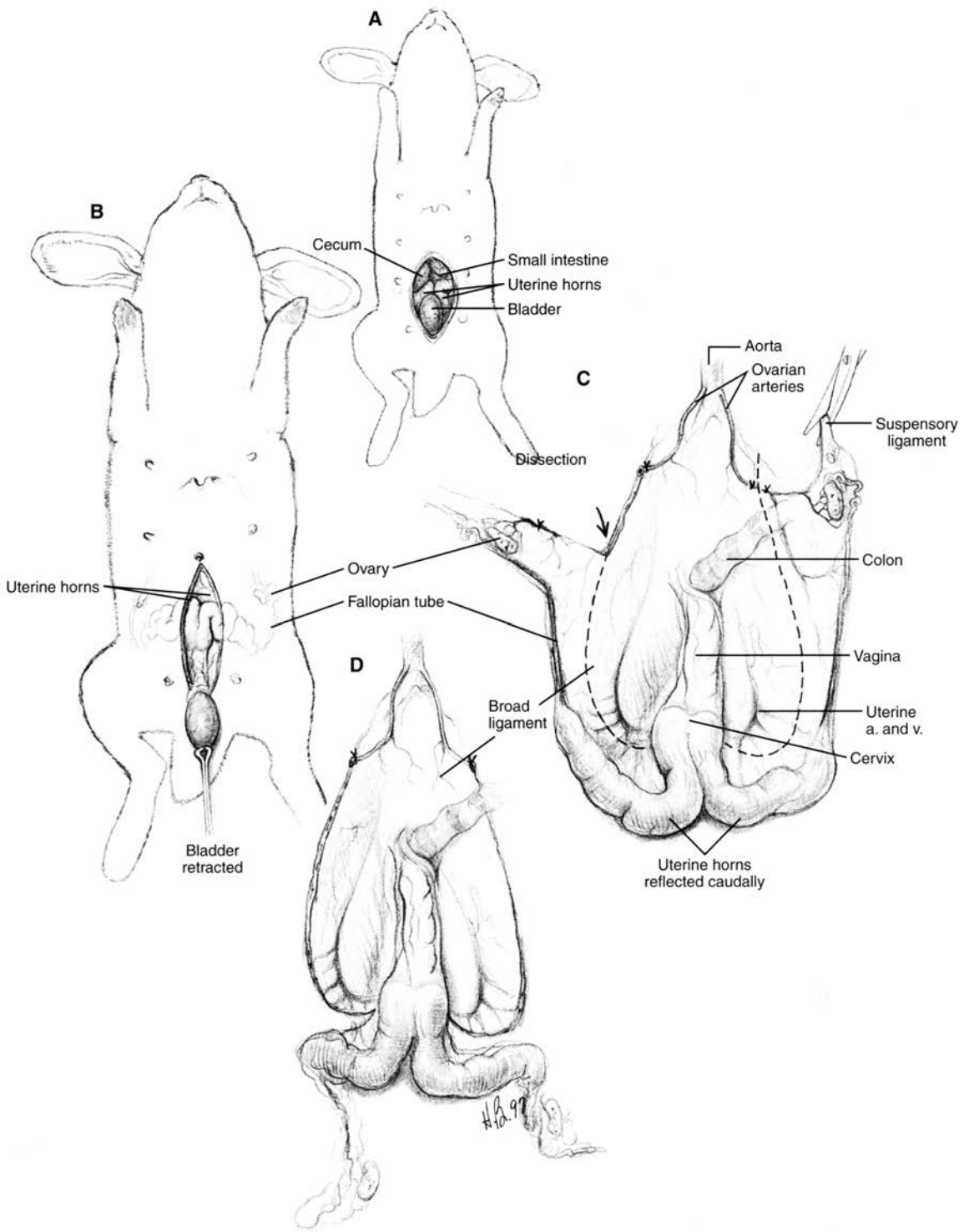


Figure 45-18. Ovariohysterectomy. **A.** With the animal placed in dorsal recumbency, a midline skin incision is made extending from the umbilicus to the level 2 cm caudal to the last pair of nipples. Using Metzenbaum scissors and forceps, the incision is continued through the linea alba through the muscle fascia layer into the abdomen, exposing small portions of cecum, small intestines, uterine horns and the bladder (if distended). Gentle retraction of the cecum laterally exposes the uterus. **B.** The bladder is retracted caudally with Babcock forceps to aid in visualizing the cervix and vagina. Using either Balfour or malleable retractors, the surgeon spreads the abdominal incision to aid in exposing the complete reproductive tract. **C** and **D**. Retracting the uterus caudally helps to expose the complete reproductive tract vagina, cervix, two uterine horns, both fallopian tubes and ovaries, and the major blood supplies. With moistened cotton tipped applicators, the fat is dissected gently to expose the abdominal aorta and the two ovarian arteries. Each ovarian artery is followed to the point where it branches to the ovary and the rest of the uterus. The surgeon places two ligatures around the vessel 3 mm apart above the branching and transects between them. The ovary is elevated, and the suspensory ligament identified and cut. The long fallopian tube and uterine horn are bluntly dissected from the broad ligament to the level 5 mm above the cervix, with care taken to control any hemorrhage from the many small vessels within the broad ligament supplying the uterine horn. This process is repeated on the opposite side.

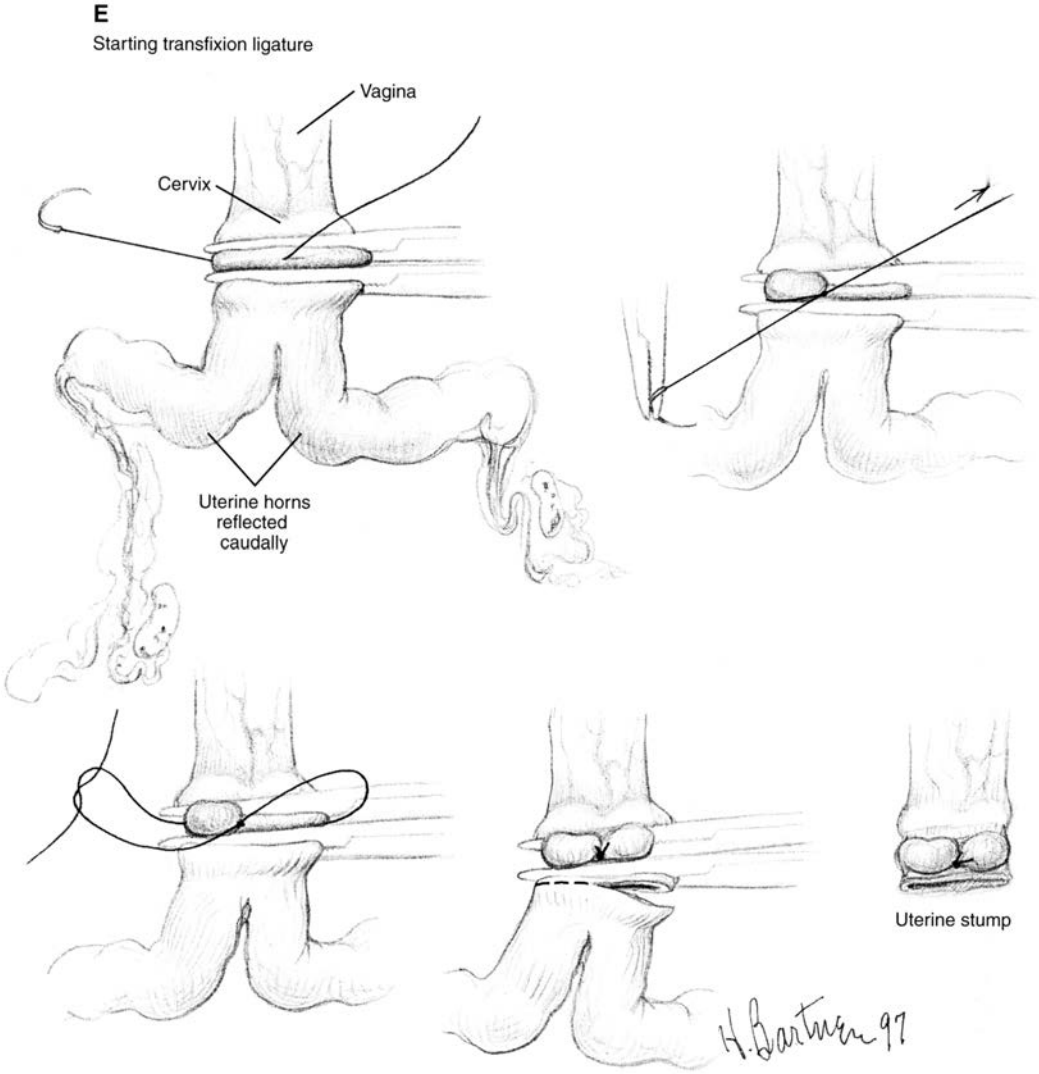


Figure 45-18 (continued). E. Continuing (with the uterus reflected caudally), the cervix is identified and is palpated to identify its anatomy. Kelly forceps are placed 4 mm apart on the uterus just below the cervix. Using 3-0 absorbable suture on a taper needle, a transfixion suture is started midway between the clamps. The transfixion ligature is completed, and the uterus is transected below the most distal clamp from the cervix with a scalpel. The uterine stump is examined for hemorrhage and is allowed to retract into the abdomen. The bladder is returned to its normal position, and the abdomen is closed routinely.

on timothy or grass hays, along with increased fluid intake, and appropriate NSAIDS and antibiotics if indicated will usually prevent recurrence of calculi. However, some rabbits may have a genetic predisposition to calculi formation, and despite corrections of dietary calcium levels, correcting any hypercalcemic conditions, and adequate fluid intake and exercise, some rabbits repeatedly form calculi. Affected animals should be periodically monitored radiographically for recurrence.[10]

Vasectomy

Vasectomy is generally performed on male rabbits for birth control purposes only.[12] However, unlike castration, the adverse side effects of an intact buck remain, including libido, urine spraying, aggressiveness, and hormonal urge to mark territory with urine and feces. The technique involves resection of a portion of each vas deferens just cranial to the bladder after a midline laparotomy (Figure 45-17). This surgical technique is currently gaining more use in biomedical research because of interest in producing transgenic animals. Bucks that have undergone vasectomy are used to induce ovulation in embryo recipient does at the same time as the embryo donor female is mated to an intact male.[17] As previously suggested in the discussion of orchiectomy, bucks that have undergone vasectomy should be separated from intact does for at least 30 days postoperatively to prevent possible pregnancy resulting from viable sperm remaining in the vas deferens.

Ovariohysterectomy

Ovariohysterectomy (OVH) is a commonly performed procedure in small animal practice and involves the surgical removal of the ovaries, fallopian tubes and the uterus. Performing an OVH on female rabbits (does) is similar to the procedure performed on dogs and cats and only requires a knowledge of the anatomic differences of rabbits for the procedure to be adapted. One major difference is that rather than having two uterine horns, a uterine body and one cervix (uterus bicornis bicollis) as in dogs and cats, rabbits have two uteri, each opening into the vagina through

a separate cervix (duplex uterus) and no uterine body. These anatomic peculiarities, at first glance, appear to complicate the traditional OVH surgery techniques taught for cats and dogs where excision of the uterus is completed at the level of the uterine body. Carefully placing a transfixion ligature just anterior to the cervix (analogous to placement in the uterine body of a dog or cat), however, enables the complete removal of the doe's reproductive tract (Figure 45-18).

Like cats, rabbits are induced ovulators with ovulation occurring 10 to 13 hours following copulation or after orgasm induced by another doe.[8,10] The gestation period is from 30 to 32 days. Female rabbits normally reach sexual maturity at 4 to 5 months, but it is best to wait until they reach at least 6 months of age before performing an OVH. Indications for performing OVH in rabbits are: (1) to prevent or treat uterine adenocarcinoma (a very common neoplasia found in 50 to 80% of does over the age of 3); (2) to correct repeated false pregnancies; (3) to prevent pregnancy; (4) to treat pyometra or uterine hyperplasia; (5) to modify aggressive behavior and biting; and (6) to decrease urine spraying.[4,8,10-12] Timing of the OVH may vary as puberty and seasonality varies with breed of rabbit and whether or not it is kept indoors or outside. Owners must be aware that cessation of some of the behaviors associated with estrus will not subside instantaneously, but may take place over several weeks. Owners are advised to launder any bedding, clean the cage well before returning the rabbit to its environment as urine scents and pheromones may still be present in the environment. Environmental pheromones may trigger undesirable behaviors. As mentioned for other abdominal surgeries, adequate pain control post surgery is critical to keeping the rabbit from opening the surgical incision. I (CJD) prefer to schedule a recheck incisional appointment 7 to 10 days postoperatively to ensure the incision has healed appropriately and to remove skin sutures if used.

References

1. Marcella KL, Wright EM, Foresman PA, et al. What's your diagnosis: raised skin patches? Lab Anim l986;15:13 15.

2. Flecknell P. Anesthesia and analgesia for rodents and rabbits. In: Laber Laird K, Swindle MM, Flecknell P. eds. Handbook of rodent and rabbit medicine. Tarrytown, NY: Elsevier Science1996:219 237.

3. Wixson SK. Anesthesia arid analgesia. In: Manning PJ, Ringler DH, Newcomer CE, eds. Biology of the laboratory rabbit 2nd ed. San Diego: Academic Press, 1994:87 109.

4. Jenkins JR. Soft tissue surgery and dental procedures. In: Hillyear EV, Quesenberry KE, eds. Ferrets, rabbitsand rodents: clinical medicine and surgery. Philadelphia: WB Saunders 1997:227 239.

5. Crowe DT Jr, Biorling DE. Peritoneum and peritoneal cavity. In: Slater D, ed. Textbook of small animal surgery. 2nd ed. Philadelphia: WB Saunders, 1993:413 415.

6. Hoyt RF Jr, DeLeonardis J, Clements S. et al. Post operative use of adjustable cervical collars in rabbits. Contemp Top Lab Anim Sci 1994;33:822.

7. Gillett NA Brooks DL, Tillman PC. Medical and surgical manage.ment of gastric obstruction from a hairball in the rabbit. J Am Vet Med Assoc 1983;183:1176-1178.

8. Harkness JE. Rabbit husbandry and medicine. Vet Clin North Am Small Anim Pract 1987;17:10l9 1044.

9. Harkness JE, Wagner JE. The biology and medicine of rabbits and rodents. 3rd ed. Philadelphia: Lea & Febiger, 1989:86 90.

10. Hillyer EV. Pet rabbits. Vet Clin North Am Small Anim Pract 1994;24:25 65.

11. Stein S, Walshaw S. Rabbits. In: Laber Laird K. Swindle MK Flecknell P, eds. Handbook of rodent and rabbit medicine. Tarrytown, NY: Elsevier Science, 1996:219 237.

12. Swindle MM, Shealy PM. Common surgical procedures in rodents and rabbits. In: Laber Laird K, Swindle MM, Flecknell P, eds. Handbook of rodent and rabbit medicine. Tarrytown, NY: Elsevier Science, 1996:239-254.

13. Wagner JL, Hackel DB, Samsell AG. Spontaneous deaths in rabbits resulting from gastric trichobezoars. Lab Anim Sci 1974;24:826.

14. Garibaldi BA, Fox JG, Otto G, et al. Hematuria in rabbits. Lab Anim Sci 1987;37:769

15. Kozma C, Macklin W, Cummins LM, et al Anatomy, physiology, and biochemistry of the rabbit. In: Weisbroth SH, Flatt RE, Kraus AL, eds. The biology of the laboratory rabbit. New York: Academic Press, 1974:62-63.

16. Kraus AL, Weisbroth SH, Flatt RE, et al. Biology and diseases of rabbits. In: Fox JG, Cohen BJ, Loew FM, eds. Laboratory animal medicine. San Diego: Academic Press, 1984:207.

17. Robl JM, Heideman JK: Production of transgenic rats and rabbits. In: Pinkert CA, ed. Transgenic animal technology. New York: Academic Press, 1994:265 277.

Suggested Readings

Flecknell P (ed). Manual of rabbit medicine and surgery. British Small Animal Veterinary Association, Quedgeley, UK. 2000.

Harcourt-Brown F. Textbook of rabbit medicine. Oxford, UK. Butterworth Heinemann, 2002.

Hernandez-Divers, SJ. Rabbits. In: Carpenter JW, eds. Exotic animal formulary, third edition. St. Louis, MO, Elsevier Saunders. 2005:407-444.

Okerman L. Diseases of domestic rabbits second edition. Osney Mead, Oxford UK, Blackwell Science. 1998.

O'Malley B. Rabbits. In Clinical anatomy and physiology of exotic species. Edinburgh, UK. Elsevier Saunders, 2005:173-195.

Quesenberry KE, Carpenter JW. Ferrets, rabbits, and rodents clinical medicine and surgery second edition. St. Louis, MO, Saunders. 2004.

Richardson VCG. Rabbits health, husbandry & diseases. Osney Mead, Oxford UK. Blackwell Science. 2000.

Silverman S, Tell LA. Radiology of rodents, rabbits, and ferrets. An atlas of normal anatomy and positioning. St. Louis, MO. Elsevier Saunders. 2005.

Jenkins JR, Brown SA. A practitioner's guide to rabbits and ferrets. Denver, CO: American Animal Hospital Association, 1993.

Kaplan HM, Timmons EH. The rabbit: a model for the principles of mammalian Physiology physiology and surgery. New York: Academic Press, 1979:137 142.

Sebesteny A. Acute obstruction of the duodenum of a rabbit following the apparently successful treatment of a hairball. Lab Anim 1977;l 1:135.

Sedgewick CJ. Spaying the rabbit. Mod Vet Pract 1982;63:401.

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Part II

Bones and Joints

Section K

Axial Skeleton

Chapter 46

Skull and Mandible

Surgical Repair of Fractures Involving the Mandible and Maxilla

Mauricio Dujowich

Introduction

Fractures of the mandible and maxilla are fairly common in dogs and cats. They are usually of traumatic origin, occurring with vehicular trauma, gunshot wounds, horse kicks, bite wounds and "high-rise syndrome" in cats. Non-traumatic causes include severe periodontal disease, oral neoplasia, radiation therapy induced osteonecrosis and metabolic derangements. Recently, the increased use of recombinant bone morphogenic-2 (rhBMP-2) protein has allowed surgeons to repair challenging fractures or non-unions, fix critical defects, and perform aggressive oncologic maxillofacial surgery that would have otherwise failed with conventional therapy. When repairing mandibular and maxillary fractures the primary goal is to permanently restore proper dental occlusion. The secondary goal of obtaining anatomical reduction of the fracture is achieved when possible.

Maxillary fractures do not require surgical intervention as often as mandibular fractures. If displacement of a maxillary fracture is not severe, occlusion is appropriate, oronasal communication and facial deformity are minimal, and no obstruction of airflow through the nasal cavity is appreciated, then conservative management is an option. Although most fractures of the oral cavity are open and may have substantial soft tissue trauma, they generally heal quickly due to abundant vascularization.

Anatomy

The mandible is made up of two halves which are firmly, but not rigidly united at the mandibular symphysis. Each half is then composed of a horizontal body and a vertical ramus (Figure 46-1). The alveoli of the lower teeth lie within the mandibular body, with the tooth roots occupying approximately two-thirds of it. The ventral third of the mandible contains the mandibular canal, through which the alveolar nerve, artery and vein course. Several mental foramina lie within the rostral aspect of the mandible. These foramina are the exit points for the mental branches of the inferior alveolar nerve and vessels, providing sensory innervation to the teeth. Typically one foramen is larger than the others.



Figure 46-1. Lateral image of the canine mandible. *A.* mental foramina, *B.* angular process, *C.* condylar process, *D.* coronoid process.

The ramus of the mandible consists of three distinct processes, the most dorsal being the coronoid process. It projects into the temporal fossa and provides an area for attachment of the temporalis muscle. The condylar (or condyloid) process is just ventral and slightly caudal to the coronoid process. This process is a point of articulation between the maxilla (retroarticular process) and mandible. Disruption of this region will result in temporomandibular joint luxation. The most ventral process is the angular process. This structure provides an area for attachment of the digastricus muscle. The masseter muscle inserts laterally on the mandible, while the pterygoid muscle inserts medially. The mandibular foramen is also located medially on the caudal aspect of the mandible.

The masseter, temporalis, and pterygoid muscles are responsible for closing the jaw and will contribute to dorsal displacement of caudal mandibular fractures. An appreciation of mandibular muscle biomechanics is important as this may influence treatment options. For example, an oblique caudo-ventral fracture of the mandibular body will be particularly unstable compared to an oblique caudo-dorsal fracture or a transverse fracture (Figure 46-2).

The maxilla is a slightly more challenging structure to understand from an anatomic standpoint (Figure 46-3). For a complete review the author refers you to the suggested reading list. Although not entirely correct, most veterinarians consider the incisors as part of the maxilla. However, these are actually housed by the incisive bone. Adding confusion, fractures of the frontal, palatine, zygomatic and nasal bones are often considered part of a maxillary fracture. In reality, the maxillary bone itself sits between all these structures. Fractures of the maxillary region may require additional evaluation due to the potential for penetration into the nasal cavity, the close proximity of the orbit, and potential damage to cranial nerves.

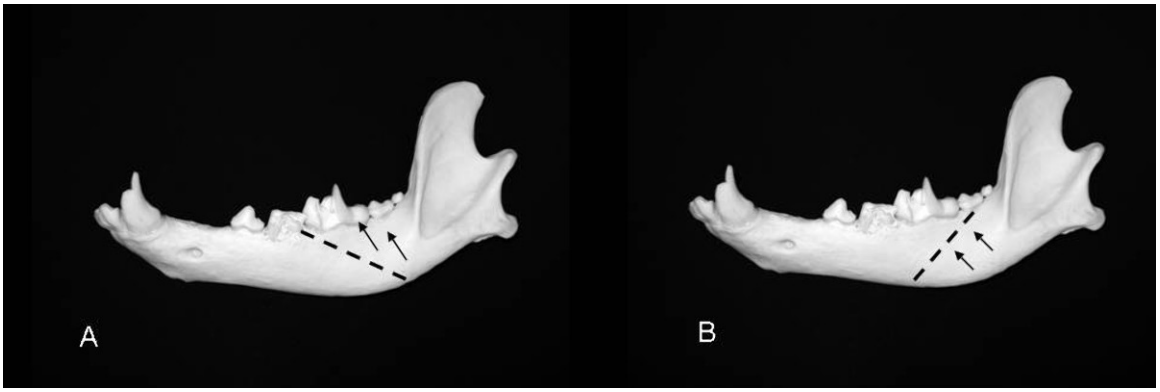


Figure 46-2. Image **A** depicts the typical muscle forces associated with a caudo-ventral mandibular fracture. The dashed line represents the fracture line. The arrows represent the pull of the muscles. Note the subsequent displacement that would occur as a result. Image **B** illustrates the beneficial effects exerted by the muscles of the jaw when dealing with a caudo-dorsal mandibular fracture. The pull of the muscles will result in a natural compression of the fracture.

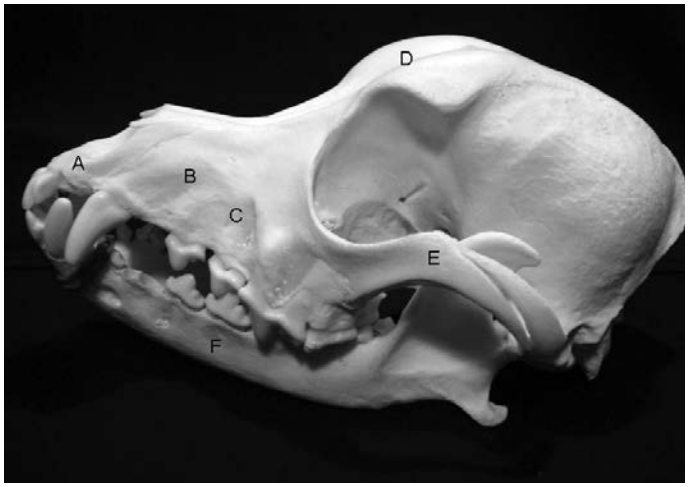


Figure 46-3. Lateral image of canine skull. *A.* incisive bone, *B.* maxilla, *C.* infraorbital foramen, *D.* frontal bone, *E.* zygomatic arch, *F.* mandible.

Clinical Presentation

As mentioned above, most dogs and cats will present subsequent to trauma. It is critical to perform a complete evaluation of the patient prior to focusing on non life-threatening oral trauma. On presentation, stabilization of the patient is the top priority. Assess the airway for patency. Evaluate the patient for thoracic trauma via auscultation and perform thoracic chest radiographs if indicated. As with all trauma patients, it is important to rule out concurrent traumatic conditions such as pneumothorax, diaphragmatic hernia, pulmonary contusions, cardiac arrhythmias and hemothorax. Ensure that there is no abdominal trauma requiring immediate surgical intervention (hemoabdomen, uroabdomen, perforated intestine etc.). Finally, do not overlook the patient's neurological and mental status. Did head trauma result in brain injury? Stabilize the patient adequately prior to managing the fracture repair.

Diagnosis

Examination of the oral cavity with the patient under sedation or short term anesthesia will provide a great deal of information and cannot be underestimated. Evaluate for gingival lacerations and trauma as this may indicate the location of the fracture. Each individual tooth should be palpated for instability. In dogs, fractures of the mandible will most commonly occur in the premolar, molar and symphyseal regions. In cats, over 70% of fractures occur at the level of the mandibular symphysis. Assess the patient's occlusion as part of your examination. Many fractures will be open and easy to diagnose. Additionally, one can palpate for crepitus and instability of the mouth. A mandibular symphyseal fracture will allow movement of one hemimandible in relation to the other.

Traditionally, radiographs have been the first line of diagnostics for viewing mandibular and maxillary fractures. A thorough knowledge of skull radiography is needed to properly interpret the more complex oblique and intraoral views that are sometimes necessary. Radiographs are ideally performed under general anesthesia. Radiographs are excellent for evaluation of multiple tooth roots. Evaluating radiographs of the head can be challenging due to the plethora of overlying bony structures. As computed tomography (CT) has become more widely available and affordable, many surgeons opt to augment conventional radiography with this imaging modality in situations where fracture evaluation is more difficult. Fractures of the ramus, caudal mandibular body and mandibular condyle are key areas that may be difficult to interpret radiographically. CT allows certain advantages for surgical planning such as greater detail, rapid acquisition of images and the ability to create three dimensional reconstructions of the fracture site. CT is particularly desirable when dealing with pathologic fractures due to neoplasia in which resection rather than fracture repair is the treatment of choice.

Conservative Management

The mainstay of medical management of maxillary and mandibular fractures is the tape muzzle. This option is acceptable in situations where the fracture is minimally displaced, there is proper dental occlusion, and the patient has good healing potential. Tape muzzles usually remain in place for approximately 6 to 8 weeks or until there is clinical union. There are a few important considerations when placing a tape muzzle. The muzzle must allow enough slack for the patient to be able to drink water and eat soft foods or a gruel. Additionally, the patient should be kept

cool and restricted as heat dissipation via panting is compromised. Placement of a tape muzzle is seldom a viable option for brachycephalic dogs and cats.

To place a tape muzzle simply cut a length of the appropriate size tape to go around the muzzle of the patient (Figure 46-4A). The "sticky" side of the tape should be up. A spacer (a pencil or a pen) should be placed between the upper and lower incisor teeth to ensure that a small gap is present after the tape muzzle is applied. This gap is not large enough to jeopardize proper alignment, but is sufficient to enable the patient to lap fluid or gruel. The next piece of tape is placed behind the neck and along both sides of the muzzle (Figure 46-4B). This piece of tape is also placed with the "sticky" side up. The ends of the tape on both sides should extend past the nose for an equal distance to that from the nose to the middle of the patient's back. The third piece of tape is placed "sticky" side down around the muzzle. Then the long ends of the second piece can be folded back onto itself. A caudo-ventral mandibular support strap may also be incorporated if desired (Figure 46-4C). It is strongly recommended to apply a tape muzzle under heavy sedation or anesthesia. An alternative to a tape muzzle is a pre-fabricated restraint muzzle. This can be conveniently swapped out with another muzzle and washed periodically. The same considerations mentioned above will apply to sizing of pre-fabricated muzzles. One of the drawbacks to muzzles is their propensity to cause a moist dermatitis. This typically resolves without complications once the muzzle is removed.

Bonding of the mandibular and maxillary canine teeth (Figure 46-5) is a conservative repair technique that may result in less morbidity than stabilizing the fracture with a tape muzzle. In order for this technique to be successful, it is necessary for all canine teeth to be present and healthy. These teeth must first be cleaned, pumiced, and acid etched. The acid etching allows the bonding agent (acrylic) to adhere more reliably to the teeth. The teeth are then aligned with the mouth open enough to allow for drinking and eating as described above and the acrylic is then applied. If the patient is unlikely to eat due to the severity of trauma or an inability to lap food, a temporary esophagostomy tube should be placed. After application, any rough or sharp edges of the acrylic are smoothed with a dental burr. The fixation is removed with a dental burr once the fracture has healed. Although application is easy, this conservative option will require two anesthetic events and the risk of anesthesia should be weighed against the benefits of intraoral bonding in each individual patient.

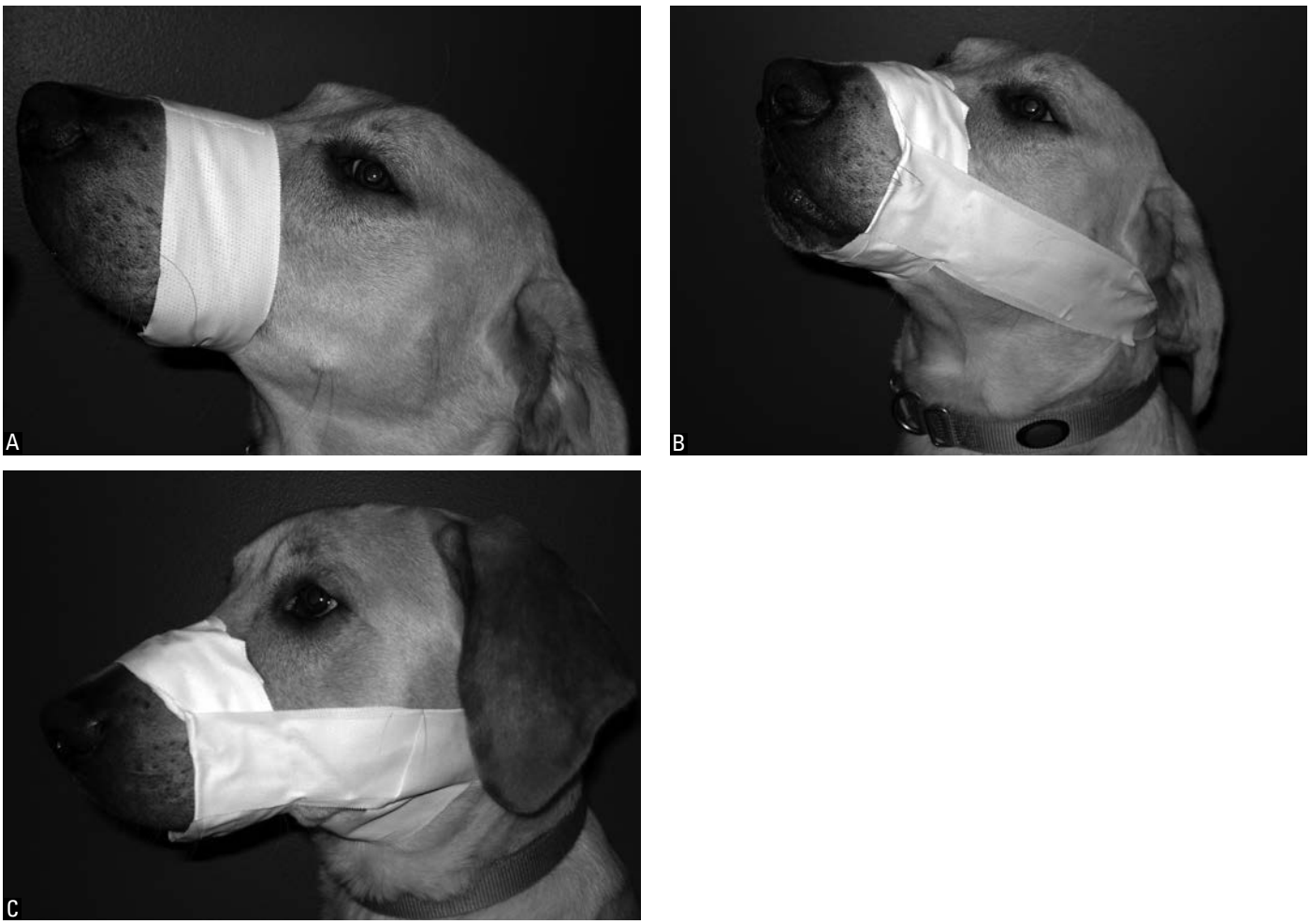


Figure 46-4. Image **A.** depicts the placement of the first length of tape. This is placed "sticky" side up. Image **B.** illustrates the application of the neck strap "sticky" side down followed by another length of tape around the muzzle ("sticky" side down). The excess length of the neck strap was then backed over onto itself. Image **C.** is showing the tape muzzle along with an optional caudo-ventral mandibular support strap.



Figure 46-5. Dental bonding of a feline patient after sustaining a mandibular symphyseal fracture along with multiple fractures to the maxilla and zygomatic arch which were contributing to a malocclusion after reduction of the symphyseal fracture. This prompted placement of a temporary esophagostomy tube and dental bonding in proper alignment.

Anesthetic Considerations

Understanding the potential ramifications of inducing anesthesia on a patient with possible head trauma is important and the anesthetist should plan accordingly. When repairing a mandibular or maxillary fracture that has compromised occlusion, it is challenging to assess proper occlusion if the patient is intubated in the customary manner. It is recommended to translocate the endotracheal tube to a pharyngostomy incision in these situations. Once the patient is anesthetized and intubated in the usual fashion, locate the lateral pharyngeal region of the patient just cranial to the hyoid apparatus, with a curved Carmalt forceps inserted through the mouth. Incise over this region through the skin, subcutaneous tissues, and mucous membrane. Make the incision large enough to reroute the endotracheal tube. Grasp the endotracheal tube through the incision and feed it retrograde through the incision. Once the patient is extubated the incision is left open to heal by second intention.

Another anesthetic consideration that is commonly overlooked is the application of local nerve blocks in the oral cavity. Mepivicaine, lidocaine, and bupivicaine are all commonly used agents in small animal dentistry. Of these, bupivicaine will have the longest duration of action (approximately 6 hours). Nerve blocks are relatively simple to perform, may help prevent "wind-up" of pain receptors and decrease the amount of inhalant anesthesia required.

There are several nerve blocks that are commonly utilized in oral procedures and these should be considered when repairing fractures of the maxilla or mandible. The mental nerve block is performed apical to the mesial root of the second mandibular premolar (Figure 46-6). This block will result in anesthesia of all ipsilateral incisors and canines of the mandible. A caudal mandibular nerve block can be performed when regional anesthesia of all the ipsilateral teeth of the mandible is necessary. The injection is made near the mandibular foramen on the lingual aspect of the mandible (Figure 46-7).



Figure 46-6. Image of mandible illustrating location for application of a mental nerve block.

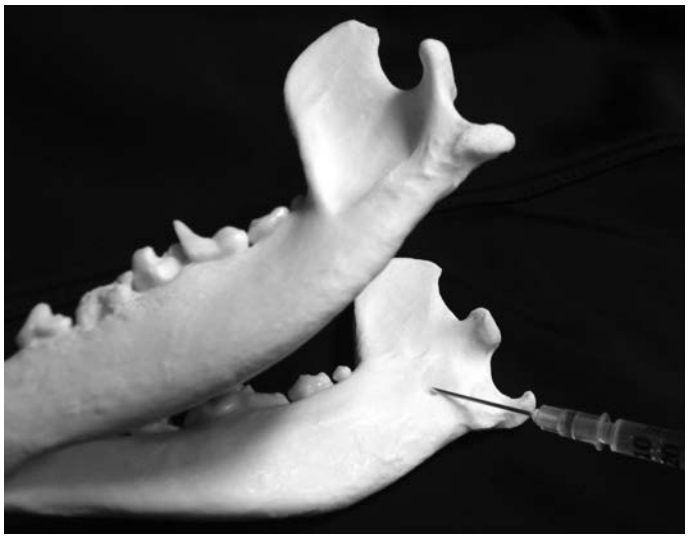


Figure 46-7. Medial aspect of the mandible depicting the location of a caudal mandibular nerve block. The mandibular foramen is the exit point for the alveolar nerve and vessels.

If regional anesthesia of the maxillary incisors, canines and premolars is desired then a palatine nerve block should be performed (Figure 46-8). This block may only be partially effective as some of the innervation of the region comes from the infraorbital nerve. For this reason, it is not uncommon to perform a palatine nerve block in conjunction with an infraorbital nerve block in dogs. To perform a palatine nerve block an injection is made at the midpoint between the mesial aspect of the maxillary carnassial tooth and midline of the palate. The cranial infraorbital block will result in anesthesia of the ipsilateral incisors and canine teeth of the maxilla. To perform this block, an injection is made apical to the distal root of the maxillary third premolar. This corresponds to the opening of the infraorbital foramen (Figure 46-9). Once the foramen is localized by palpating through the oral mucosa the syringe is advanced approximately 1 mm into the foramen prior to injection. In cats it is not recommended to advance the needle because the infraorbital canal is short and orbital trauma may result. For anesthesia of all the ipsilateral teeth of the maxilla, a caudal infraorbital block may be performed by advancing the needle 2 to 3 mm into the infraorbital canal. Again, this is not recommended in the cat.



Figure 46-8. Ventral aspect of the maxilla illustrating the proper location for application of a palatine nerve block.

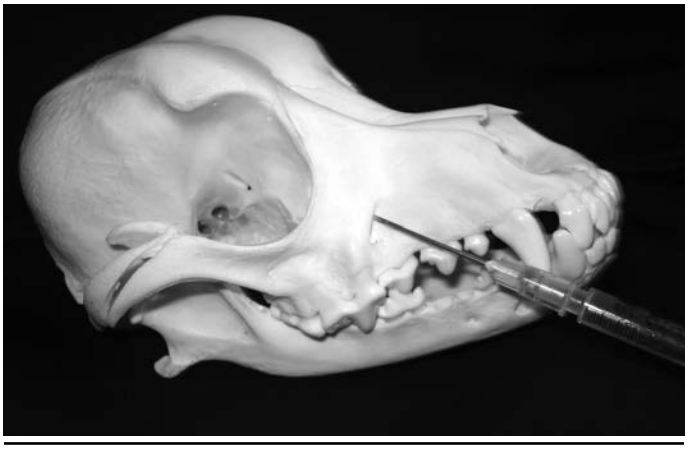


Figure 46-9. Lateral view of the skull depicting the appropriate location for placement of an infraorbital nerve block.

Surgical Considerations

There are multiple structures that must be considered when performing surgery of the mandible and maxilla. These structures are frequently compromised prior to surgical intervention, making it that much more important to limit additional iatrogenic trauma. Use of an intranasal Folley catheter may assist with reduction and controlling nasal bleeding. The maxillary nerve passes through the alar canal and should be avoided during maxillary fracture repair.

Tooth roots must be avoided when drilling into the mandible or maxilla. Damage to the nerve root may necessitate additional intervention at a later time. The teeth should be thoroughly evaluated for damage and viability. If a fractured tooth root is present with weak periodontal ligament attachment, the tooth should be removed. If the viability of the tooth is questionable then adequate follow-up is necessary to minimize future complications. When approaching the caudo-lateral aspect of the mandible, the parotid duct and gland must be avoided. Positioning will depend on the region that is fractured. Typically, mandibular body fractures are repaired with the patient in dorsal recumbency, mandibular ramus fractures in lateral recumbency, and maxillary fractures in ventral recumbency.

External Fixation

External methods of mandibular and maxillary fracture stabilization include external skeletal fixation, interdental wiring and interdental fixation. These techniques offer the potential advantage of being less invasive than internal fixation methods. Decreased morbidity, avoidance of iatrogenic trauma to important structures of the mandible and maxilla, and preserving blood supply are all potential benefits of external fixation.

Interdental Wiring

Wires that are placed around teeth adjacent to a fracture are called interdental wires. Placement relies on a solid tooth-bone interface and any loose teeth incorporated into the wire may result in instability and subsequent failure of the repair. For placement, drill a hole on the superficial aspect of the mandible or maxilla between the two teeth closest to the rostral fracture fragment and then do the same on the caudal fracture fragment (Figure 46-10). An alternative method is to use a hypodermic needle or Kirschner wire passed through the gingival line at the level of the neck of the tooth. The cerclage wire is then fed through the holes and contoured around the teeth in a figure eight fashion. Twist and tighten the wire evenly. Bend the wire ends into the mucosa to avoid damaging surrounding surfaces. Twenty to 24 gauge wire is appropriate for most dogs and cats. Interdental wiring is commonly bolstered with interdental fixation.

Interdental Fixation

Similar to interdental wiring, healthy, intact teeth are required rostral and caudal to the fracture line when applying an interdental fixation. As mentioned above, interdental wires are commonly applied prior to interdental fixation in dogs. Doing so results in a stronger, more stable repair. Interdental fixation involves placement of an acrylic layer over prepared teeth to act as an intraoral splint (Figure 46-11). The teeth must first be cleaned, polished and acid etched. The acrylic is then applied, usually spanning at least two teeth rostral and caudal to the fracture. The acrylic splint is left in place for approximately 6 weeks or until healing has been confirmed. The splint may then be removed by sectioning it with a dental burr.

External Skeletal Fixation

The advent of positive profile pins for use in external skeletal fixation has allowed greater versatility and success. Highly comminuted mandibular fractures (i.e. gunshot wounds) are ideal candidates for repair with external skeletal fixation. Type

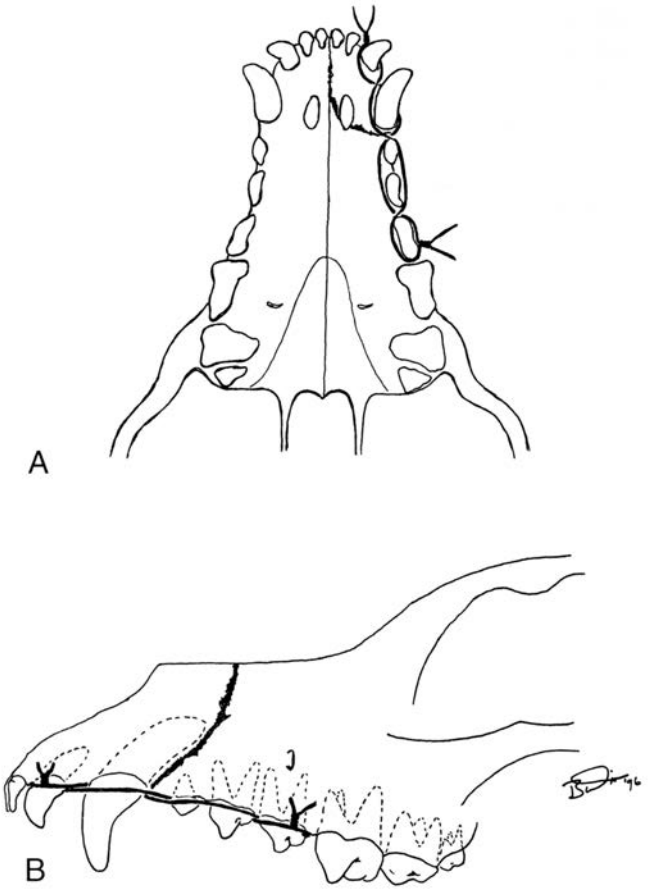


Figure 46-10. A. and **B.** Figure of eight interdental wire used to stabilize a transverse maxillary fracture. Wire loop is twisted from both ends to ensure uniform tension.

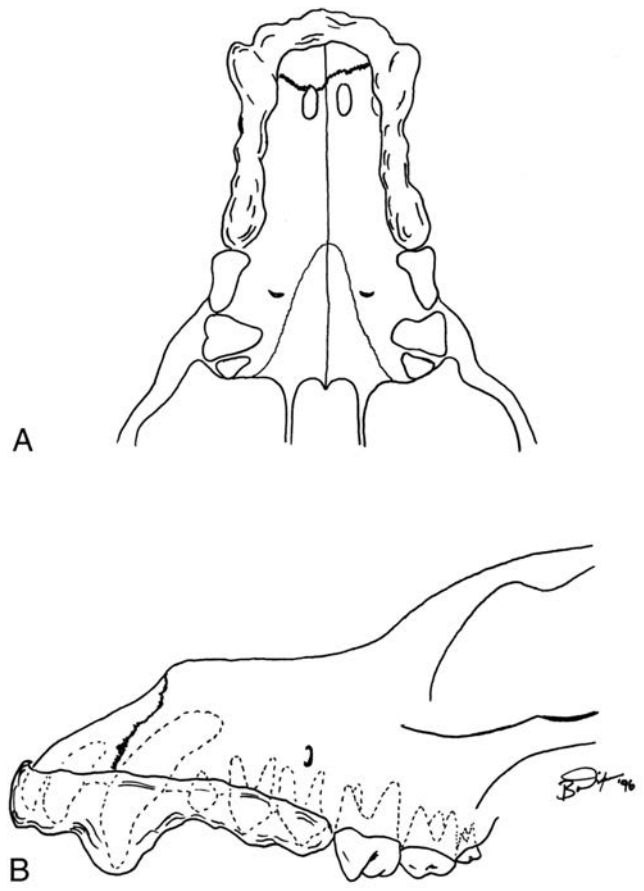


Figure 46-11. A. and **B.** Rostral maxillary and incisive bone fracture stabilized with an acrylic dental splint.

1-a fixators are used for mandibular fractures (Figure 46-12). Typically, all fixation pins are half-pins, but a centrally-threaded full-pin can be applied across the mandibular symphysis. The fixator is applied percutaneously by making release incisions through the skin, pre-drilling the bone, and placing positive-profile end-threaded pins. The pins are placed in the ventro-lateral aspect of the mandible to avoid tooth roots. Ideally, three pins are placed on either side of the fracture, but there may only be enough room for two pins on either side. This varies depending on patient size and fracture extent. The fixation frame can be built with clamps and rods, or acrylic.

Premature pin loosening is one of the major limiting factors of the external skeletal fixation system. Thermal osteonecrosis is thought to contribute to premature pin loosening. To avoid thermal osteonecrosis and subsequent premature loosening of fixations pins, pin sites should be pre-drilled prior to insertion of a fixation pin with a low speed (< 200 RPM) power drill. Acrylic fixators are discussed later in this chapter and add yet another level of versatility to external skeletal fixation. This method of fixation may be a superior alternative in certain comminuted fractures of the mandible in which pins need to be placed on the rostral aspect of the mandible. An acrylic column can be molded to any shape desired around the mandible (Figure 46-13). Alternatively, epoxy putty found at hardware stores may be substituted for acrylic to form the fixation frame.

Internal Fixation

Internal fixation of mandibular and maxillary fractures may include interfragmentary wiring and bone plating. An advantage of internal fixation is the ability to achieve excellent reduction and stabilization. It is important to remember, however, that proper dental occlusion takes precedence over apparent "anatomic reduction" of the internally fixated oral fracture. Additionally, post-operative morbidity may be reduced with internal fixation compared to external skeletal fixation. This is attributable to the absence of percutaneous implants.

Interfragmentary Wires

Interfragmentary wires involve using cerclage wire to reduce relatively simple fractures (Figures 46-14 and 46-15). They should only be used in situations where anatomical reconstruction can be achieved. Placement of two interfragmentary wires is recommended as this will help counter shear and rotational forces. Always drill and pre-place all wires prior to tightening. Wire size will depend on the animal; sizes between 16 to 22 gauge are typically used. Holes are pre-drilled into the bone for application of the wire. The holes are drilled with Kirschner wires perpendicular to, and 5 to 10 mm away from the fracture line. As with all other drilling of the mandible or maxilla, care must be taken to avoid drilling through tooth roots. Slight angling of the holes toward the fracture line will allow for easier tightening of the wire once it is applied.

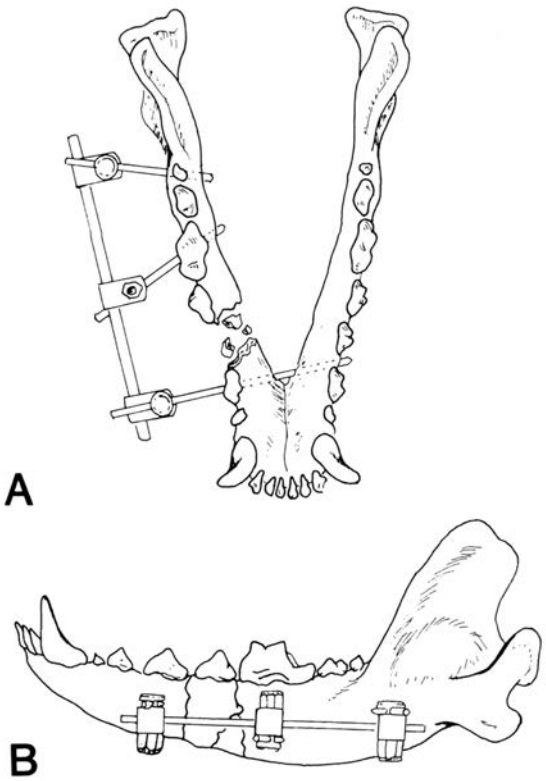


Figure 46-12. Application of an external fixator using positive profile pins to repair a comminuted mandibular fracture. **A.** Dorso-ventral view. **B.** Lateral view.

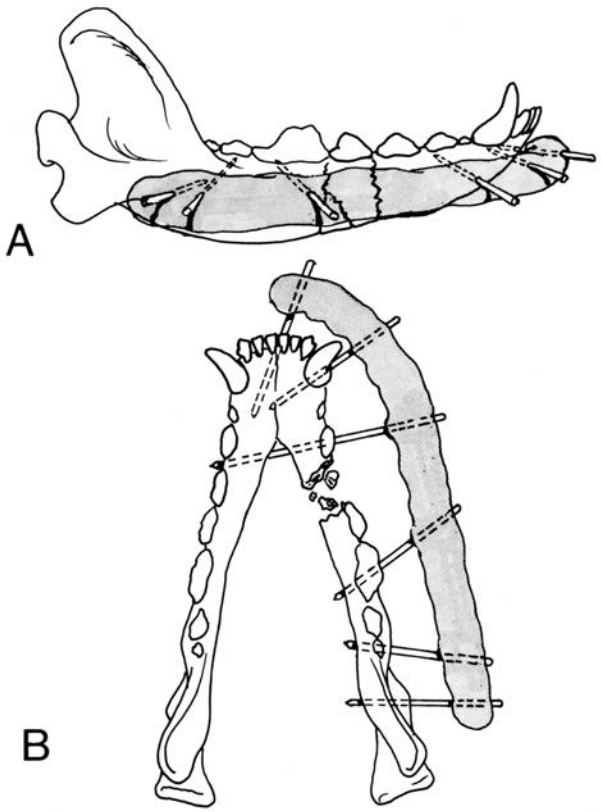


Figure 46-13. An acrylic external fixator applied to a comminuted mandibular fracture. **A.** Lateral view. **B.** Dorso-ventral view.

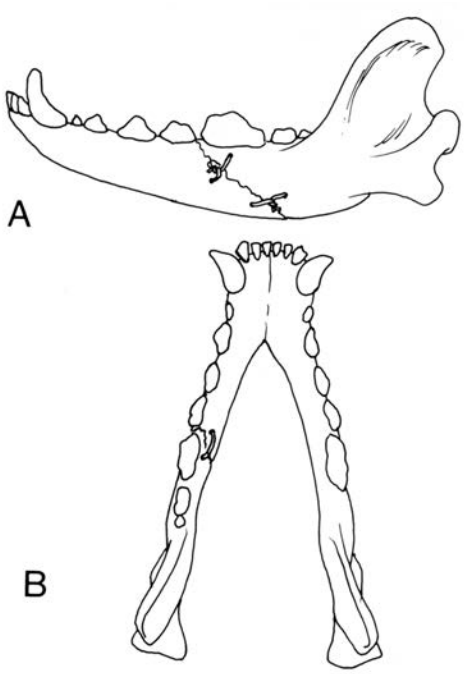


Figure 46-14. Hemicerclage wires used to repair an oblique mandibular fracture. **A.** Lateral view **B.** Dorso-ventral view.

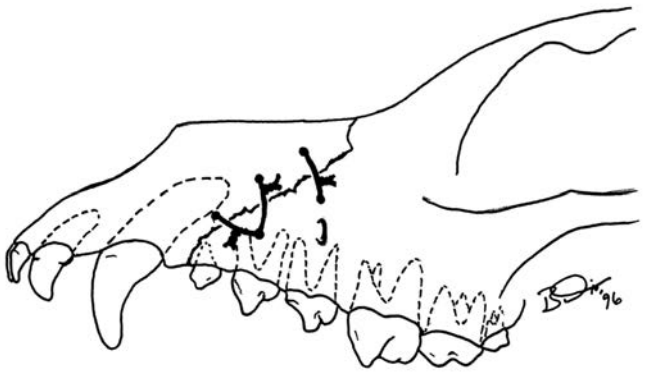


Figure 46-15. Oblique fracture of the maxilla repaired with three interfragmentary wires. All wires should be preplaced before tightening. The two rostral wires are placed using a triangulated wiring technique which may be used for oblique fractures.

After the wires are passed through the drill holes they are tightened with wire twisters. Pull evenly on both wires and twist; with unequal tension, one wire will twist around the other and the fixation will fail due to knot slippage. It is important to ensure that the wire is tight to avoid any unnecessary instability. The ends of the wire are bent toward the bone and away from the gingival margin to avoid damage or irritation of nearby structures. This is done by twisting and bending the wire at the same time to prevent any loosening of the wire while it is being bent. Care must be taken to ensure that the wire is not over- or under-twisted. As the wire is over-twisted and becomes tighter, its color will become dull instead of shiny. Many surgeons twist the wire until the point at which it starts to dull. Once the wire is appropriately bent it is then cut with wire cutters. Three twists are typically left behind to ensure knot security of the tightened wire. Interfragmentary wires are used frequently with maxillary fractures since other fixation methods are either difficult to apply in the presence of the

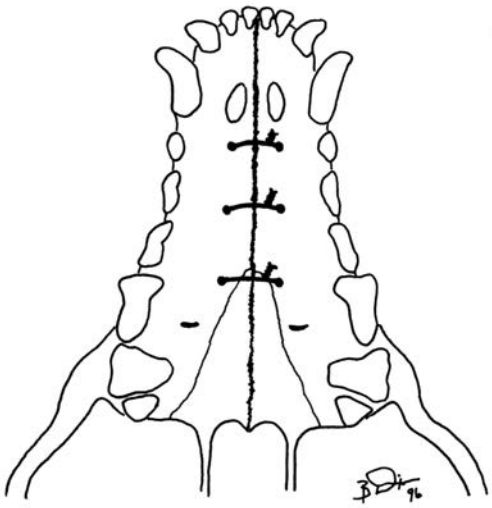


Figure 46-16. Interfragmentary wires used to stabilize a longitudinal split of the palatal bone.

nasal passages or cost prohibitive. Sometimes a Kirschner wire is incorporated into a figure eight wire fixation to help prevent collapse of a maxillary fracture into the nasal passages.

Interfragmentary wires have also been used successfully for the treatment of midline palatal fractures (Figure 46-16).

Symphyseal Fracture of the Mandible

Symphyseal fractures are the most common type of mandibular fracture encountered in cats and they typically occur as a component of "high rise syndrome". Diagnosis can usually be done on initial physical examination by palpating instability at the level of the symphysis (Figure 46-17). The clinician should be able to appreciate one side of the mandible moving in relation to the other. However, once the patient's overall status is evaluated and confirmed stable, a sedated exam is likely to be much less stressful for the patient and the clinician. This will also help to avoid missing other oral cavity injuries.



Figure 46-17. Image of mandibular symphyseal fracture in a cat. Note the step defect associated with the mandible.

Proper reduction of the symphyseal fracture is accomplished through placement of a wire around the rostral mandible just caudal to the canine teeth (Figure 46-18). To do this, make a small incision ventral to the symphysis that is large enough to insert two 16 or 18 gauge hypodermic needles. Insert one needle just caudal to the canine tooth along the lateral aspect of the mandible, as close to the mandible as possible to avoid iatrogenic damage to soft tissues. Next, thread an appropriately sized cerclage wire through the needle (usually 18 or 20 gauge). Place another hypodermic needle in the same fashion as described above on the contralateral side. Thread the cerclage into this hypodermic needle and out the ventral aspect of the mandible. The result is encircling of the symphyseal fracture with cerclage. The cerclage can now be tightened with wire twisters, being sure to achieve proper reduction while tightening. The excess wire can then be cut while leaving at least three twists with the patient. The wire ends are bent down and the small incision is closed or left to heal by second intention.

After the fracture has healed, the wire is usually removed by cutting it with wire cutters. This is best done by cutting the wire intraorally and then either pulling the wire through ventrally or cutting the wire twists to create two separate wires. This latter approach may allow easier passage of the wires. Once the wires are removed, palpate the symphysis to verify that it is stable. Heavy sedation of the patient is recommended as this greatly facilitates wire removal.

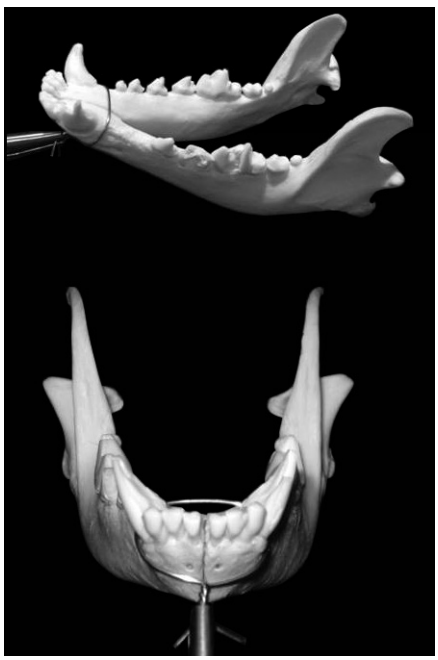


Figure 46-18. Application of interdental wire around a symphyseal fracture. The cerclage wire is placed just caudal to the canine teeth and tightened on the ventral aspect of the mandible.

Bone Plates

With recent advancement in plating technologies there are several different options depending on the repair goals. Bone plates have a distinct advantage of allowing the surgeon to apply them in compression, neutralization, or buttress. For easily reconstructable fractures a limited contact plate (LC), dynamic

compression plate (DCP), or even better, LC-DCP is recommended. Small locking plates like a 2.0 mm string of pearls plate (SOP) can also be very versatile as the plate behaves as an "internal" external fixator and allows the surgeon the ability to contour the plate in almost any direction (Figure 46-19). Miniature maxillofacial reconstruction plates are also available and are very easy to work with from a contouring standpoint. Their main disadvantage is weakness in comparison to other plating options. In human maxillofacial surgery it is common practice to use resorbable plates, however, the high cost of these plates generally precludes their use in veterinary medicine.

When bone plates are applied on the mandibular body they are placed on the ventro-lateral aspect of the mandible. The tooth roots should be avoided when drilling and placing screws. This may be a disadvantage as a result of the "tension band" effect on the alveolar surface. Due to the pull of the muscles of mastication there is a bending force at the alveolar surface causing separation of the fracture at the tooth surface and compression at the ventral aspect of the fracture. To counter this "tension band" effect an interdental wire may be applied or a miniature plate placed more dorsally on the mandible that will allow screw placement between the tooth roots. Lastly, when applying bone plates care must be taken during contouring of the plate to avoid iatrogenic malocclusion.

Postoperative Care

In the immediate postoperative period, the patient should be monitored carefully for any airway obstruction secondary to the fracture repair. Adequate intravenous analgesia should also be provided. Patients should be transitioned to oral analgesics and maintained on these for 5 to 10 days. If substantial discomfort is expected when trying to administer oral medications then a feeding tube (e.g. esophagostomy tube) should be used. These are relatively easy to place and require minimal care. When placing an esophagostomy tube, always check proper placement into the distal third of the esophagus with a lateral radiograph. Initiate an appropriate feeding regimen according to the patient's needs. If oral intake is possible, easily swallowed soft foods are recommended. The ideal food item is nutritionally complete, requires minimal chewing and does not adhere to the repair site. Recheck examination will depend on the type of fracture, repair method used, and patient age. In general most fractures of the maxilla and mandible will heal by 6 to 8 weeks. Once clinical union is achieved implants may be removed if necessary. Potential complications of fracture repairs include sequestra, osteomyelitis, implant failure, malocclusion, nonunion or malunion, tooth root injury and periodontitis.

Suggested Readings

Bennet JW, Kapatkin AS, Marretta SM. Dental composite for the fixation of mandibular fractures and luxations in 11 cats and 6 dogs. VetSurg 23:190, 1994.

Bos RR, Rozema FR, Boering G, et al. Bio-absorbable plates and screws for internal fixation of mandibular fractures. A study of six dogs. Int J Oral Maxillo Surg 18:365, 1989.

Boudrieau RJ: Fractures of the mandible In Johnson AL, Houlton JEF, Vannini R, ed.: AO principles of fracture management in the dog and cat. Thiemie: AO publishing, 2005, p98.

Boudrieau RJ: Fractures of the maxilla In Johnson AL, Houlton JEF, Vannini R, ed.: AO principles of fracture management in the dog and cat. Thiemie: AO publishing, 2005, p116.

Evans HE: The skeleton In Miller's Anatomy of the Dog. Philadelphia: WB Saunders, 1993, p128.

Johnson AL: Management of Specific Fractures In Fossum TW, ed.: Small Animal Surgery. Saint Louis: Mosby, 2007, p1015.

Kern DA, Smith MM, Stevenson S, et al. Evaluation of three fixation techniques for repair of mandibular fractures in dogs. J Am Vet Med Assoc 206:1883, 1995.

Legendre L. Intraoral acrylic splints for maxillofacial fracture repair. J Vet Dent 20:70, 2003.

Lopes FM, Gioso MA, Ferro DG, et al. Oral fractures in dogs of Brazil-a retrospective study. J Vet Dent 22:86, 2005.

Umphlet RC, Johnson AL. Mandibular fractures in the dog. A retrospective study of 157 cases. Vet Surg 19:272, 1990.

Umphlet RC, Johnson AL. Mandibular fractures in the cat. A retrospective study. Vet Surg 17:333, 1988.

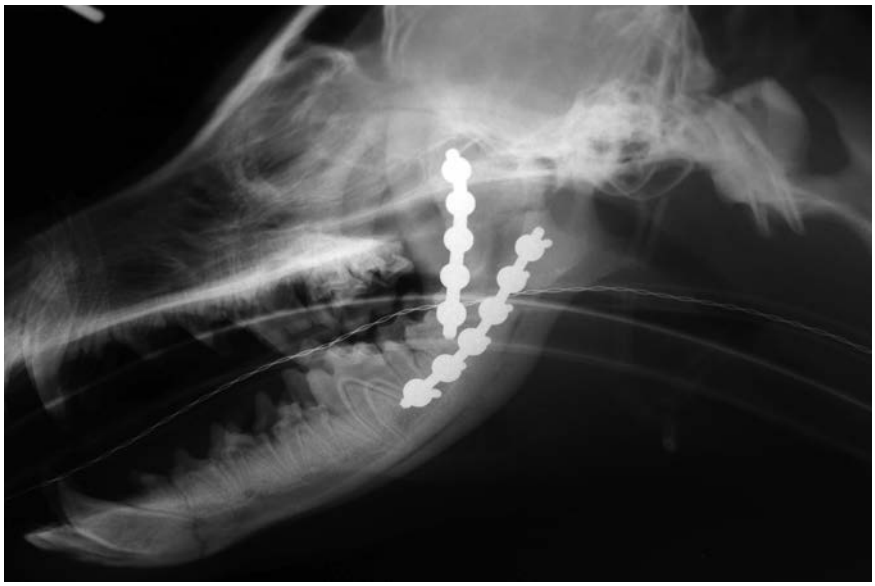


Figure 46-19. Application of two string of pearls locking plates to a fracture of the vertical ramus. Courtesy of Dr. Karl Kraus.

Verstraete FJ, Maxillofacial fractures In Slatter D, ed.: Textbook of Small Animal Surgery. Philadelphia: Saunders, 2003, p2190.

Verstraete, FJ ed.: Oral and maxillofacial surgery in dogs and cats. Elsevier, 2012, p233.

Acrylic Pin Splint External Skeletal Fixators for Mandibular Fractures

Dennis N. Aron

Acrylic pin splints are external skeletal fixators that use acrylic as both the connector rod and linkage. This fixation method can be accomplished in numerous ways, using either homemade materials or commercial kits (Acrylic Pin External Fixation System, Innovative Animal Products, Rochester, MN). Use of an acrylic pin splint has several advantages over standard metal external skeletal fixators for the mandible. The acrylic pin splint is lightweight, radiolucent, and versatile. The acrylic pin splint enables the surgeon to position pins to avoid tooth roots and vital structures easily and to combine pins of various sizes in a singular frame (Figure 46-20). The acrylic pin splint is easy to contour to the shape of the mandible (Figure 46-20). The advantage of using a homemade acrylic pin splint is that the surgeon can purchase specifically needed components from different sources. The commercial kit provides convenience of application because it contains all materials in a single package.

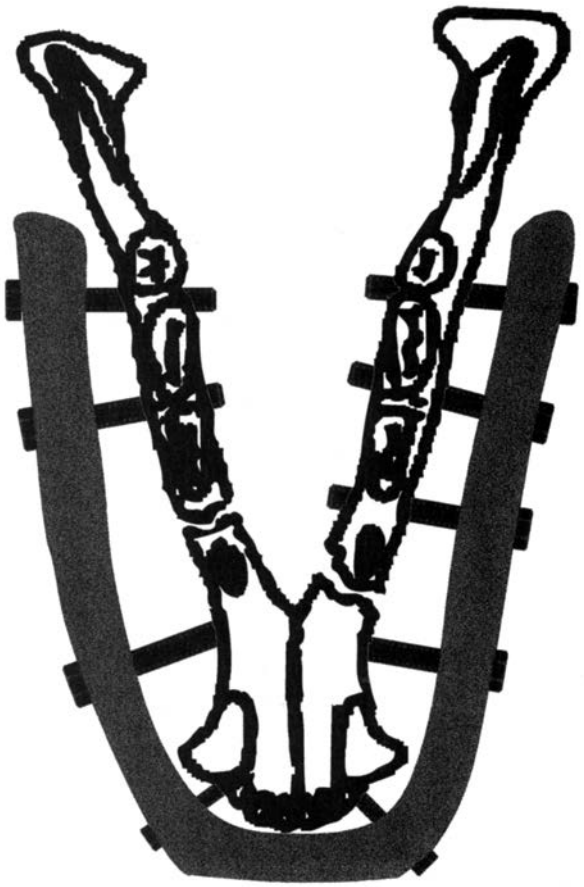


Figure 46-20. Acrylic pin splint is easy to contour. Normal occlusion is a high priority in splinting.

The homemade splint consists of methylmethacry-late, which can be obtained as either hoof repair (Tech-novit Hoof Acrylic, Jorgensen Laboratories, Loveland, CO) or dental molding acrylic (Orthodontic Resin, L.B. Caulk Co., Milford, DE). The acrylic column can be free-formed or injected into a tube to serve as a mold. When free-formed, the acrylic is molded by hand to the required shape. The free-form method is easiest with most applications to the mandible, especially for smaller dogs and cats. The tube method may be best for larger dogs. The commercial kit uses a tube method. Research has shown that a 3/4-inch acrylic column diameter provides fixation strength comparable with or greater than that of the medium Kirschner 3/16-inch connector rod. Given this guideline, the surgeon can extrapolate the needed width of the acrylic column to various sizes of animals.

Two considerations are important to predictable and consistent success when using acrylic pin splints for mandibular fractures. First, the surgeon needs to establish normal occlusion and mastication for the patient. Failure to accomplish this goal predisposes the patient to abnormalities of the temporomandibular joint and pain, with the possibility of negative consequences on nutritional balance. Normal occlusion in the dog is seen when the mandibular canine teeth are positioned between the maxillary incisors and canine teeth and the mandibular fourth premolar is situated between the maxillary third and fourth premolars. Achieving normal occlusion is always a higher priority than accomplishing accurate reduction at the fracture site (See Figure 46-18). When performing surgical correction of mandibular fractures, placement of the endotracheal tube through a pharyngostomy enables the surgeon to assess occlusion during the operative procedure. When the endotracheal tube is positioned routinely, it interferes with normal closure of the mouth and prevents the surgeon from assessing accurate occlusion.

The second important consideration is the need to use screws or positive profile end-threaded pins (fasteners) for attachment of the acrylic column to the mandible. The mandible is a relatively flat bone without two nicely separated dense cortices. This configuration predisposes nonthreaded pins to premature loosening, which leads to discomfort and, possibly, to delayed healing with the fixation of mandibular fractures. Because of this situation, screws or threaded pins, which provide a screwed-in anchorage, are advantageous when used for treating fractures of the mandible with external skeletal fixation. Bone screws work well for this purpose because they can be obtained in varied sizes corresponding to patient size. The head of the screw and exposed thread provide a secure linkage to the acrylic column. For use in particularly small animals is a small-diameter (0.9, 1.1, 1.6, 2.0, and 2.4 mm) positive-profile end-threaded pin (Miniature Interface Fixation Half Pins. IMEX Veterinary, Inc., Longview, TX) that is an excellent fastener designed to be used with acrylic. One end is intended to provide screwed-in fixation with the bone, and the opposite end is a roughened thread to allow for strong linkage with the acrylic column. The pin is remarkably stiff, given its diminutive size, a positive mechanical property not found in most small-diameter pins. Fully threaded Steinmann pins or negative-profile threaded pins should not be used with the acrylic pin splint because they are mechanically weak and are predisposed to loosening or breakage. The threaded pins

and screws should be inserted by first drilling a hole with a sharp drill bit sized to approximate the core diameter of the fastener. This gives maximum stability to the fastener-bone interface. The tip of the threaded pin must exit the transcortex completely to engage thread throughout the bone.

Often, a combination of threaded and smooth fasteners is used together. When this method is used, at least one threaded fastener needs to be positioned in each bone segment on either side of the fracture. By combining smooth and threaded fasteners, the surgeon gains both stability and ease of application, especially when using a biphase technique (see later). At least two fasteners need to be positioned in each bone segment on either side of the fracture. Frequently, more fasteners are placed in each individual bone segment, a maneuver that enhances the strength of the construct. It is possible, and advantageous, with the acrylic pin splint to stabilize fractures involving both hemimandibles with a singular acrylic column (See Figure 46-20). The vertical ramus of the mandible is a poor location for securing fasteners because this soft, flat bone does not hold a fastener well. Because of this limitation, caudal mandibular fractures do not lend themselves well to fixation with the acrylic pin splint.

Free-Form Acrylic Pin Splint

The patient is administered a perioperative antibiotic regimen. The appropriate number of fasteners is placed into each bone segment. Aseptic technique is always used when applying the fasteners and during fracture manipulation and closure of the soft tissues, when using an open reduction technique. Aseptic technique is not necessary for application of the acrylic connector when this procedure is done after closure of the wound. Fasteners can be wedged between tooth roots, but they should not be drilled through these roots, and mandibular vessels and nerves need to be avoided. If smooth pins are used in the configuration, they need to be bent to lie parallel to but elevated from the skin, to allow secure adherence to the column and room to accommodate the acrylic mass (Figure 46-21). Fasteners should be positioned so, after the acrylic column is in place, distance of 1 to 2 cm will be present between the acrylic column and the skin. This distance is necessary to avoid thermal damage to the soft tissues and bone while the acrylic sets. Moistened gauze sponges can be placed to protect the skin and to cool the pins, thereby impeding conduction of excessive heat to the bone. All methylmethacrylate products use two components, a liquid (monomer) and a powder (polymer). For the Caulk orthodontic dental resin, three parts powder are mixed with one part liquid. For Technovit Hoof Acrylic, two parts powder are mixed with one part liquid. A disposable cup and wooden tongue depressor can be used to mix the acrylic. These two portions are mixed until they become doughy (3 to 4 minutes). The acrylic is hand molded to form a column long enough to incorporate all the preplaced fasteners and wide enough to provide adequate strength for the particular size of the animal. Approximate occlusional alignment and fracture reduction are achieved. The acrylic column is placed on the fasteners and is conformed to the appropriate shape; then final occlusional alignment and fracture reduction are completed and held. The acrylic is adequately hardened 8 to 12 minutes after mixing, to enable the surgeon to abandon temporary holding of occlusion and reduction.

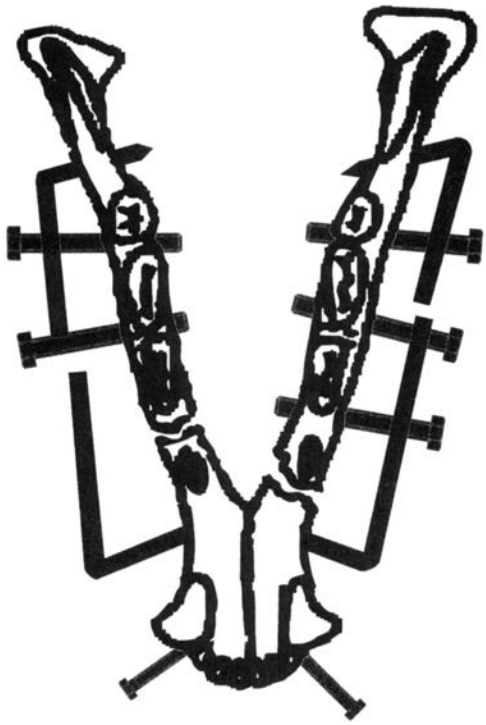


Figure 46-21. Free-form acrylic pin splint.

A biphase technique can be used to facilitate application of the acrylic pin splint. With this technique, the surgeon applies a temporary adjustable reduction device such as Kirschner clamps and connector rods (phase 1) separate and external to the acrylic column, to hold occlusional alignment and fracture reduction temporarily (Figure 46-22). The acrylic is mixed and molded to all fasteners and is allowed to set (phase 2); then the external device is removed. The long pins are cut short once the acrylic has hardened; alternatively, the long pins can be bent over to lie flush with the acrylic column, and more acrylic can be mixed and

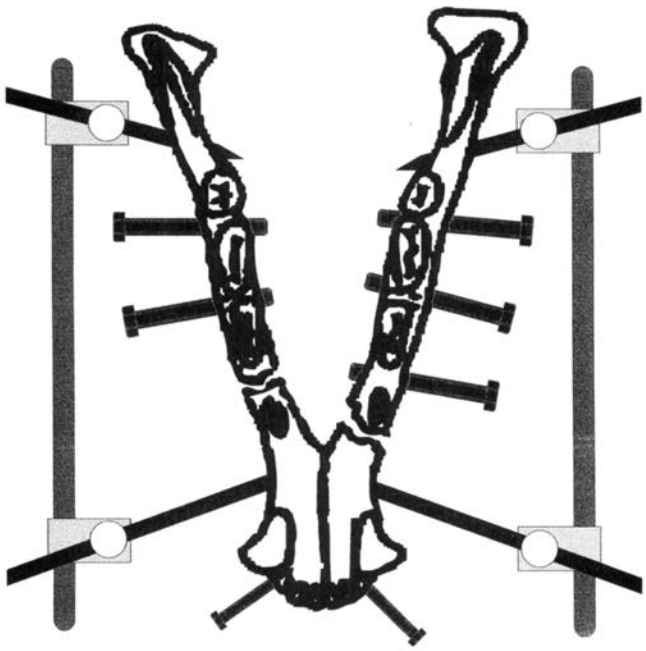


Figure 46-22. Biphase technique using Kirschner clamps and connector rods.

added to the column to incorporate the bent pins (Figure 46-23). This technique enhances the stability of the smooth pin acrylic linkage. The surgeon must bend the pins over using one pair of pliers as a lever positioned at the point of bend and another pair of pliers or hand chuck to exert bending of the pin. This prevents the formation of high stresses at the fastener-bone interface when bending over the pin.

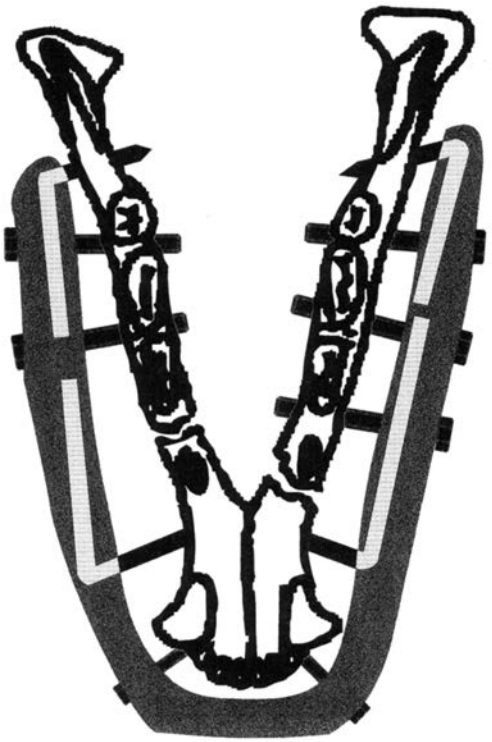


Figure 46-23. Long pins cut short and bent to lie flush with acrylic.

Tube Acrylic Pin Splint

For this splint, either a commercial device or a homemade tube can be used. A homemade method is described here. The patient is administered a perioperative antibiotic regimen. The appropriate number of fasteners is placed into each bone segment using sterile technique, and surgical wounds are closed. Plastic tubing is pressed over the ends of the fasteners and is positioned 1 to 2 cm from the skin. Corrugated plastic anesthetic tubing (anesthesia breathing circuit, 1/2-inch for small frames and 3/4-inch for large frames, King Systems Corp., Nobelsville, IN) or Silastic tubing works well, serving as an injection mold for the acrylic. The most dependent end of each tube is plugged with cotton, and modeling clay is used at each junction of the tube and fastener to prevent excessive leakage of acrylic at these sites. Approximate occlusional alignment and fracture reduction are achieved. The powder and liquid components of the acrylic are mixed and are poured into the top end of the plastic tube. This maneuver can be facilitated by using a large-dose syringe to inject the acrylic into the plastic tube. Accurate occlusional alignment and fracture reduction are maintained until the acrylic sets. The acrylic must fill the tube completely, and no air bubbles can be present to weaken the acrylic column. If large air bubbles are noted, holes can be made in the plastic tube and more acrylic can be injected into the area before or after the acrylic sets. The biphase technique can easily be adapted to the tube acrylic pin splint, with considerations and technique similar to that described for the free-form method. A frame alignment kit (Innovative Animal Products, Rochester, MN) is available and is advantageous because it allows phase 1 reduction equipment to be placed either above or below the plastic tubes.

The fracture reduction or the splint can be adjusted after the acrylic has set by removing a short segment of the acrylic column with a hacksaw blade, obstetric or Gigli wire, or a cast cutter. A portion of the tubing is peeled back, and several channels are drilled into a portion of acrylic on either end of the cut column to provide an anchor for the new acrylic patch. A small amount of acrylic is mixed and hand molded to fill the gap and to overlap a portion of the exposed acrylic containing the channels. Occlusional alignment or fracture reduction is then manipulated, while the acrylic is still soft, and is held until the acrylic hardens. New fasteners can be placed to add additional strength to the configuration or to replace fasteners that are loose. Fasteners are placed adjacent to the existing acrylic column using aseptic technique. The fasteners are then incorporated into the column with the addition of a new patch of acrylic.

Suggested Readings

Egger EL. Management of mandibular fractures with external fixation. In: Proceedings of the 5th annual Complete Course in External Skeletal Fixation. Athens, GA:, 1996:113-115.

Toombs JP. Nomenclature and Instrumentation of external skeletal fixation systems. In: Proceedings of the 5th annual Complete Course in External Skeletal Fixation. Athens, GA:, 1996:2-9.

Chapter 47

Cervical Spine

Cervical Disc Fenestration

M. Joseph Bojrab and
Gheorghe M. Constantinescu

Indications

Ventral fenestration for cervical disc disease is advocated in animals demonstrating pain, stiffness of the neck, or foreleg paresis. This technique is effective when degenerating discs protrude and cause nerve fiber and rootlet disorders, which account for most cervical disc problems. This procedure accomplishes intervertebral disc decompression by opening the ventral annular fibers for removal of the nucleus pulposus.

Cervical fenestration is not effective if foreleg paralysis or tetraplegia results from the presence of disc material within the spinal canal. These circumstances indicate a decompressive procedure.

Surgical Technique

The animal is placed in dorsal recumbency with a sandbag under the neck to produce dorsal flexion of the cervical spine, facilitating exposure. A ventral midline skin incision is made from the larynx to the thoracic inlet. The paired bellies of the sternohyoid muscle are separated (Figure 47-1), and the trachea is displaced laterally and is held with a self-retaining retractor. Blunt dissection of the deep fascia reveals the V-shaped longus colli muscle (Figure 47-2), which lies on the midline. Locating this muscle is essential to ensure midline identification. The ventral tubercles of the first and second cervical vertebrae is located at the level of the wings of the atlas (Figure 47-3A) for orientation. Because a disc is not present at this interspace, it is not fenestrated. The remaining ventral tubercles are midline projections that are directed caudally from the caudal ventral aspect of the vertebrae and provide the insertion site for the two bellies of the longus colli muscle (Figure 47-3B). The ventral entrance to the intervertebral space is covered by these bellies and their tendinous attachment. The muscle attachment is snipped with scissors, exposing the ventral longitudinal ligament. A No. 10 scalpel blade is used to cut the longitudinal ligament and ventral annular fibers (Figure 47-4A). A tartar scraper (SCLB Miltex Tartar Scraper, Victor Medical, Irvine, CA) (Figure 47-5) is used to fenestrate the disc (See figure 47-4B). All readily accessible cervical discs (C2-3, C3-4, C4-5, C5-6) are fenestrated.

The self-retaining retractor is removed, and the sternohyoid muscle bellies are sutured with a 3-0 polydioxanone (PDS, Ethicon, Somerville, NJ). The skin is then closed.

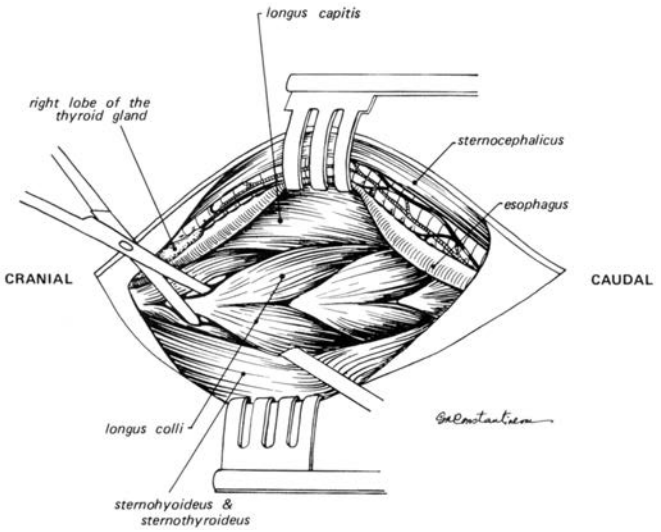


Figure 47-2. Trachea and esophagus are retracted to the left, and the longus colli muscle insertions are identified and cut with scissors.

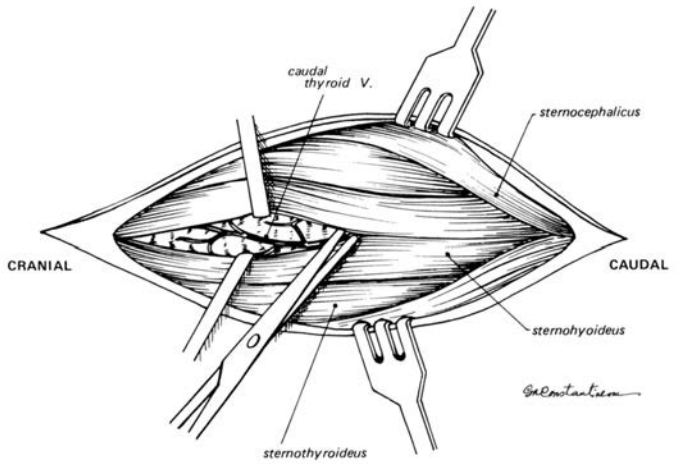


Figure 47-1. Ventral cervical incision from the larynx to the thoracic inlet exposing the trachea by separating between the sternohyoid muscles.

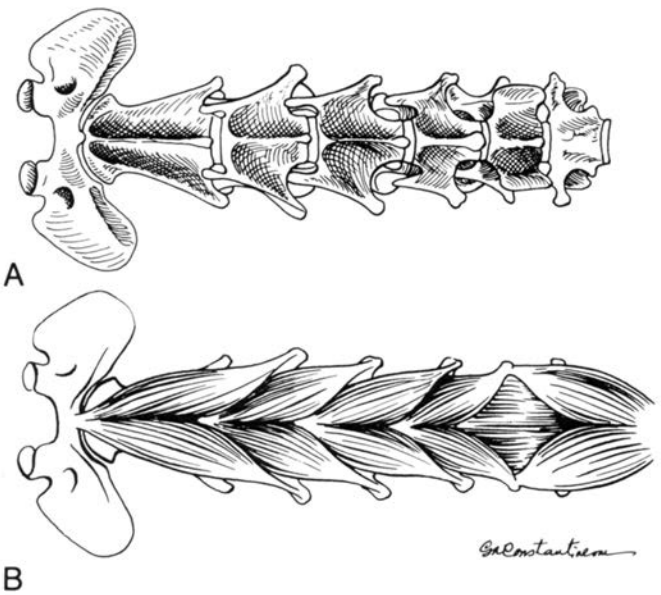


Figure 47-3. A. Ventral aspect of the cervical vertebral column. **B.** Longus colli muscle identification and placement.

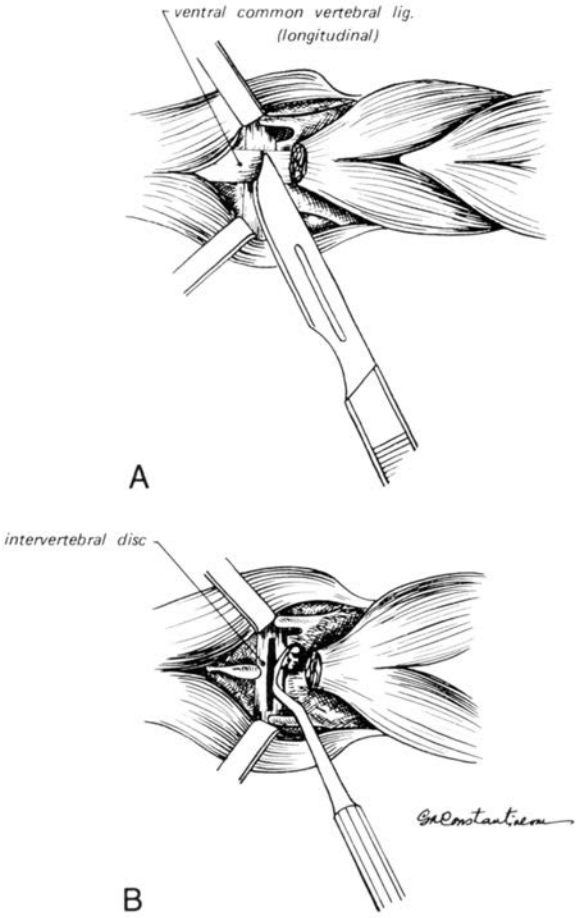


Figure 47-4. A. After the longus colli muscle attachment is cut, a No. 10 scalpel is used to incise the ventral longitudinal ligament and annular fibers. **B.** A tartar scraper is used to fenestrate the disc.



Figure 47-5. A schematic drawing of the Miltex Scaler B tartar scraper.

Postoperative Care

Antibiotics are given for 5 to 10 days postoperatively. Corticosteroids (dexamethasone, 1 mg/lb body weight) are administered intramuscularly once or possibly twice each week. Buffered aspirin is given for 7 to 10 days if pain persists. After 10 to 14 days, complete remission of signs is expected.

Ventral Slot for Decompression of the Herniated Cervical Disk

Karen Kline and Kenneth A. Bruecker

The ventral approach to the cervical spine allows for direct access to the vertebral bodies and intervertebral disks. The ventral slot procedure requires minimal dissection through normal tissue planes and minimal disruption of normal anatomic structures. Minimal manipulation of the spinal cord is necessary, and recovery is usually rapid with few complications.[1-5]

Patient Position

The patient is placed in dorsal recumbency with the forelimbs secured caudally. The cervical spine should be supported by placing a vacuum positioner or rolled towel beneath the neck. Excessive dorsiflexion (hyperextension) should be avoided. The head can be secured by placing one inch tape on the rostral third of the mandible and securing it to the sides of the table. Gentle traction can thus be applied to the cervical spine resulting in distraction of the intervertebral disk spaces and enhanced access to the spinal canal (Figure 47-6).

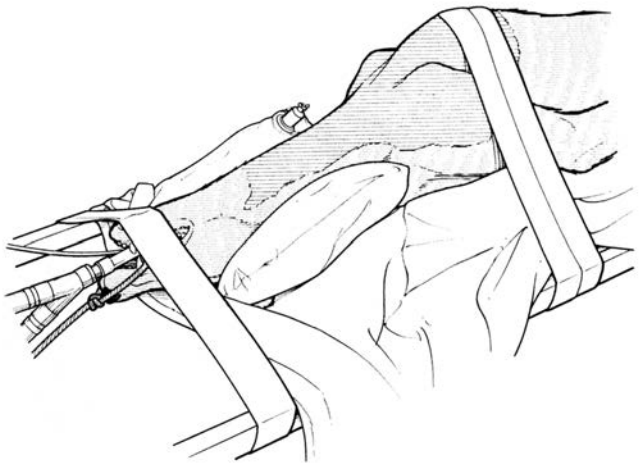


Figure 47-6. Proper position of patient with head and neck stretched for ventral decompression. (From Bruecker KA, et al: Clinical evaluation of three surgical methods for treatment of caudal cervical spondylomyelopathy of dogs. Vet Surg 1989; 18: 197.

Approach to the Cervical Vertebrae and Intervertebral Disks[1-5]

A cutaneous incision is made from the larynx to the manubrium. The paired muscle bellies of the sternocephalicus muscles are sharply separated. The paired sternohyoideus muscles are sharply separated on the midline exposing the trachea. The thyroid ima, a single unpaired blood vessel, lies between the left and right sternohyoideus muscles. If the branches of the thyroid ima are ligated and transected on the right, then this vessel can be reflected with the left sternohyoideus muscle.

Blunt dissection along the right side of the trachea allows retraction of the trachea to the left and retraction of the right

carotid sheath to the right. Care should be taken to identify and protect the right recurrent laryngeal nerve. The endotracheal tube must be of sufficient length to avoid collapse of the trachea during retraction. The esophagus should also be retracted to the left exposing the longus colli muscle. An esophageal stethoscope or soft rubber tube placed in the esophagus will enhance palpation of the esophagus during retraction. Care should be used when retracting these tissues. This retraction can be aided with the use of 4x4 surgical sponges or laparotomy pads if the patient is a large breed canine. These tissues can be retracted digitally and held in place by paired self-retaining retractors that are placed cranial and caudal to the affected interverbral disk spaces once the paired longus colli muscles have been identified and bluntly dissected along the median raphe.

The tendons of insertion of the longus colli muscles are transected from their origins on the caudoventral midline aspect of the affected cervical vertebral bodies, thus exposing the underlying intervertebral disk. This can be done at each disk space intended for surgery. The location of the intended intervertebral disk can be determined by palpating the large, prominent transverse processes of C6. The C5-6 intervertebral disk lies on the midline at the cranial aspect of the C6 transverse processes. Palpating along the midline, the large ventral prominence of the caudal aspect of each vertebral body and the origin of the tendon of the longus colli muscle can be palpated. The transverse processes of C1 can also be used as a point of reference. The ventral process of C1 is particularly prominent and sharp ventrally; this also can or may be palpated. (Sharp/Wheeler). There is no intervertebral disk at C1-2.

Technique[2,3]

Further elevation of the longus colli muscle with a periosteal elevator should be performed in preparation for the ventral slot. The retractors can be repositioned between the muscle bellies of the longus colli muscles. The prominence of the point of origin of the longus colli muscle on the caudoventral midline aspect of the cervical vertebral body can be removed with rongeurs and the intervertebral disk fenestrated.

Using a #11 or # 15 blade to fenestrate, a defect is made in the ventral anulus fibrosus. Starting on the midline of the cranial aspect of the vertebral body caudal to the disk, with the cutting edge of the blade directed towards the surgeon, the blade is gently advanced until the disk is reached. Alternatively, a hypodermic needle can be used to localize the intervertebral disk space. With the blade directed in a slightly cranial direction, the blade is inserted to the level of the dorsal anulus fibrosus, against and parallel to the vertebral end plate. This distance can be estimated from the lateral radiographic view of the cervical spine. The blade is advanced to no more than 1/2 the width of the intervertebral disk. The cutting edge of the blade is then directed cranially and advanced up to the caudal end plate of the cranial vertebra. The blade is then directed to left lateral and advanced to no further than 1/2 the width of the disk space. Again, the blade is angled cranially such that it is against and parallel to the caudal end plate of the cranial vertebral body. The blade is directed caudally and advanced up until the cranial end plate of the caudal vertebral body is reached. The blade is then directed and advanced towards the midline to complete the rectangular shaped excision (window) (Figure 47-7). This portion of excised ventral anulus fibrosus can then be removed with rongeurs and the nucleus pulposus gently removed with curettes or dental scraper (Figure 47-8). Care must be taken such that additional disk material is not forced dorsally into the spinal canal. This can be accomphished by directing the curette or dental scraper in a direction parallel to the plane of the patient's body instead of ventrodorsally.

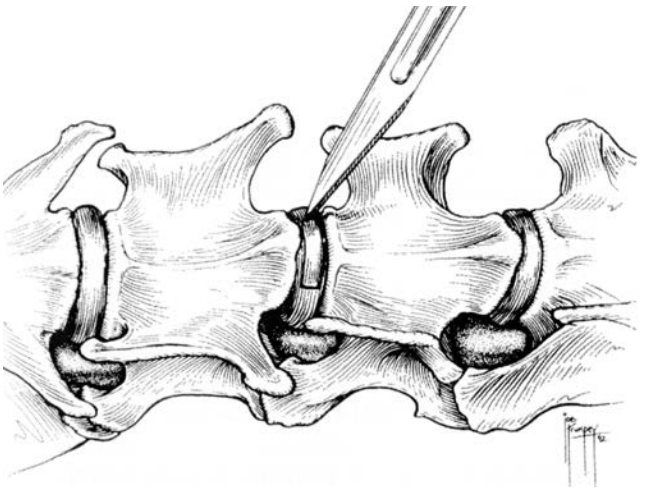


Figure 47-7. Creation of fenestration window in the ventral aspect of the cervical disk. (From Wheeler SJ and Sharp NJH: Small Animal Spinal Disorders, Diagnosis and Surgery. Mosby 1994; 76, Fig 156.)

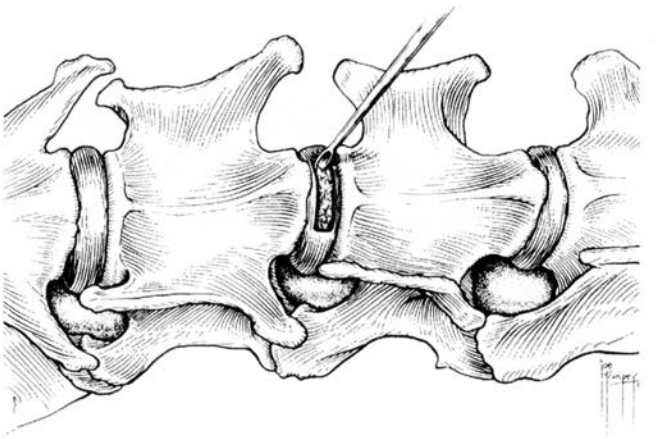


Figure 47-8. Removal of nucleus pulposus to complete the fenestration in preparation for ventral slot. (From Wheeler SJ and Sharp NJH: Small Animal Spinal Disorders, Diagnosis and Surgery. Mosby 1994; 76, Fig 157.)

Following fenestration, a high speed 4-5 mm carbide burr is used to create a slot in the vertebral bodies cranial and caudal to the intervertebral disk. Overheating of the burr can be prevented with saline lavage. We prefer a long, narrow slot for removal of herniated disk material. The slot should be no wider than 1/3 the vertebral body width and no longer than 1/3 the vertebral body length (Figure 47-9). Since the disk space angles craniodorsally, the caudal aspect of the slot can begin at the endplate of the caudal vertebral body (Figure 47-10). The slot can be deepened to the level of the cortical bone of the ventral spinal canal. The depth of the defect can be determined by identifying the difference in bone density of the cortical and cancellous bone.

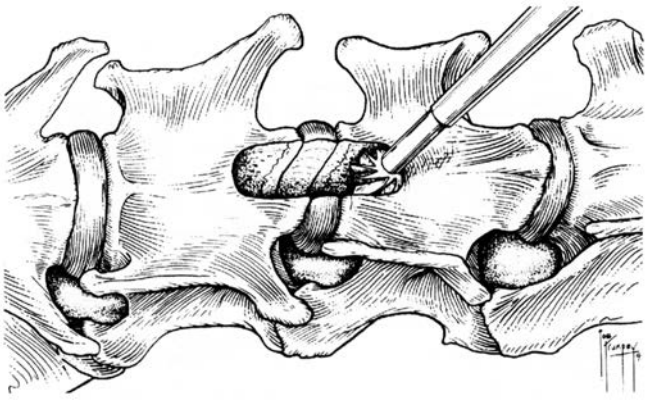


Figure 47-9. Long, narrow slot created with a high speed bur. (From Wheeler SJ and Sharp NJH: Small Animal Spinal Disorders, Diagnosis and Surgery. Mosby 1994; 79, Fig 167.)

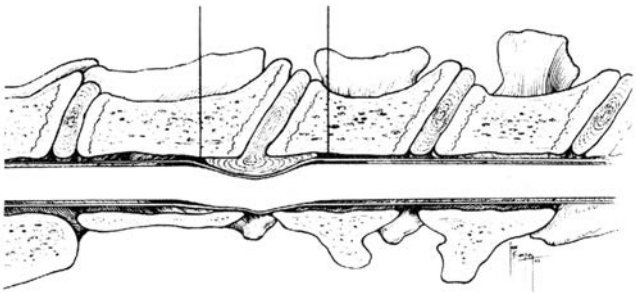


Figure 47-10. Sagittal section of cervical spine indicating the orientation of the slot with respect to the disk space and spinal canal. (From Wheeler SJ and Sharp NJH: Small Animal Spinal Disorders, Diagnosis and Surgery. Mosby 1994; 78, Fig 165.)

Cortical bone is white and hard whereas the cancellous bone is red to purple in color. The inner cortical bone tends to have a pearl color and can appear transparent as it becomes thinner with drilling. Once the burr has penetrated the inner cortical layer, a small bone curette can be used to enlarge the slot. The remaining dorsal anulus fibrosis and dorsal longitudinal ligament can be removed with rongeurs, forceps, curettes or hemostats. Small instruments such as ophthalmic spatulas, loop curettes, fine curved forceps and suction can be used to retrieve herniated disk material from the canal (Figure 47-11). Disk material on the midline should be removed first and then laterally extruded disk material can be removed to avoid damage to the venous sinus.

Damage to the venous sinus results in excessive hemorrhage and obstruction of visualization of the spinal cord. This can be controlled with suction and hemostatics, such as Gelfoam[a] or Surgicel.[b] Suction can be used to evacuate the blood. A small piece of precut Gelfoam[a], presoaked in saline, can be placed at the site of the hemorrhage. Cottonoid[c] or sponge is placed over the Gelfoam[a] to prevent inadvertent aspiration of the hemostatic. Suction of the overlying sponge or Cottonoid[c] is performed until hemorrhage has stopped. The sponge or Cottonoid[c] can then be removed. The hemostatic can be removed after 5 minutes and disk material retrieval can be resumed. In some cases, a small remnant of either Gelfoam or Surgicel can be left at the site to aid in hemostasis. Monofilament absorbable suture material

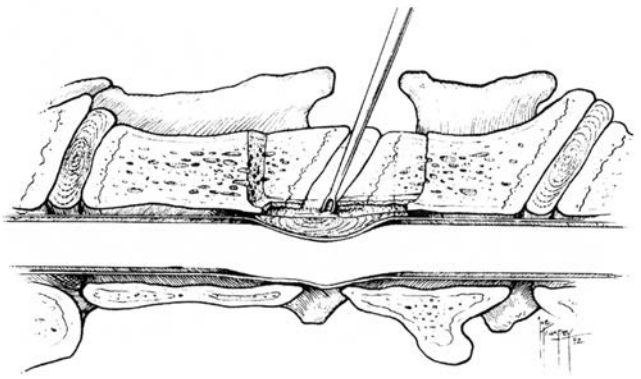


Figure 47-11. Sagittal section depicting removal of disk material from the spinal canal via the slot. (From Wheeler SJ and Sharp NJH: Small Animal Spinal Disorders, Diagnosis and Surgery. Mosby 1994; 81, Fig 174.)

such as 3-0 or 2-0 PDS is used to close the sternohyoideus and sternocephalicus muscles. Closure of subcutaneous tissues and skin is routine.

Post-operative Management

Analgesics such as opiods or NSAIDS should be continued for 24-48 hours postoperatively. Corticosteroids are not indicated in the post-operative period. A thoracic harness should be used instead of a neck collar.

Post-operative management of cervical decompressive slot patients is generally divided into ambulatory or non-ambulatory convalescence. Patients with an ambulatory status post-operatively are generally managed in the following manner: cage confinement, brief exercise 2 to 3 times a day for 2 to 3 weeks, and home on restricted exercise and/or passive range of motion exercises 2 to 3 times a day. Non-ambulatory patients are managed in the following manner: elevated padded cage rack or waterbed, turned every 2 to 4 hours to prevent decubital ulcers and passive lung congestion or pneumonia, bladder expressions to 3 times a day, passive range of motion exercises at least 2 to 3 times a day, and frequent hydrotherapy until return to an ambulatory status is achieved. Non-ambulatory patients will require support to be held in a sternal position to eat and drink and to avoid aspiration pneumonia.

Crate or pen confinement is recommended for 6 to 8 weeks with gradual return to normal activity to follow.

Neurologic recovery is generally very rapid. Neck pain usually subsides within 24 to 48 hours. Tetraparetic patients may begin to show improvement within days, as well. Owners, however, should be counseled as to the unpredictabilty of spinal surgery and its complications to include delayed return to function and recurrent neck pain.

References

1. Piermattei DL. An atlas of surgical approaches to the bones and joints of the dog and cat. 3rd ed. WB Saunders, 1993; 54-59.

2. Swaim SF. Ventral decompression of the cervical spinal cord in the dog. JAVMA 1974; 164, 491-495.

[a]Gelfoam: Upjohn Co., Kalamazoo, MI [b]Surgicel: Johnson and Johnson, Arlington, TX [c]Cottonoid: Codman and Scurtleff, Randolf, MA

3. Seim HB and Prata RG. Ventral decompression for the treatment of cervical disk disease in the dog: a review of 54 cases. J Am Anim Hosp Assoc 1982; 18, 233-240.

4. Sharp NJ and Wheeler SJ: Cerviacl Disc Disease. In Small Animal Spinal Disorders. Philadephia; Elsevier, 2005. 96-105.

5. Fry TR, Johnson AL, Toombs J. Surigical treatment of cervical disc herniations in ambulatory dogs. Ventral decompression vs. fenestration in111 cases (1980-1988). Progress in Veterinary Neurology 1991;2, 165-173.

Surgical Treatment of Caudal Cervical Spondylomyelopathy in Large Breed Dogs

Karen L. Kline and Kenneth A. Bruecker

Introduction

There are two separate philosophical approaches to the surgical treatment of caudal cervical spondylomyelopathy (CCSM) in large breed dogs, direct decompression versus decompression by distraction and stabilization. In general, patients with malformation/malarticulation or static compressive lesions benefit from direct decompressive surgical techniques whereas patients with dynamic compressive lesions such as cervical vertebral instability (CVI) require distraction and stabilization. As witnessed from a review of the literature on the subject, no one technique for repair of dynamic lesions is considered the gold standard. Repair of these compressions is contingent upon the patient's demeanor, general overall health, surgeon experience, and owner expectations for recovery.

Treatment by Direct Decompression using an Inverted Cone Modified Ventral Slot[1]

The inverted cone modified ventral slot is a direct decompressive technique for the removal of hypertrophied dorsal anulus fibrosus associated with cervical vertebral instability. This technique is most useful in patients with a static lesion, unchanged by distraction. The hypertrophied dorsal anulus fibrosus can be difficult to remove from the canal using the classic ventral decompressive slot technique.[1,2,3,4] This technique or a combination of this technique with the classic approach may have merit in allowing better retrieval of anulus from the canal. The slot resembles an inverted cone wherein the base of the cone is at the ventral spinal canal.[1] (Figure 47-12).

Technique

The approach to the affected intervertebral disk space is the same as described for ventral cervical slot. Using a high speed bur, the slot is created from the caudal aspect of the intervertebral disk to involve the caudal 1/4 of the cranial vertebral body. The width of the slot is limited to 1/5 the width of the vertebral body. The slot is enlarged as it is deepened by moving the bur in a sweeping motion laterally, creating an elliptical slot. The slot is carried to the level of the inner cortical layer while preserving the dorsal anulus fibrosus. The dorsal anulus fibrosus can then be retracted back into the slot and excised (Figures 47-13 and 47-14). The inner cortical bone layer is removed with the high speed bur and additional anulus and dorsal longitudinal ligament can be excised (Figure 47-15). Closure is routine.

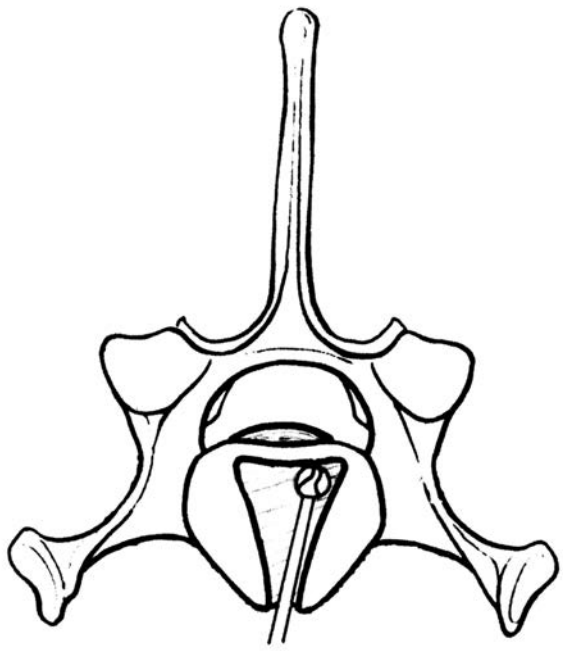


Figure 47-12. Diagramatic cross-sectional representation of the inverted cone decompressive slot at the level of the intervertebral disk space.

Treatment by Distraction and Stabilization Utilizing Pins or Screws and Polymethyl Methacrylate[5,6]

Distraction and stabilization utilizing Steinmann pins or bone screws and polymethyl methacrylate has been described. Advantages of this technique include: adequate spinal cord decompression without entering the spinal canal, reduced risk of iatrogenic cord trauma and bleeding, as well as improvement in the percent, rate and duration of recovery as compared to other techniques. In addition, a neck brace is not required. This technique is used most commonly for dynamic lesions that involve both the annulus fibrosus and the dorsal longitudinal ligament.

Technique[5]

A ventral approach, as described for the ventral decompressive slot, is performed to expose the vertebral bodies and intervertebral spaces cranial and caudal to the affected intervertebral space. The patient is positioned in dorsal recumbency such that the cervical spine is distracted, as described for the ventral slot. The affected intervertebral space is then pulled into additional linear traction by one of two techniques. A Gelpi retractor, modified by blunting the tips, can be used as a vertebral retractor. A defect is created in the vertebral bodies cranial and caudal to the affected vertebral bodies with a high-speed surgical bur. The defects are created just large enough to accept the tips of the modified Gelpi retractor. The retractor is engaged, and the affected intervertebral space spread an additional 2 to

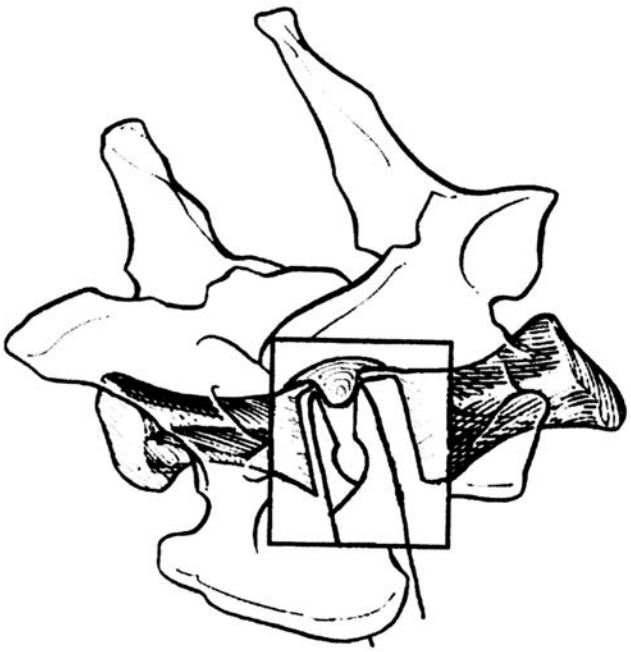


Figure 47-13. The dorsal anulus fibrosus (DAF) is retrieved into the slot by applying traction prior to removal with a rongeur.

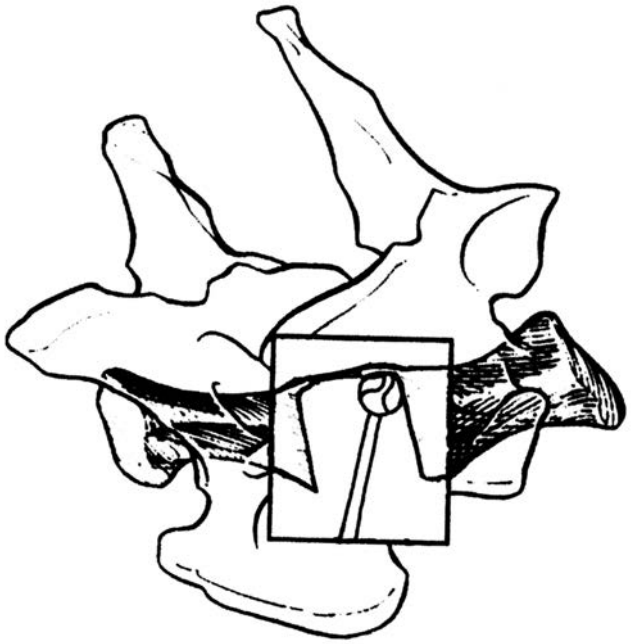


Figure 47-15. A high speed bur is used to remove the dorsal cortical bone shelf providing surgical access to the spinal canal.

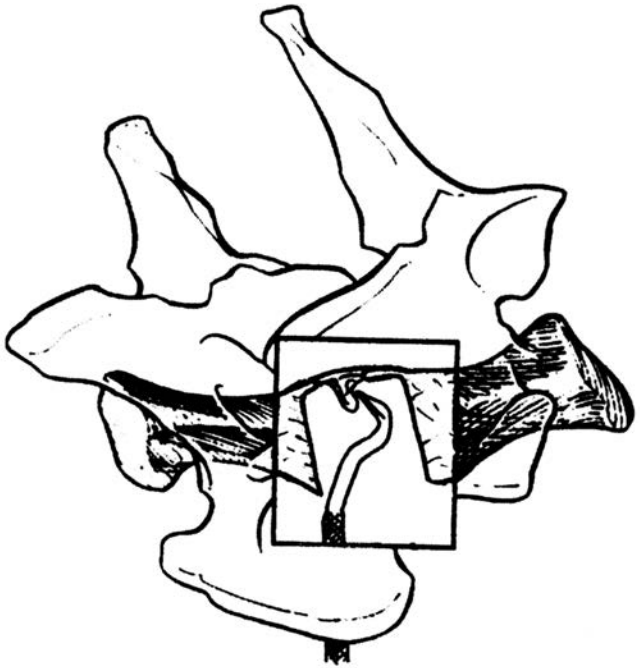


Figure 47-14. Retrieval of additional compressive material into the slot. Note retention of dorsal cortical bone shelf and progressive spinal cord decompression.

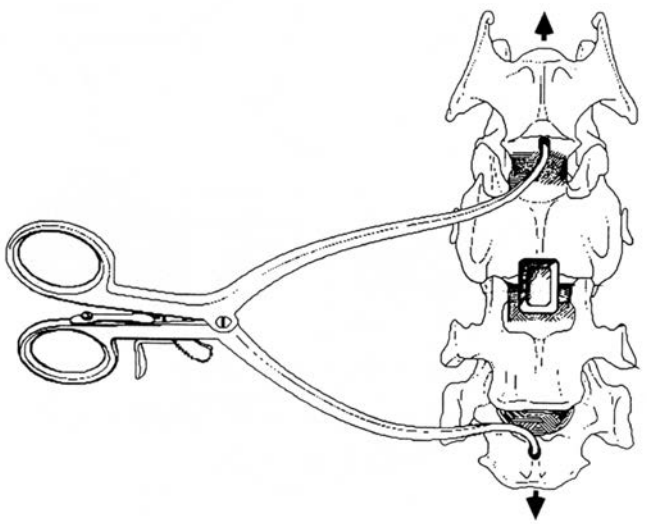


Figure 47-16. Gelpi retractors, modified by blunting the tips, is inserted into the slots created in the vertebral bodies adjacent to the affected disk spaces. (From Bruecker KA, Seim HB. Caudal cervical spondylomyelopathy. In Slatter, Textbook of Small Animal Surgery. 1993: 1064.)

3 mm (Figure 47-16). This technique of vertebral spreading may have merit over insertion of the tips of the Gelpi retractor into fenestrated disk spaces. Fenestration of the intervertebral disks may predispose them to degenerative changes and collapse.[7] Distraction results in decompression of the spinal cord.[8,9]

A ventral slot is performed at the affected intervertebral space, however the slot is wider and shorter than a classic ventral decompressive slot. The depth is carried only to the level of the inner cortical bone layer. The spinal canal is not entered. The width of the slot should be no more than 1/2 the width of the vertebral body. The length of the slot is determined by the thickness of the vertebral endplates. Once the cortical endplate on each vertebral body has been removed, burring should cease. Autogenous cancellous bone is harvested from the heads of the humeri and placed into the distracted slot. Two 7/64 or 1/8 inch Steinmann pins are inserted into the ventral surface of the vertebral body cranial to the affected intervertebral space and two similar size pins are inserted into the vertebral body caudal to the affected intervertebral space. The pins are inserted on the ventral midline of the vertebral body and directed 30-35 degrees dorsolaterally to avoid entering the spinal canal. It is important that two cortices

are engaged by each pin. The pins are cut leaving approximately 1.5 to 2 cm exposed. The exposed portion of each pin is notched with pin cutters allowing the bone cement to grip and prevent pin migration. Bone screws 3.5 to 4.0 mm in diameter long enough to engage both cortices may be used instead of Steinmann pins. Sterile polymethyl methacrylate powder is mixed with liquid monomer until it reaches a doughy consistency and can be handled without sticking to the surgeon's gloves. The cement is then meticulously molded around each pin (Figure 47-17). Irrigation with sterile saline solution for 5-10 minutes dissipates the heat of polymerization. The vertebral spreaders are removed once the cement has hardened. Closure of the longus colli muscle is performed cranial and caudal to the cement mass. The remainder of the closure is routine. Postoperative care includes strict confinement for 4-6 weeks.

Treatment by Distraction and Stabilization utilizing a Polymethyl Methacrylate Plug[11]

Another technique utilizing an intervertebral plug of polymethyl methacrylate to accomplish distraction and stabilization has been described.[11] There is no apparent advantage in rate of recovery and overall success rate as compared to distraction and stabilization using pins and polymethyl methacrylate, however risk of implant failure or iatrogenic spinal cord trauma from improperly placed pins is less with this technique. In addition, this technique can be performed at multiple disk spaces if necessary.[11]

Technique[11]

A ventral approach, as described for ventral decompression, is performed to expose the vertebral bodies and intervertebral spaces cranial and caudal to the affected intervertebral space(s). The affected intervertebral space is then pulled into additional linear traction as previously described in the pins and polymethyl methacrylate technique. The original authors of the PMP technique have successfully used other vertebral spreaders as well. The affected disk material is removed to the level of the dorsal anulus fibrosus. Troughs are cut into the endplates using a high speed drill and a 2 to 4 mm bur to anchor the PMP. These anchor troughs should be made approximately 5 to 10 mm in lateral width, 4 mm in depth and 4 mm in dorsoventral height (Figure 47-18). An angled attachment will allow better access to the caudal vertebral endplate. One gram of sterile cefazolin powder can be mixed with the sterile polymethyl methacrylate. The polymethyl methacrylate powder is mixed with liquid monomer until it reaches a liquid consistency and can be infused into the intervertebral disk space to the level of the ventral aspect of the vertebral bodies and gently packed digitally. Irrigation with sterile saline solution for 5 to 10 minutes dissipates the heat of polymerization. The vertebral spreaders are removed once the cement has hardened. Autogenous cancellous bone is harvested from the heads of the humeri and placed ventral to the vertebral bodies and PMP to stimulate osseous fusion (Figure 47-19). Closure of the longus colli muscle is performed over the cancellous bone graft. The remainder of the closure is routine. A neck brace may be used post-operatively to limit excessive movement, but may not be required (Dixon). The Synthes Locking Plate (Syncage-C intervertebral implant and cervical spine locking plate) may prove to be a viable option in the future. The Synthes locking plate has been discussed in the treatment of dynamic lesions to include single lesions (as repaired with the cement plug), or as a rescue technique after a failed ventral slot decompression or with multiple lesions. To date, the use of the Locking plates on multiple lesions is still undergoing further evaluation.[18] Preliminary results with this technique are encouraging. A swivel ring in the plate hole means that the screws may be inserted at any angle within a range of +/- 20 degrees and the screw holes lock in the plate via a unique locking mechanism. This device (the Syncage) is designed to maintain distraction. It stays within the intervertebral space and is packed with

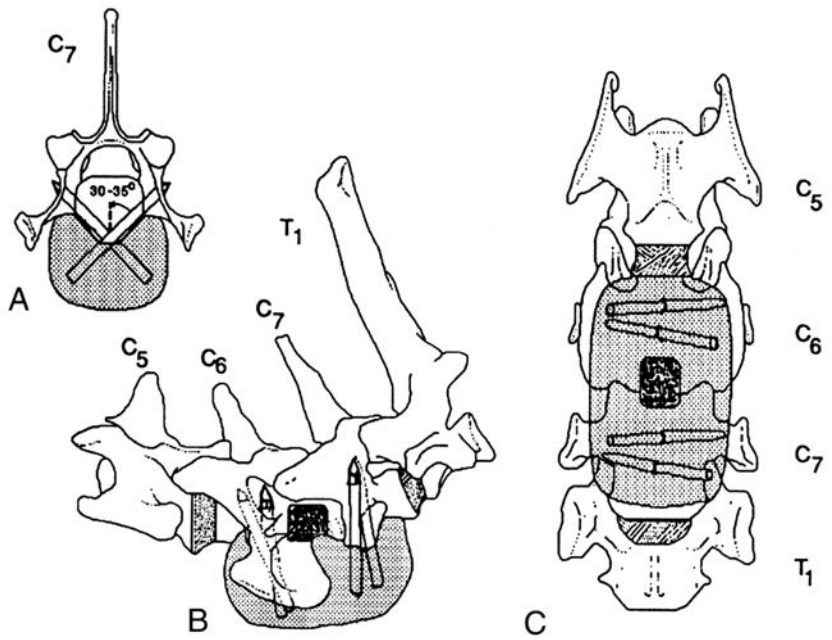


Figure 47-17. Placement of the cancellous bone, pins and bone cement to treat CVI. (From Bruecker KA, Seim HB. Caudocervical Spondylomyelopathy in Large Breed Dogs. In, (ed)Bojrab, Current Techniques in Small Animal Surgery, 3rd ed. Lea & Febiger. 1989: 583).

cancellous bone. This device adds strength and bridge greater than one space.[18] The utility of this device for multiple lesions in the canine is yet to be elucidated. Limitations of this technique can include cost of the implants and the lack of case numbers that support further use and feasibility of this technique.

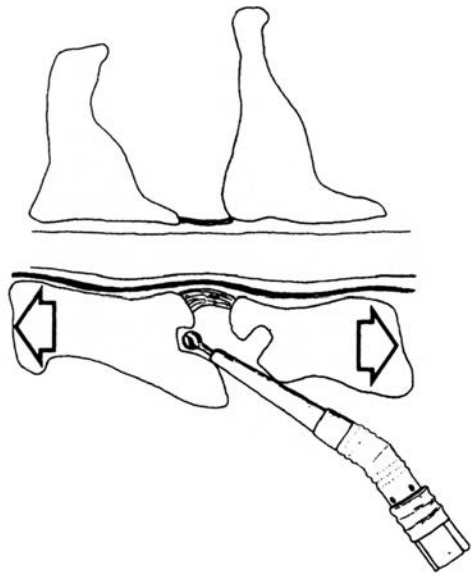


Figure 47-18. Partial diskectomy is performed leaving only a thin layer of dorsal anulus fibrosus (DAF). Creation of anchor holes is accomplished with a high speed bur and angle attachment. (From Dixon BC, Tomlinson JL, Kraus KH. Modified distraction-stabilization technique using an interbody polymethyl methacrylate plug in dogs with caudal cervical spondylomyelopathy. J Am Vet Med Assoc 1996; 208: 63).

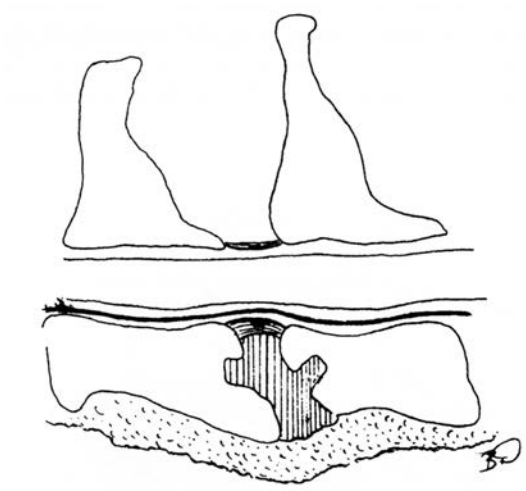


Figure 47-19. The PMP is placed into the prepared disk space while traction is maintained. After the PMP hardens, the traction device is removed and cancellous bone graft (CG) is liberally packed along the ventral aspect of the vertebral bodies. The remaining thin layer of DAF protects the spinal cord from the PMP. (From Dixon BC, Tomlinson JL, Kraus KH. Modified distraction-stabilization technique using an interbody polymethyl methacrylate plug in dogs with caudal cervical spondylomyelopathy. J Am Vet Med Assoc 1996; 208: 63).

Treatment by Direct Decompression using a Continuous Dorsal Laminectomy[12]

Continuous dorsal laminectomy is a decompressive technique. This technique is most useful in patients with multiple lesions and dorsal lesions. Although this technique does not address the underlying pathophysiologies associated with CCSM, relief of spinal cord compression is achieved. Dorsal laminectomy is advocated for single or multiple, dorsal, traction non-responsive (static) lesion(s).[18] The major disadvantage of this procedure is the significant, short-term morbidity with deterioration in neurological status, which can be substantial in the giant breed dogs who most likely require this technique. The most common lesions associated with the use of this technique are bulbous articular facets, ligamentum flavum hypertrophy or a combination of both.

Approach[13]

With the patient in sternal recumbency the front feet are secured cranially and the head and neck elevated from the surgical table. Tape placed over the muzzle and thorax help secure the neck. A midline incision is made in the skin over the dorsal processes of the cervical spine from the poll of the cranium to T3. After the subcutaneous fascia and aponeurosis of the platysma muscle are incised, an incision is made through the median fibrous raphe. The origins of the splenius and serratus dorsalis muscles can be incised from the raphe and reflected to expose the nuchal ligament, dorsal spinous processes of the thoracic vertebrae and the long spinal muscles. These muscles are separated from the midline and reflected form the dorsal spinous processes to expose the dorsal laminae.

Technique[12]

After exposure of the cervical vertebrae, the dorsal spinous processes of the affected vertebrae are removed with rongeurs and the dorsal lamina is carefully removed using a high speed surgical bur. The length of the laminectomy may be from 3/4 the length of each vertebrae up to a continuous laminectomy extending from C4 to C7. The width of the laminectomy is limited by the medial aspect of the articular facets of the cranial vertebra. The initial depth of the laminectomy defect is to the periosteum of the inner cortical layer of the laminae. Following penetration into the spinal canal, the remaining laminae and ligamentum flava are gently excised and removed en bloc (Figure 47-20). Kerrison rongeurs can be quite useful for this procedure. If needed, resection of the lateral aspects of the vertebral arches can be continued to the level of the ventral vertebral veins using rongeurs. It is important to preserve the articular facets. Hypertrophied joint capsule and ligamentum flavum is resected to achieve decompression of the spinal cord. Transarticular hemicerclage wires or lag screws may need to be placed through the facets for additional stability. If stabilization is required, an appropriate sized hole is drilled through the articular facet. Removal of the articular cartilage is achieved using a high speed surgical bur. An 18-gauge stainless steel wire is placed through the hole and twist tightened or, alternatively, the hole is tapped and a lag screw placed. Cancellous bone is placed around the joint to promote arthrodesis.[14,15,16,17,18] An autogenous fat graft placed over the laminectomy site will

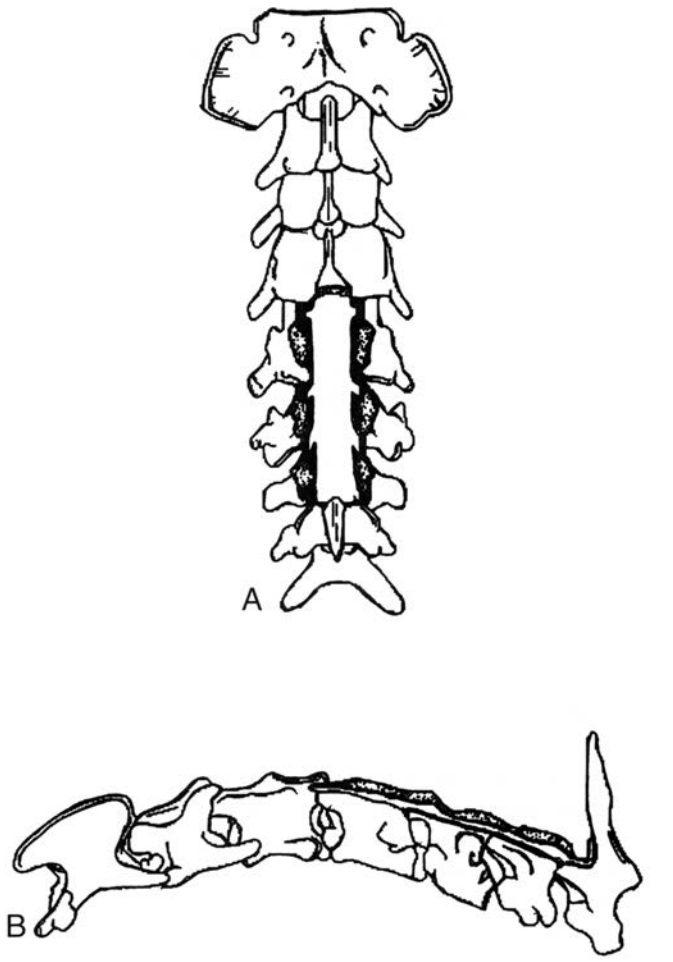


Figure 47-20. A. and **B.** The dorsal laminae have been removed from C4 through C7 to provide direct decompression of the caudal cervical spinal cord.

prevent the formation of a fibrous laminectomy membrane with subsequent stricture and spinal cord compression. Paraspinal muscles and fascia are approximated and the remaining closure is routine. A cervical bandage or brace is generally required.

Post-operative Management of CCSM Patients

Analgesics may be necessary for 24 to 48 hours postoperatively. Corticosteroids are not indicated in the postoperative period and may be contraindicated. Non-steroidal antiinflammatories and oral opiods can be used for post-operative pain management. A cervical bandage of rolled cotton and stretch gauze can be placed postoperatively to prevent excessive head and neck movements. This bandage can remain in place for 3 weeks. If warranted and tolerated, a neck brace constructed of fiberglass cast material or a heat moldable splint material, incorporating the cervical and cranial aspect of the thoracic spine may limit movement, thereby promoting fusion. Handles built into the brace may allow for better assistance when rising and walking. A thoracic harness should be used instead of a neck collar. Post-operative management of CCSM patients is generally divided into ambulatory or non-ambulatory convalescence. Patients with an ambulatory status post-operatively are generally managed in the following manner: cage confinement, brief exercise 2 to 3 times a day for 2 to 3 weeks, and home on restricted exercise and/or passive range of motion exercises. Non-ambulatory patients are managed in the following manner: elevated padded cage rack or waterbed, passive range of motion exercises and turned every 2 to 4 hours, bladder expressions 4 to 5 times a day, serial neurologic evaluations and frequent hydrotherapy (swimming with support) until return to an ambulatory status is achieved. Care most be taken especially in the giant breeds to monitor for and prevent aspiration pneumonia secondary to recumbancy and poor lower esophageal sphincter tone after anesthesia. Patients who are recumbent should be held up in sternal recumbancy when offered food and water to prevent the occurrence of aspiration. Crate or pen confinement is recommended for 6 to 8 weeks with gradual return to normal activity to follow.

Neurologic recovery is generally very rapid, but exceptions do occur. Neck pain usually subsides within 24 to-48 hours. Tetraparetic patients should begin to show improvement within days, as well. Any neurologic improvement within 3 weeks of surgery is encouraging. The neurologic status 6 weeks postoperatively is a good indication of ultimate neurologic recovery, however patients may show improvement in function up to 6 months postoperatively.[4,5] Serial neurologic exams and compliant owners are essential in the follow-up of these patients. Iatrogenic spinal cord trauma, post-operaative compressive hemorrhage, irreversible demyelination and myelomalacia or agenesis of the affected spinal cord limits the success of surgical techniques used to treat CCSM.

References

1. Goring RL, Beale BS, Faulkner RF. The inverted cone decompression technique: A surgical treatment for cervical vertebral instability "Wobbler Syndrome" in Doberman pinschers. Part 1. J Am Anim Hosp Assoc 1991; 27: 403-409.

2. Chambers JN, Betts CW. Caudal cervical spondylopathy in the dog: a review of 20 clinical cases and the literature. J Am Anim Hosp Assoc 1977; 13: 571-576.

3. Chambers JN, Oliver JE, Bjorling DE. Update on ventral decompression for caudal cervical disk herniation in Doberman pinschers. J Am Anim Hosp Assoc 1986; 22: 775-778.

4. Bruecker KA, Seim HB, Withrow SJ. Clinical evaluation of three surgical methods for treatment of caudal cervical spondylomyelopathy of dogs. Vet Surg 1989; 18: 197-203.

5. Bruecker KA, Seim HB, Blass CE. Caudal cervical spondylomyelopathy: decompression by linear traction and stabilization with Steinmann pins and polymethyl methacrylate. J Am Anim Hosp Assoc 1989; 25: 677-683.

6. Ellison, GW, Seim HB, Clemmons RM. Distracted cervical spinal fusion for management of caudal cervical spondylomyelopathy in large breed-dogs. J Am Vet Med Assoc 1988; 193: 447-453.

7. Lincoln JD, Pettit GD. Evaluation of fenestration for treatment of degenerative disk disease in the caudal cervical region of large dogs. Vet Surgery 1985; 14: 240-246.

8. Seim HB, Withrow SJ. Pathophysiology and diagnosis of caudal cervical spondylomyelopathy with emphasis on the Doberman pinscher. J Am Anim Hosp Assoc 1982; 18: 241-251.

9. Seim HB, Bruecker KA. Caudal Cervical Spondylomyelopathy (Wobbler Syndrome). In, (ed) Bojrab, Disease Mechanisms in Small Animal Surgery, 2nd ed. Lea and Febiger. 1993: 979-983.

10. Walker TL. Use of Harrington Rods in Caudal Cervical Spondylomyelopathy. In, (ed)Bojrab, Current Techniques in Small Animal Surgery, 3rd ed. Lea and Febiger. 1989: 584-586.

11. Dixon BC, Tomlinson JL, Kraus KH. Modified distraction-stabilization technique using an interbody polymethyl methacrylate plug in dogs with caudal cervical spondylomyelopathy. J Am Vet Med Assoc 1996; 208: 61-68.

12. Lyman, R. Continuous dorsal laminectomy for the treatment of Doberman pinschers with caudal cervical vertebral instability and malformation. Abstracts, 5th Annual Meeting of the American Animal Hospital Association 1987: 303-308.

13. Piermattei DL. An atlas of surgical approaches to the bones and joints of the dog and cat. 3rd ed. WB Saunders, 1993; 60-69.

14. Walker TL, Tomlinson JL, Sorjonen DC, Kornegay JN. Diseases of the spinal column. In, (ed) Slatter, Textbook of Small Animal Surgery. WB Saunders, 1985; 1367-1391.

15. Trotter EJ, deLahunta A, Geary JC, Brasmer, TH. Caudal cervical vertebral malformation-malarticulation in Great Danes and Doberman Pinschers. J Am Vet Med Assoc 1976; 10: 917-930.

16. Dueland R, Furneaux RW, Kaye MM. Spinal fusion and dorsal laminectomy for midcervical spondylolisthesis in a dog. J Am Vet Med Assoc 1973; 162: 366-369.

17. Hurov LI. Treatment of cervical vertebral instability in the dog. J Am Vet Med Assoc 1979; 175: 278-285.

18. Sharp N, Wheeler S. Cervical Spondylomyelopathy. Small Animal Spinal Disorders. Second edition. Elsevier. 2005. 211-246.

Surgical Treatment of Atlantoaxial Instability

Kurt Schulz

This topic is written based on the available literature through 2010 and does not cover the most current literature on this topic.

Two categories of surgical techniques have been described. Both dorsal and ventral approaches aim to stabilize the atlantoaxial joint in the normal position; however, only ventral approaches allow for complete fusion of the involved cervical vertebrae and permit excision of the dens if necessary.

Ventral Approach

Atlantoaxial instability can be resolved permanently by fusing the two vertebrae in anatomic alignment, a procedure that is easier from a ventral approach. This approach also allows access to the dens if removal is indicated because of fracture or severe dorsal displacement. With the dog in dorsal recumbency, the head and neck should be extended and supported by padding under the cervical area (Figure 47-21A). The surgical approach is made through a ventral midline incision extending from the larynx to the manubrium, followed by separation of the paired sternothyroid muscles. The trachea, esophagus, and carotid sheath are bluntly dissected to allow lateralization. The paired hypaxial muscles ventral to the atlas and axis then are separated carefully on the midline and are lateralized with self-retaining retractors.

The joint capsule of the atlantoaxial articulation should be identified and opened with a No. 11 Bard-Parker blade (Figure 47-21B). In chronic cases, the joint capsule may be thickened and may contain increased volumes of joint fluid. The joint may be reduced to normal position by retraction with small, pointed reduction forceps on the caudal body of the axis. If the dens is fractured or ununited, it should be removed through an incision through the membrane between the two articulations. The ligaments attached to the apex of the odontoid process are exposed through a ventral opening in the fascia covering the foramen magnum. The dens may be removed after careful severance of these apical and alar ligaments. Removal of the dens should not be necessary if it is united to the body of C2 and, if accurate, stable realignment can be accomplished.

Arthrodesis of CI and C2 is optimized by removal of the articular cartilage from the joint spaces and placement of a cancellous bone graft obtained from the proximal humerus. Access to the joints may be increased by gentle caudal retraction of C2 with reduction forceps, and the cartilage may be removed with rongeurs or an air drill. Because of the architecture and location of the joints, it is unrealistic to expect removal of all the articular cartilage; removal of the ventral 75% from all four articular surfaces is probably adequate. The bone graft is packed into the joint spaces after adequate removal of cartilage and lavage of the surgical site.

Ventral stabilization of the atlantoaxial joint may be achieved using pins alone, pins and polymethylmethacrylate, lag screws, or bone plates. A power drill is necessary for accurate placement of pins and screws. If pins alone are to be used, two small Steinmann pins or large Kirschner wires are driven from the center of the axis across the atlantoaxial joint and are seated in the atlas just medial to the alar notch (Figure 47-21C and D).[1] The point of each pin must be kept as ventral as possible to avoid penetrating the dorsal surface of the thin wings of the atlas. The length of the pins is premeasured from the point of entry into the axis to the palpable medial aspect of the alar notches on the atlas. When both pins are seated, they are cut off close to the body of the axis. The protruding ends are crimped and bent to prevent cranial migration of the pins into the occipital condyles.

The addition of polymethylmethacrylate to the stabilization technique may increase the odds of successful arthrodesis by enhancing stability and may reduce the risk of pin migration (KS Schultz, Waldron DR, unpublished data). Pins are first placed into the atlas (Figure 47-22A). This placement is facilitated by gentle dorsiflexion of the atlantoaxial joint that allows visualization of the spinal canal. Kirschner wires or small threaded pins are directed perpendicular to the long axis of the spine from ventral to dorsal into each of the pedicles of the atlas. The atlantoaxial joint is then reduced, and pins are placed across the joints as described for pin stabilization alone. One or two pins are then placed into the caudal body of the axis (Figure 47-22B). All pins are cut short and are bent, leaving enough pin length to engage a small mass of polymethylmethacrylate (Figure 47-23). Antibiotic powder should be added to the cement, and cool saline flush should be applied during polymerization of the cement to dissipate heat.

The surgical approach and preparation of the atlantoaxial joints are identical for stabilization with lag screws.[2] In small dogs,

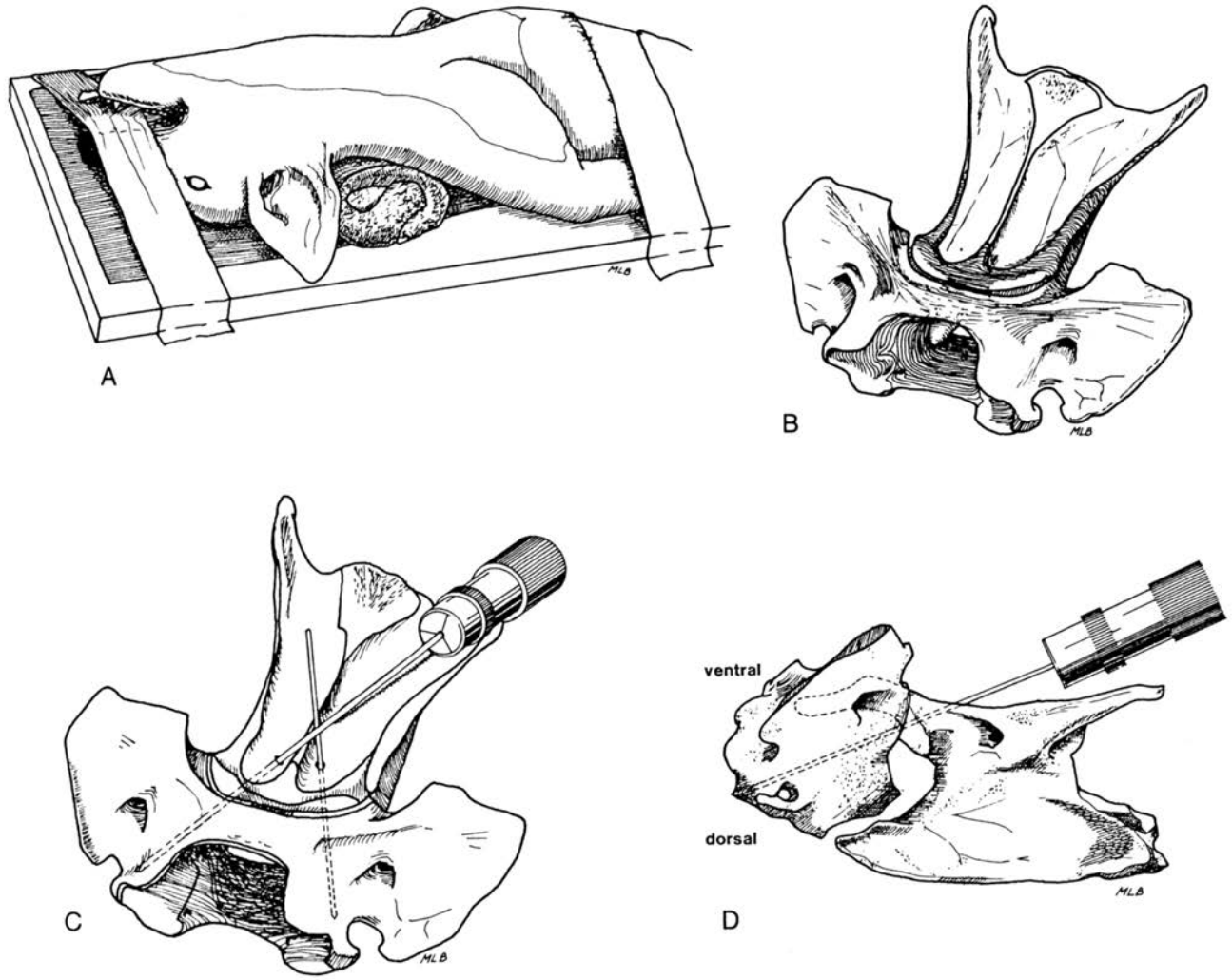


Figure 47-21. A. Positioning of the patient for a ventral approach to the atlantoaxial joint. **B.** The ventral aspect of the atlantoaxial joint seen from a craniolateral view. **C.** Pin placement through the atlantoaxial joints from the ventral body of the axis. Accurate seating of the pins into the medial side of the alar notch is essential. **D.** A lateral view of the stabilization pin placement from the ventral body of the axis, through the atlantoaxial joint, and into the heavy bone surrounding the neural canal.

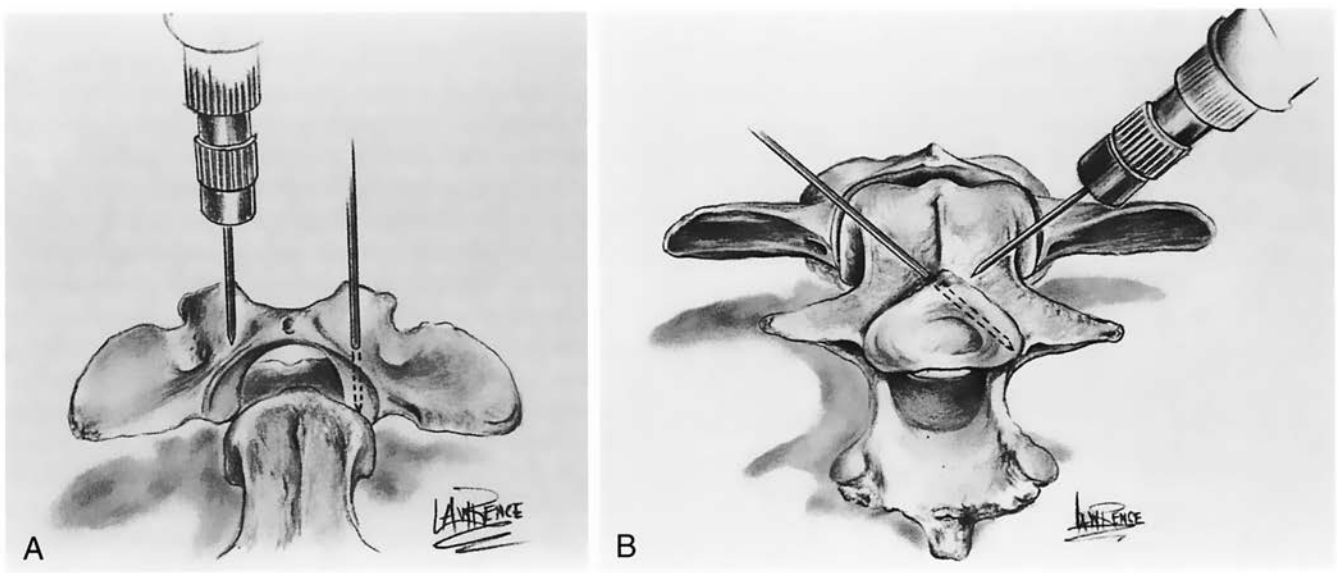


Figure 47-22. A. Pin placement into the lateral masses of CI. **B.** Pin placement into the caudal body of C2.

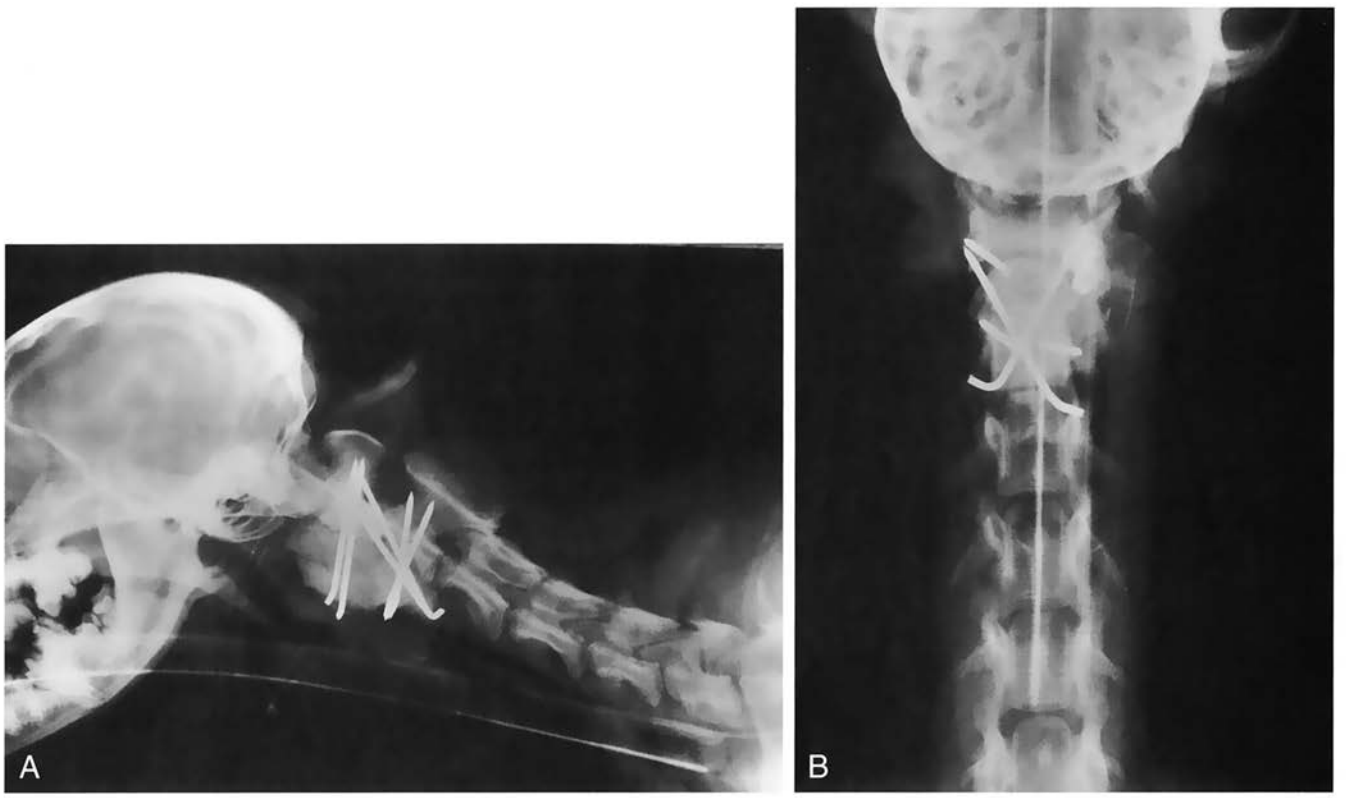


Figure 47-23. Lateral and ventrodorsal radiographs showing stabilization of the atlantoaxial joint with ventral pins and polymethylmethacrylate.

1.5-mm cortical screws are placed across each of the joints in a lag fashion. This technique may be facilitated by use of a cannulated drill and screw system. In either case, placement of the screws is in a direction similar to that of the transarticular pins. Ventral application of bone plates has also been described; however, the size of most patients may limit the practical application of this technique.[3]

Postoperative radiographs should be obtained after stabilization with any of the ventral techniques to demonstrate reduction of the atlantoaxial joint and accurate placement of implants. Neck braces should be maintained if possible for several weeks, and initial cage rest is strictly enforced. Radiographs may be obtained 8 weeks postoperatively to evaluate maintenance of reduction and progression of arthrodesis.

Complications of ventral stabilization techniques include implant migration and loosening.[4] The result may be subsequent instability and recurrence of neurologic signs. Placement of pins or screws within the vertebral canal may also worsen the neurologic signs. Tracheal necrosis has been reported with the ventral approach; therefore, gentle dissection and attention to preservation of the delicate blood supply of the region are indicated. As with any surgical implantation of polymethylmethacrylate, concern exists for thermal injury and infection.

Dorsal Approach

The dorsal arch of the atlas is secured to the dorsal spine of the axis with heavy suture material, orthopedic wire, or grafts of the nuchal ligament. Descriptions of these techniques are available in the third edition of this text. Although ventral techniques are more difficult, we recommend them because of their lower failure rate.[4] Complications of dorsal techniques include instability resulting from breakage of the suture, wire, or graft and fracture of the axis or atlas. Wire stabilization may fail because of cycling, and the addition of polymethylmethacrylate to the wire technique has been recommended to alleviate this complication. Fracture of the axis may be due either to inappropriate placement of the holes or to the remaining motion of the joint, which places excessive forces on the stabilization technique.

Medical management including cervical splinting has been successful in selective cases; however, surgical therapy is recommended for patients demonstrating significant neurologic signs that have no other contraindications for anesthesia or surgery.[5] Ventral techniques are technically challenging, but because of the higher failure rates of dorsal techniques, the routine use of dorsal procedures should be avoided.[4]

References

1. Sorjonen DC, Shires PK. Atlantoaxial instability: a ventral surgical technique for decompression, fixation, and fusion. Vet Surg 1981;10:22-29.

2. Denny HR, Gibbs C, Waterman A. Atlanto-axial subluxation in the dog: a review of thirty cases and an evaluation of treatment by lag screw fixation. J Small Anim Pract 1988;29:37-47.

3. Thomas WB, Sorjonen DC, Simpson ST. Surgical management of atlantoaxial subluxation in 23 dogs. Vet Surg 1991;20:409-412.

4. McCarthy RJ, Lewis DD, Hosgood G. Atlantoaxial subluxation in dogs. Compend Contin Educ Pract Vet 1995;17:215-226.

5. Gilmore DR. Nonsurgical management of four cases of atlantoaxial subluxation in the dog. J Am Anim Hosp Assoc 1984; 20:93-96.

Surgical Treatment of Fractures of the Cervical Spine

Karen L. Kline and Kenneth A. Bruecker

General Considerations

When considering treatment options for a patient with a spinal fracture, luxation or subluxation, several factors should be considered; 1) results of the neurologic examination, 2) is the fracture pathologic or traumatic, and 3) is the fracture stable or unstable.

The neurologic examination is critical in determining prognosis. If the patient has lost all sensory and motor function caudal to the lesion, the prognosis is unfavorable and treatment is generally supportive. Surgery in this situation may be indicated for prognostic purposes only (ie. exploratory laminectomy). If deep pain perception is still present, the prognosis is guarded to favorable (depending on the degree of neurologic dysfunction and the timing of the event or injury) and surgical decompression and stabilization is performed with curative intent.

Patients with pathologic fractures have an underlying localized or generalized disorder. Examples of this would include a solitary plasma cell tumor, multiple myeloma or other classifications of paraneoplastic or infectious disorders. The cause of the underlying disorder must be determined and therapy instituted prior to or concurrent with spinal fracture/luxation repair.

Physical examination findings and radiographic assessment may be helpful in determining the inherent stability of the fracture/luxation.[1] In small animal patients, traumatic disruption of the spinal column can be divided into dorsal compartment injuries, ventral compartment injuries, or combined compartment injuries. Combined compartment injuries are more devastating and more common than injuries isolated to one compartment. The majority of spinal injuries are flexional injuries, but occasionally hyperextension or direct compression injuries may occur. Rotation is a common concurrent force associated with these injuries.

Fractures may be classified as stable or unstable by the radiographic appearance and by the force causing the injury. Forces resulting in damage to the dorsal compartment generally result in an unstable injury. Examples include laminar or pedicle fracture, dorsal spinous process fracture, articular process fracture, and supraspinous/interspinous ligament rupture.[2]

If surgery is deemed necessary, it is important to select a technique that will not further destabilize the spine. Herniated disk material or osseous fragments within the spinal canal may be anticipated in flexion or bursting type injuries. Concussive and contusive forces can cause spinal cord swelling even without evidence of an extradural mass. Extradural hematoma formation can be quite extensive and can be delineated on MRI or CT scan imaging. Infolding of the ligamentum flavum during hyperextension injuries may also result in spinal cord injury.

Generally, stable fractures in patients with good voluntary motor movements to the limbs are successfully managed by conservative means, including the use of analgesics, non-steroidal anti-inflammatory agents, body splints, and strict cage confinement.[3,4] Serial neurologic examinations are performed (twice daily) to determine the response to treatment.

Surgical management is indicated 1) if the fracture/luxation is considered unstable, 2) if the patient presents nonambulatory paraparetic or tetraparetic with no voluntary motor movements, or 3) if with conservative therapy, the patient remains unacceptably static or deteriorates neurologically.

Several factors must be considered when selecting a stabilizing technique: 1) location of the fracture/luxation (cervical, thoracic, lumbar, sacral), 2) presence of a compressive lesion within the spinal canal (ie. osseous fragment, disk material, hematoma), 3) size of the patient, 4) age of the patient, 5) equipment available, 6) experience of the surgeon, and 7) physical and emotional capability of the owner to provide postoperative nursing care.

Surgical Techniques

The two objectives of any surgical technique used to repair spinal fracture/luxation are decompression and stabilization. Many techniques have been successfully used to stabilize spinal fracture/luxation in small animals. In the following discussion, techniques commonly used to repair fractures and luxations of the spine will be described as they are indicated in various regions of the vertebral column. These chapters will be divided into surgical treatment of cervical spinal fractures, luxations and subluxations and surgical management of thoracolumbar, lumbar and lumbosacral fractures, luxations and subluxations. The above discussion regarding prognosis and patient selection in cases of spinal trauma applies to both categories of injury and disease.

Fractures of the Cervical Spine

Cervical spinal fractures are uncommon.[4,5,6] Most fractures of the cervical spine involve C1 (axis), particularly the dens and/or body.[6] In fact, the most frequent anatomic location of cervical fracture/luxation is the cranial cervical region with 80% occurring at C1-2. Because the cervical region has the largest ratio of vertebral canal to spinal cord diameter, conservative management consisting of external support and cage rest in unstable and/or displaced fractures may carry a more favorable prognosis than elsewhere in the spine.[7] Mortality rates can be as high as 35 to 40% with surgery.[7] Severe intraoperative hemorrhage may also occur with C2 fractures and reduction can be challenging.[5,7,8] External splints, though cumbersome, may be made from various materials. Surgery is best reserved for those animals that 1) are tetraplegic or have poor ventilatory function 2) show neurologic deterioration despite proper confinement or external fixation, and 3) remain painful beyond the initial 48 to 72 hour period following injury.[5]

Fractures of the dorsal spine of the axis should be approached dorsally and stabilized with orthopedic wire to reestablish the continuity of displaced fragments. A decompressive hemilaminectomy can be performed if fragments of bone are present in the

spinal canal, or if a displaced body fracture cannot be reduced. Atlantoaxial subluxation can be repaired from a dorsal approach utilizing either a double or single wiring or suturing technique.[7]

C1-C2 body fractures/luxations, traumatic cervical disk extrusions, and atlantoaxial subluxation can be approached ventrally. Ventral cross-pin techniques may be used for stabilization of atlantoaxial subluxation[10] (Figure 47-24).

Fractures and luxations rarely occur from C3 to C7 however, a predisposition to luxations at C5-C6 may exist.[6,11] Fracture/luxations of C3-C7 may be approached dorsally or ventrally. Dorsal techniques include articular facet wiring or screwing, dorsal spinous process plating and multiple Steinmann pins and polymethyl methacrylate (described in detail under Fractures of the T-L and Lumbar Spine). Ventral techniques include pins and polymethyl methacrylate and ventral body plating (plastic [footnote a] or metal [footnote b]). One advantage to the ventral approach is that a ventral slot can be performed if disk fragments have extruded into the spinal canal.

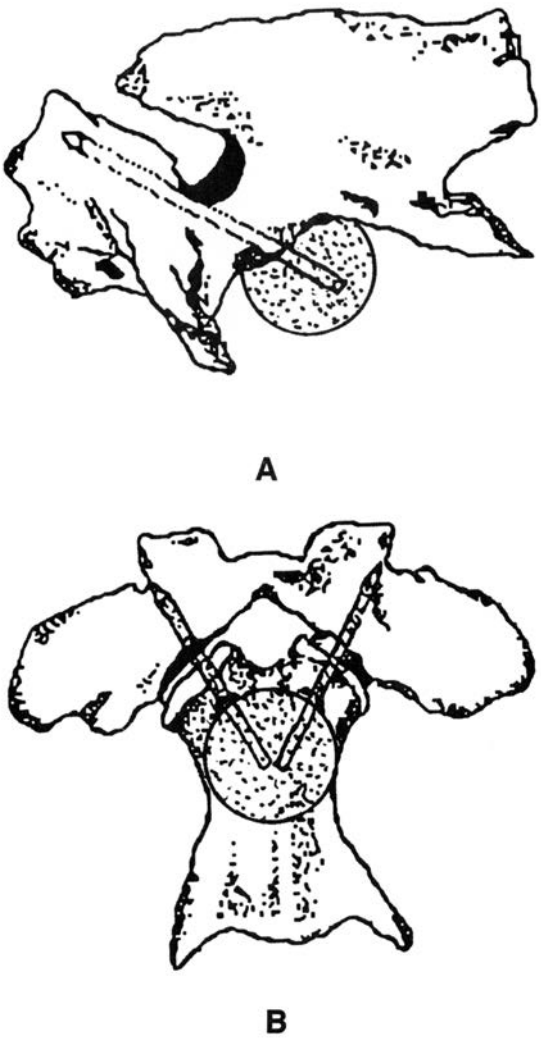


Figure 47-24. A. and **B.** Pin placement for arthrodesis of atlantoaxial joints in treating atlantoaxial subluxation by the ventral approach. The exposed portions of the pins (depicted within the dotted circle) can be notched and covered with methyl methacrylate to prevent pin migration. (From Sorjonen DC and Shires PK. Atlantoaxial instability: A ventral surgical technique for decompression, fixation, and fusion. Vet Surgery 1981;10:22-29.)

The use of pins (or screws)and polymethyl methacrylate should be considered for cervical spinal fractures involving the vertebral bodies of C2-C7. The ventral aspect of the involved vertebrae is exposed.[12] Once the fracture is reduced, a minimum of two trocar tip pins should be placed in the cranial fragment and a minimum of two pins should be placed in the caudal fragment. Alternatively, the fractured vertebral body can be bridged by insertion of pins into the vertebrae cranial and caudal to the fracture. It is important to engage two cortices with each pin. The pins are inserted on the ventral midline of the vertebral body and directed 30 to 35 degrees dorsolateral to avoid entering the spinal canal. In addition, the pins can be angled cranially and caudally to enhance stability of the implant. The pins are cut leaving 1 to 1.5 cm exposed. The exposed pins can be notched with pin cutters and covered with sterile polymethyl methacrylate[13] (Figure 47-25). Preferentially, specific purpose acrylic pins with threaded trocar tips and knurled shaft allows good bone anchor and foothold for the PMMA. The heat of polymerization is dissipated with 5 to 10 minutes of cool saline irrigation. A neck brace may be used for 4 to 6 weeks postoperatively. The limiting factor of this technique is the purchasing ability of the pins in small fragments. Screws can also be used as described above.[14,15,16] The main disadvantage of the above described techniques can be failure if used to span more than one intervertebral space especially in cases where the vertebral body is shattered or collapsed. In these cases, at least 3 implants should be placed on either side of the fracture and Steinman pins used to reinforce the cement. In some reports[2,11] if dorsal stability is required (ie especially after facet luxation), screws can be placed transarticularly.[5] Reduction of cervical fracture/luxations can be facilitated by gently distracting the affected vertebral bodies. Fenestration of the adjacent intervertebral disks or slots drilled into the vertebral bodies cranial and caudal to the fracture/luxation can be created to accommodate a vertebral distractor. A Gelpi retractor, modified by blunting the tips, is a useful vertebral distractor.

Stabilization with ventral locking plates and screws has become another method of repair and will be of interest in the future once the technique is perfected and the price of the spinal plates becomes less cost prohibitive.

After cervical spinal stabilization, complications can include Horners syndrome (which can be permanent or transient) and respiratory depression and/or distress secondary to diaphragmatic paresis or paralysis. This occurs in the aftermath of hemorrhage into or contusion to the phrenic nerve nuclei located at the C4-6 cervical spinal cord segments.

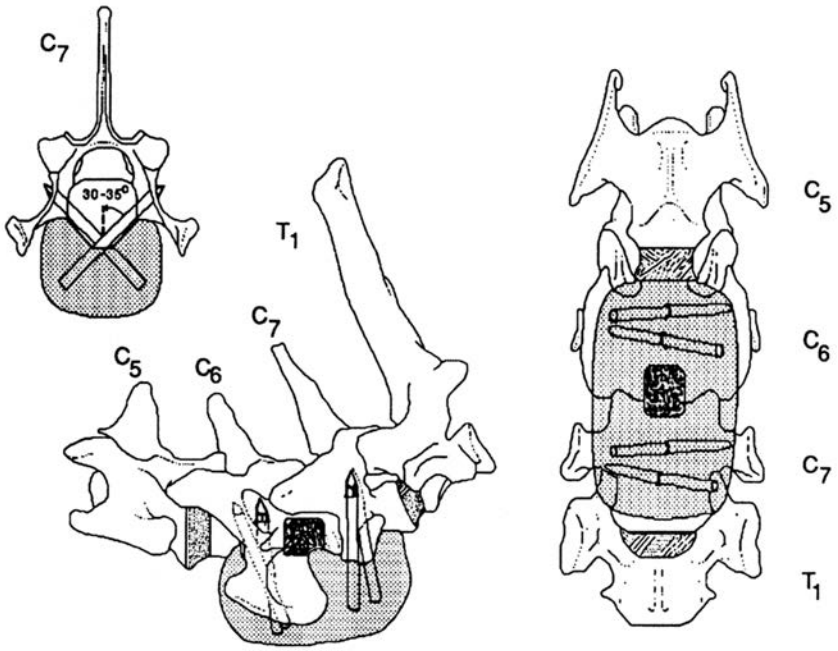


Figure 47-25. Stabilization with ventrally placed Steinmann pins and methyl methacrylate of cervical fractures/luxation. Ventral slot can be performed to remove herniated disk material. (From Blass CE, Waldron DR, van Ee RT. Cervical stabilization in three dogs using steinmann pins and methyl methacrylate. J Am Anim Hosp Assoc 1988;24:61-68.)

References

1. Feeney DA and Oliver JE. Blunt spinal trauma in the dog and cat: neurologic, radiologic and therapeutic correlations. J Am Anim Hosp Assoc 1980;16:664-668.

2. Swaim SF. Biomechanics of cranial fractures, spinal fractures, and luxations, in (ed) Bojrab, Pathophysiology in Small Animal Surgery. 1981:774-778.

3. Carberry CA, Flanders JA, Dietze AE, et al. Nonsurgical management of thoracic and lumbar spinal fractures and fracture/luxations in the dog and cat: a review of 17 cases. J Am Anim Hosp Assoc 1989;25:43-54.

4. Feeney DA and Oliver JE. Blunt spinal trauma in the dog and cat: insight into radiographic lesions. J Am Anim Hosp Assoc 1980;16:885-890.

5. Sharp NJ and Wheeler SJ: Trauma. In Small Animal Spinal Disorders. Philadelphia; Elsevier, 2005, 282-305.

6. Stone EA, Betts CW, Chambers JN. Cervical fractures in the dog: a literature and case review. J Am Anim Hosp Assoc 1979;15:463-471.

7. Hawthorne JC, et al. cervical vertebral fractures in 56 dogs: a retrospective study. JAAHA, 35, 135-146.

8. Boudrieau RJ. Distraction-stabilization using the Scoville-haverfield self-retianing laminectomy retractors for repair of 2nd cervical vertebral fractures in 3 dogs. Vet and Comp Orthopaedics and Traumatology 10, 71.

9. Oliver JE and Lewis RE. Lesions of the atlas and axis in dogs. J Am Anim Hosp Assoc 1973;9:304-313.

10. Sorjonen DC and Shires PK. Atlantoaxial instability: A ventral surgical technique for decompression, fixation, and fusion. Vet Surgery 1981;10:22-29.

11. Basinger RR, Bjorling DE, Chambers JN. Cervical spinal luxation in two dogs with entrapment of the cranial articular process of C6 over the caudal articular process of C5. J Am Vet Med Assoc 1986;188:865-867.

12. Piermattei DL. An atlas of surgical approaches to the bones and joints of the dog and cat. 3rd ed. WB Saunders, 1993;45-89.

13. Blass CE, Waldron DR, van Ee RT. Cervical stabilization in three dogs using steinmann pins and methylmethacrylate. J Am Anim Hosp Assoc 1988; 24:61-68.

14. Rouse GP and Miller JI. The use of methyl methacrylate for spinal stabilization. J Am Anim Hosp Assoc 1975;11:418-425.

15. Rouse GP. Cervical Spinal Stabilization with polymethylmethacrylate. Vet Surg 8.1979.1.

16. Schulz KS, et al. Application of ventral pins and polymethylmethacrylate for management of atlantoaxial instability: results in 9 dogs. Vet Surg 26.317-325.

Chapter 48

Thoracolumbar and Sacral Spine

Intervertebral Disc Fenestration

James E. Creed and Daniel J. Yturraspe

Indications

Fenestration of thoracolumbar intervertebral discs is appropriate for dogs of breeds predisposed to disc herniation (such as the dachshund and Pekingese), with clinical signs ranging from lumbar pain to paresis, that are otherwise in good health and are less than 8 years of age. One study indicated that only 5% of dogs with thoracolumbar disc herniations were more than 8 years of age.[1] Whether older dogs are less likely to have recurrent problems is unknown, but in such dogs a conservative approach seems advisable initially.

Fenestration should be considered when signs of disc herniation are first evident; the operation is definitely recommended if signs progress in severity or on the first recurrence. Dogs presented with caudal motor paralysis should undergo spinal cord decompression, because disc fenestration alone is not appropriate treatment for paralysis. If the dog still perceives pain in the rear toes, fenestration should also be accomplished. Fenestration can be performed within a variable period after disc herniation; we prefer to operate within the first 2 to 3 days. The patient can then recuperate from surgery while hospitalized to treat signs produced by that herniation.

Preoperative Preparations

Corticosteroids and antibiotics are administered preoperatively. Anesthesia is induced with a short-acting anesthetic agent and maintained by endotracheal administration of an acceptable volatile agent. Intravenous fluids are administered during surgery and postoperatively. An area of the back extending from the vertebral border of each scapula to the crest of each ilium is clipped and prepared for surgery. The dog is positioned in ventral recumbency on an insulating pad to conserve body heat. It is most convenient for surgeons to operate from the side of the patient opposite that of their dominant hand. Radiographs and a skeleton should be available for reference.

Surgical Technique

A dorsolateral approach[2] is used to gain access to eight intervertebral discs between T10 and L5. Discs between T9-10 and L5-6 can also be fenestrated if they are calcified or partially herniated. These discs are not routinely fenestrated because of their low incidence of herniation. They are also technically more difficult to fenestrate because of anatomic differences. Not only is the L5-6 disc more difficult to fenestrate, but also considerable risk of creating a femoral nerve deficit exists if the adjacent ventral nerve branch is damaged.

A skin incision is made from one to two spinous processes rostral to the anticlinal vertebra (T11) to one vertebra rostral to the ilium. This incision may be made directly on the dorsal midline or 1 to 2 cm lateral to the midline on the side from which discs are to be fenestrated. The cutaneous trunci muscle, subcutaneous fat, and superficial fascia are incised in the same plane and are reflected sufficiently to expose lumbodorsal fascia 1 to 2 cm lateral to the dorsal midline (Figure 48-1A). Lumbodorsal fascia and aponeurosis of the longissimus thoracis et lumborum muscle

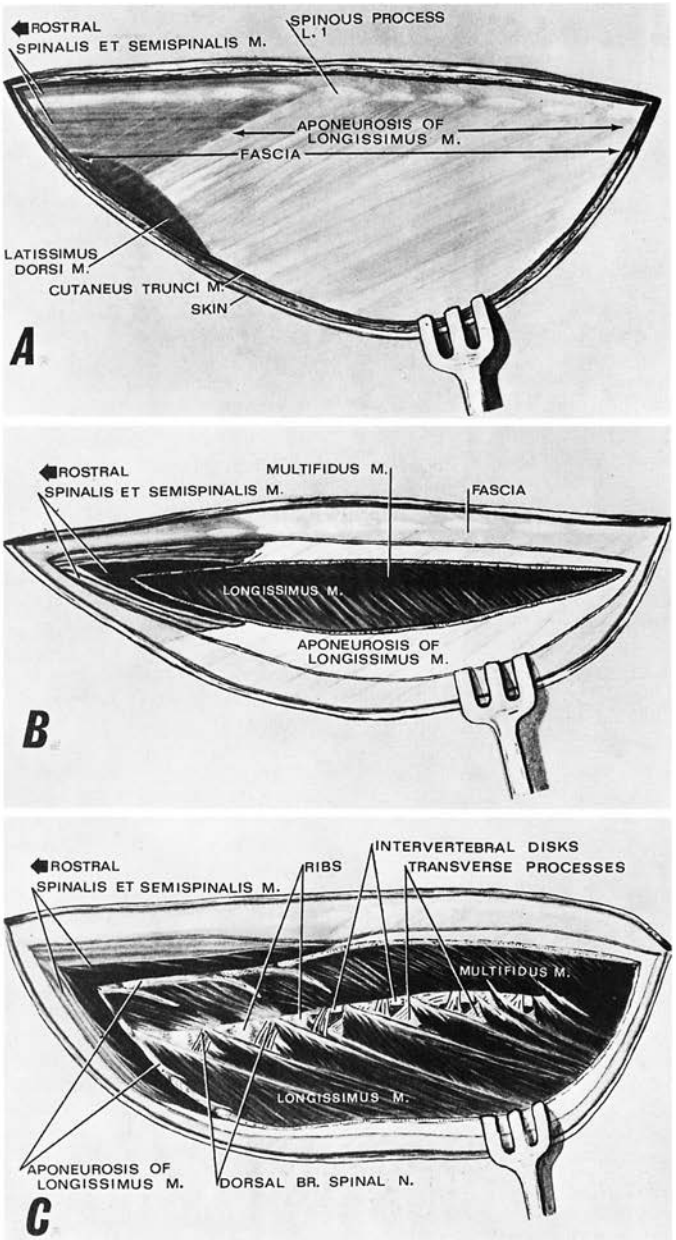


Figure 48-1. Surgical anatomy of the dorso-lateral approach to the thoracolumbar discs of the dog. **A.** The skin, subcutaneous fascia, fat, and cutaneous trunci muscle have been incised and reflected laterally on the left side of the dog. **B.** The deep external fascia of the trunk, the aponeurosis of the longissimus thoracis muscle, and the caudal edge of the spinalis et semispinalis muscles have been incised to expose the underlying multifidus and longissimus muscles. **C.** The multifidus muscle is separated from the longissimus thoracis muscle by blunt dissection to expose the thoracolumbar spine for intervertebral disc fenestration.

are incised along an imaginary line from a point 5 mm lateral to the spinous process of T9 to a point 1 to 2 cm lateral to the comparable process of L6 (Figure 48-1B). In the rostral portion of the surgical field, the caudal border of the spinalis and semispinalis thoracis muscles, interposed between the lumbodorsal fascia and aponeurosis of the longissimus thoracis muscle, is also incised (Figures 48-1B and 48-2).

Access to intervertebral discs is gained by opening the intermuscular septum between multifidus lumborum and thoracis muscles medially and longissimus dorsi and sacrococcygeus dorsalis lateralis muscles laterally (Figures 48-1C, 48-2 and 48-3). This septum is the first one lateral to the dorsal spinous processes; it is easiest to locate in the midlumbar region, where fat is interposed superficially between muscles. Muscles are easily divided by blunt dissection in the lumbar region; however, the septum is less distinct over the ribs. All blunt dissection is done with a curved semisharp Adson, or comparable, periosteal elevator in each hand. As tubercles of the last four ribs are exposed, care should be taken not to disturb small nerves and vessels coursing craniolaterally immediately dorsolateral to each tubercle. Separating muscles is carried to the base of the lumbar transverse processes.

The novice should completely separate muscles to this level taking care to avoid dorsal branches of spinal nerves (See figure 48-1C). This provides good visualization of intervertebral discs and adjacent structures. Experienced surgeons can "tunnel" down to each lumbar transverse process, thereby avoiding considerable tedious dissection and trauma. The short transverse process of L1 lies adjacent to the last rib, assuming the thirteenth rib is present, and is used as an anatomic reference point. All other lumbar transverse processes can be "tunneled" down to by referring to the lateral radiograph and estimating the distance between each process. If judgment is correct, the veterinary surgeon will never see dorsal branches of each rostral spinal nerve or its allied vessels. As the operation proceeds caudally from T13 to L1, succeeding transverse processes are progressively deeper.

As the surgeon exposes lumbar transverse processes (L1-5), the lumbar discs are exposed. The lateral anulus of intervertebral discs lies immediately rostral to the base of each transverse process (Figure 48-4). In the caudal thoracic area, discs are rostromedial to the head of each rib. The T10-11 disc is difficult to expose because it is 1 to 2 cm ventromedial to and is partially covered by the rib tubercle. Each disc can be visualized by elevating tissue off the lateral anulus with a periosteal elevator. Use of a small self-retaining retractor (Gelpi or Weitlaner) or hand-held retractors enhances visualization. Care should be taken not to invade intervertebral foramina, which lie immediately dorsal to each disc

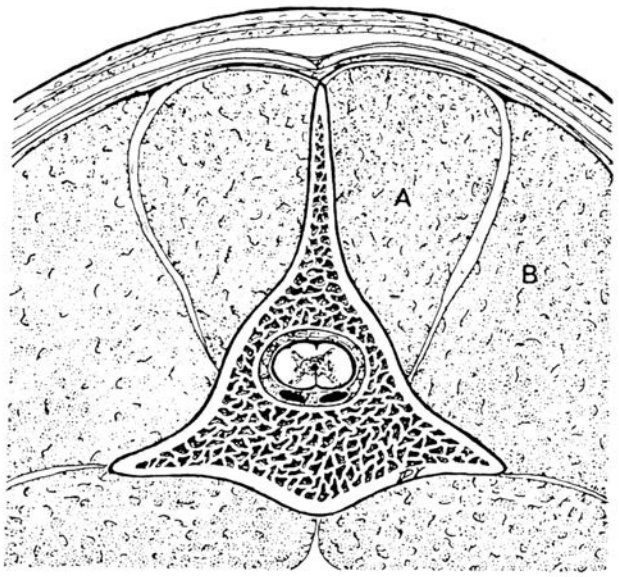


Figure 48-3. Cross section through L4. *A.* Multifidus lumborum muscle. *B.* Longissimus lumborum muscle.

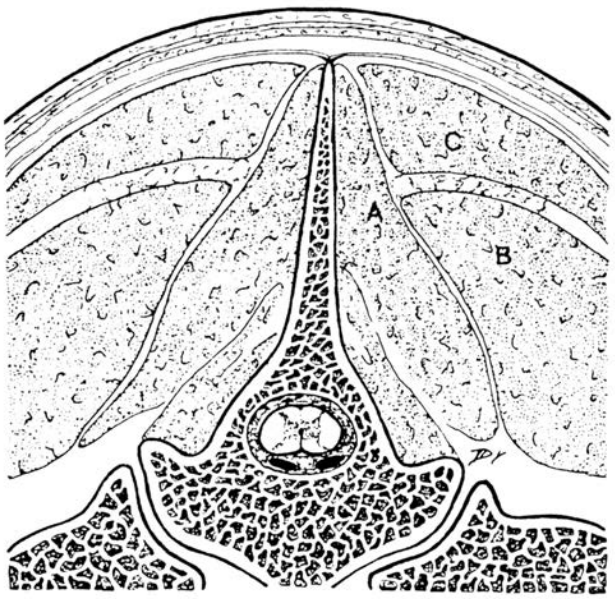


Figure 48-2. Cross section through T12. *A.* Multifidus thoracis muscle. *B.* Longissimus thoracis muscle. *C.* Spinalis et semispinalis muscles.

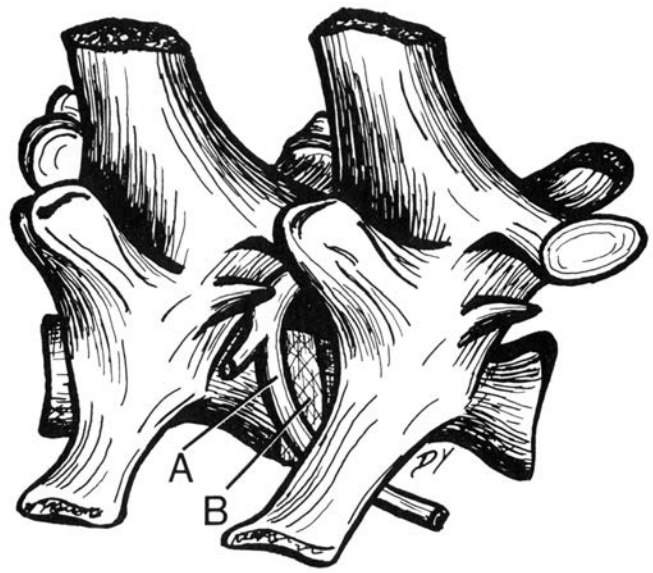


Figure 48-4. L3-4 showing the relation of the spinal nerve to the intervertebral disc. *A.* Ventral branch of L3 spinal nerve. *B.* Intervertebral disc.

and contain spinal nerves and allied vessels. The inexperienced surgeon may overcompensate while attempting to avoid intervertebral foramina and work too far ventrally, where one risks injuring ventral branches of spinal nerves. Ventral branches of spinal nerves pass adjacent to the ventrolateral aspect of each disc (See figure 48-4).

In the lumbar area, ventral branches of the spinal nerves are located under the intertransverse fascia and are not visible in the surgical field unless an attempt is made to expose them. To ensure that a ventral branch is not traumatized, the tip of a curved mosquito hemostat can be introduced into the intertransverse fascia adjacent to the ventrolateral border of the anulus and the jaws can be spread gently. This exposes the ventral nerve branch occasionally, and creates a landmark for the surgeon to avoid. If the L5-6 disc is fenestrated, the ventral branch of the fifth lumbar nerve should be identified and avoided to ensure it is not damaged.

A disc's lateral anulus is visualized best for fenestration if adjacent muscle is retracted rostrodorsally with a curved, semisharp periosteal elevator. This instrument also protects dorsal branches of spinal nerves and associated vessels. A pointed scalpel blade is used either to incise or to remove an elliptical section of the anulus fibrosus. The anulus should not be cut where it cannot be visualized. Fenestration is accomplished with a modified dental-claw tartar scraper or the eye portion of a large suture needle held in a needle holder. Modifications to dental tartar scrapers include grinding off the sharp tip and sides of the claw. The nucleus pulposus is removed using a circular motion. The tip of the hook or needle-eye is directed upward, with care taken not to break through the dorsal anulus. A partially herniated disc must he fenestrated cautiously, to avoid forcing additional nucleus pulposus into the spinal canal (Figure 48-5). The surgeon must remove as much disc material as possible.



Figure 48-5. The correct position of a modified dental claw tartar scraper to fenestrate a disc, in this case a partially herniated disc.

Fenestrating T10-11 disc requires special care to avoid creating pneumothorax; pleura, directly ventral to this disc, rises and falls with respiratory movement. If existence of pneumothorax is in question, irrigating the area with saline solution and expanding the lungs by compressing the ventilation bag should provide an answer; air bubbles will appear in the surgical field if significant pneumothorax exists.

Minimal hemorrhage associated with exposure and fenestration of thoracolumbar discs can usually be controlled by topical pressure on bleeding tissue with a periosteal elevator. Rarely, hemostatic forceps or electrocautery is required to control bleeding.

Every disc fenestrated should be identified to ensure no discs are missed between T10 and L5. If clinical signs merit decompression of the spinal cord, decompression should be performed first, followed by disc fenestration. Fenestration is more compatible with hemilaminectomy than with dorsal decompression. Hemilaminectomy and fenestration can be performed from the same side; although the multifidus muscle is badly traumatized, no adverse clinical signs have been observed. Lateralization of signs often dictates performing a decompressive surgical procedure and fenestration on opposite sides of the spinal column.

Debridement of tissue is not necessary when the "tunnel" technique is used to expose lumbar discs. Performing a hemilaminectomy on the same side, or division of the multifidus and longissimus dorsi muscles down to the level of transverse processes for improved exposure, may necessitate some debridement. Aponeurosis of the longissimus and spinalis et semispinalis muscles in the caudal thoracic area and overlying thoracolumbar fascia are approximated with one suture line of absorbable suture material. Subcutaneous tissues are apposed with similar material, catching underlying fascia occasionally to obliterate dead space. The skin incision is closed with any dermal suture. A light-pressure bandage may he applied around the trunk of the dog and left in place for 4 to 7 days.

Postoperative Care and Prognosis

Corticosteroid and analgesic agents should be administered for 1 to 3 days postoperatively because most dogs experience some discomfort. Thereafter, treatment depends on clinical signs. Because corticosteroids are used in association with this operation, skin sutures should be left for at least 3 weeks to avoid incisional dehiscence. Dogs routinely go home 48 to 72 hours after surgery, or as soon as voluntary urination is evident. In addition to preventing subsequent attacks of disc prolapse, fenestration eliminates the need for prolonged confinement of dogs with functional ambulatory ability. Physical therapy can be initiated within a day or so of surgery in patients with caudal paralysis.

Paresis, if present, remains unchanged in most animals immediately postoperatively. Because clinical signs occasionally are more severe immediately after the procedure, the client must be forewarned of this possibility. Deterioration in neurologic status can be associated with the operation. If pathologic changes in the spinal cord, which may or may not be known,

are progressive at the time of surgery, disc fenestration itself will not be responsible for a worsened neurologic state. Such a condition may result from spontaneous herniation of additional nucleus pulposus while the dog is anesthetized for radiographs or surgery. Overzealous fenestration of a partially herniated disc may also force additional material into the spinal canal. Trauma to the spinal cord from the fenestration hook is an unlikely cause of increase in neurologic deficit. The client should be advised that some dogs suddenly deteriorate neurologically without radiographs or operation.

The most likely potential surgical complications are 1) failure to fenestrate a disc, 2) creating a pneumothorax, 3) injury to spinal nerves, 4) damage to the spinal cord, and 5) cutting spinal arteries.

In most dogs, evidence of some degree of spinal nerve injury exists for at least a few days postoperatively. Dogs may have slight scoliosis, with deviation to the operated side, and sag (paralysis) of abdominal muscles ipsilateral to the operated side may be noticeable. If the ventral branch of the fifth lumbar (L5-6) has been damaged, the dog will have at least a temporary femoral nerve deficit. Severity of these signs is directly correlated with the expertise of the veterinary surgeon.

We are aggressive in promoting thoracolumbar disc fenestration because it is impossible to predict severity of a recurrent disc attack. Herniation of a cervical disc has not been observed to cause permanent caudal paralysis or death from diffuse myelomalacia; in the thoracolumbar region, however, such a sequela is not unusual. Fenestration, properly performed, should minimize chances of subsequent disc episodes, and the dog's locomotion should not be compromised.

The dorsolateral approach is preferred for fenestrating thoracolumbar discs because it 1) permits decompression by hemilaminectomy when this procedure is also indicated, 2) results in minimal trauma, and 3) provides easy access to nine discs. Thoracolumbar intervertebral disc fenestration is more difficult than cervical disc fenestration, and the potential for severe and possibly permanent neurologic injury can not be overemphasized. Success with this procedure requires a thorough understanding of anatomy and basic surgical principles. Consequently, the novice should perform this surgical procedure on a cadaver before attempting it on a clinical patient.

References

1. Gage ED: Incidence of clinical disc disease in the dog. J Am Anim Hosp Assoc 11:135, 1975.

2. Yturraspe JD. Lumb WV: A dorsolateral muscle separating approach for thoracolumbar intervertebral disc fenestration in the dog. J Am Vet Med Assoc 162:1037, 1973

3. Bartels KE. Creed JE: Yturraspe DJ. Complications associated with the dorsolateral muscle-separating approach for thoracolumbar disc fenestration in the dog. J. Am Vet Med Assoc 183:1081, 1983

Prophylactic Thoracolumbar Disc Fenestration

M. Joseph Bojrab and Gheorghe M. Constantinescu

Surgical fenestration of the intervertebral space provides a means of prophylaxis in disc disease. If protrusion exists, surgical removal of the nucleus remaining in the intervertebral area will eliminate the pressure causing the protrusion. When all other discs that are potential problems (T9-10 to L5-6) are fenestrated at the same time, complete prophylaxis against future disc protrusions is achieved. The material already extruded into the canal cannot be removed by disc fenestration alone; however, fenestration of other degenerated discs is recommended, so vigorous physical therapy, such as hydrotherapy and cart walking, can be prescribed without fear of causing another protrusion or even extrusion.

The ventral fenestration technique described here facilitates access to all potentially offending discs with a minimum of surgical trauma. Ten discs are fenestrated (T9-10 to L5-6). The thoracic discs are exposed through a left tenth intercostal thoracic approach, and the lumbar discs are exposed through a paracostal abdominal incision (Figure 48-6).

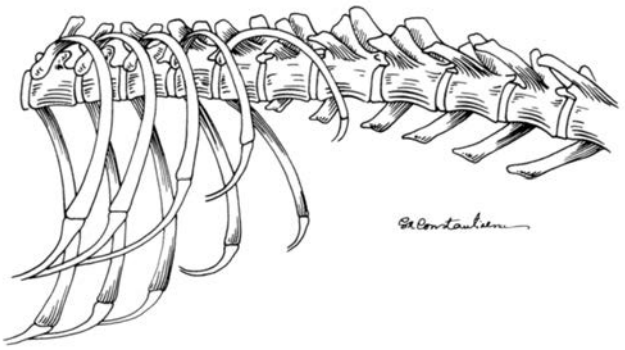


Figure 48-6. Diagrammatic representation of the ventral vertebral column from the left lateral view. Note the relation of the vertebral costal foveae and the rib heads to the various disc spaces.

Surgical Technique

The patient is medicated preoperatively with corticosteroids (dexamethasone 1 mg/lb) and antibiotics. The patient is placed in right lateral recumbency, and the left lateral side is clipped and prepared aseptically. The skin incision is made over the thirteenth rib from the dorsal to the ventral midline. The subcutaneous tissue is dissected, the incision is slid caudally, and a paracostal incision is made into the abdomen. The left kidney is located and is reflected ventrally with the peritoneum. Frazier laminectomy retractors are positioned (Figure 48-7), and the abdominal viscera are packed off with a laparotomy pad. This retroperitoneal abdominal exposure affords access to the LI-2 through L5-6 intervertebral spaces. The iliopsoas (psoas minor) muscle is hooked with a muscle retractor and is retracted away from the ventral midline (Figure 48-8). The ventral crests can be palpated.

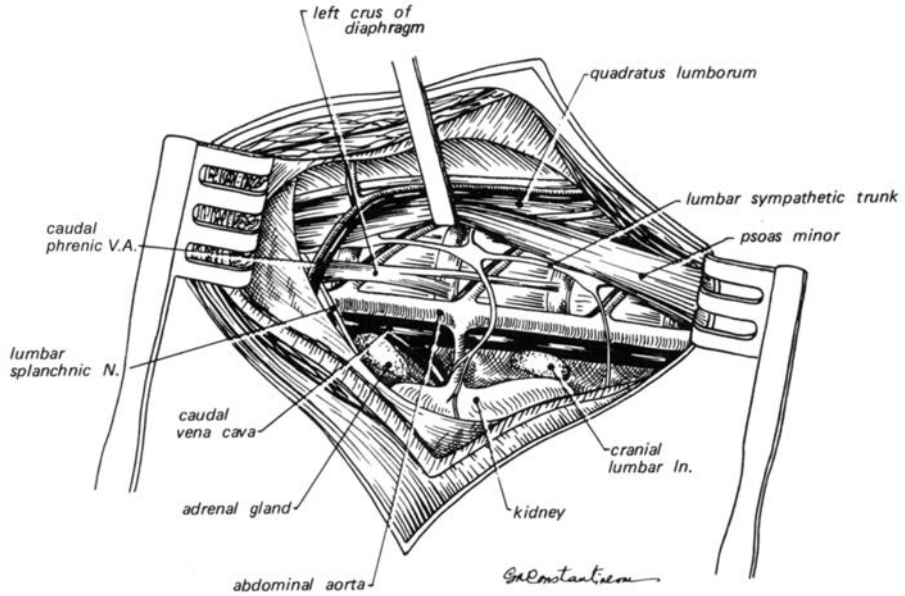


Figure 48-7. Paracostal incision by retroperitoneal exposure for lumbar disc fenestration.

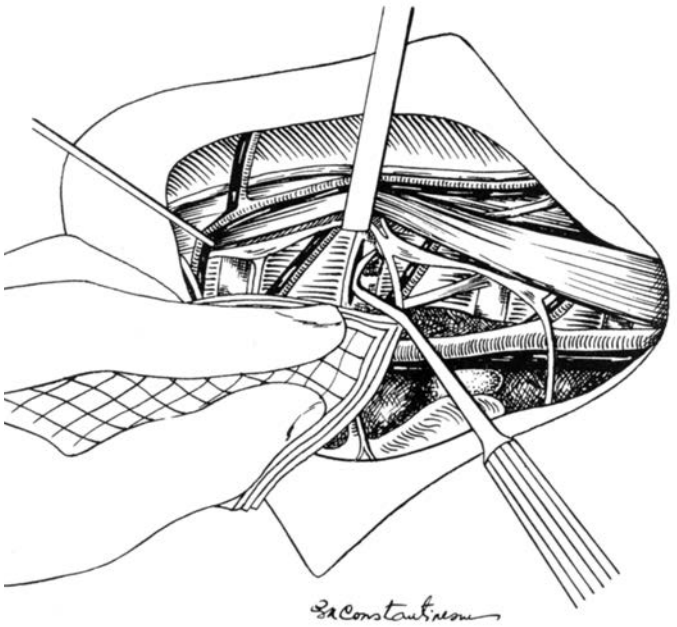


Figure 48-8. The sublumbar muscles and sympathetic trunk have been elevated, and the crus of the diaphragm and the aorta have been depressed during a lumbar disc procedure.

The transverse processes are identified and are numbered for orientation. Medial to the first transverse process is the T13-L1 intervertebral space. This space is not easily exposed from the abdominal approach and thus is fenestrated from the thorax. The remaining intervertebral spaces (LI-2 to L5-6) are fenestrated by first cutting the ventral longitudinal ligament and annular fibers of the ligament of the rib head with a scalpel. The nucleus pulposus is removed with a Miltex scaler B tartar scraper. An inward, upward, and outward motion is used to clear the intervertebral space of as much nucleus as possible. Once this maneuver has been completed, the retractors are removed, and the muscle layers are individually sutured with 2-0 synthetic absorbable suture material.

The skin incision is slid in the cranial direction, and an incision is made into the thorax between the tenth and eleventh ribs. Frazier laminectomy retractors are placed (Figure 48-9), and ventilation is instituted. The T9-10 through T13-L1 intervertebral spaces are located and are dissected free of pleura; the sympathetic trunk and intercostal vessels are carefully avoided. When the dissection is complete, the discs are fenestrated in the same manner as already described (Figure 48-10). The thorax, latissimus dorsi muscle, and skin are closed in a routine manner.

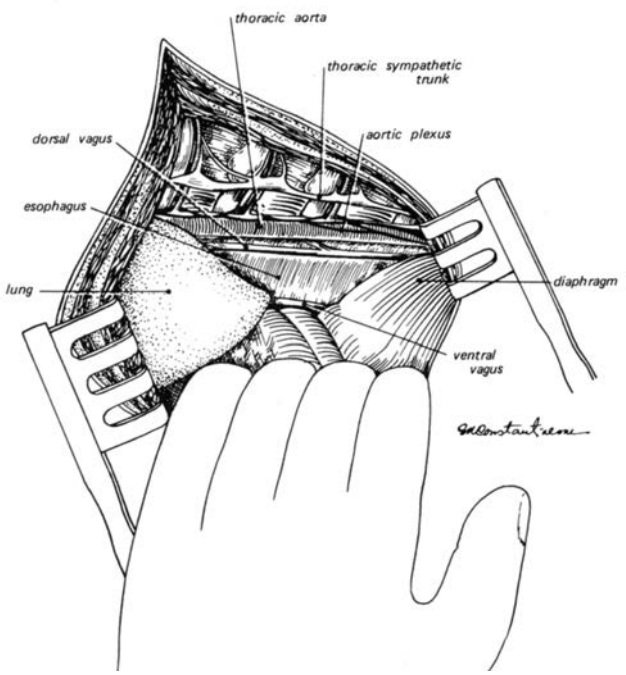


Figure 48-9. Exposure for thoracic disc fenestration.

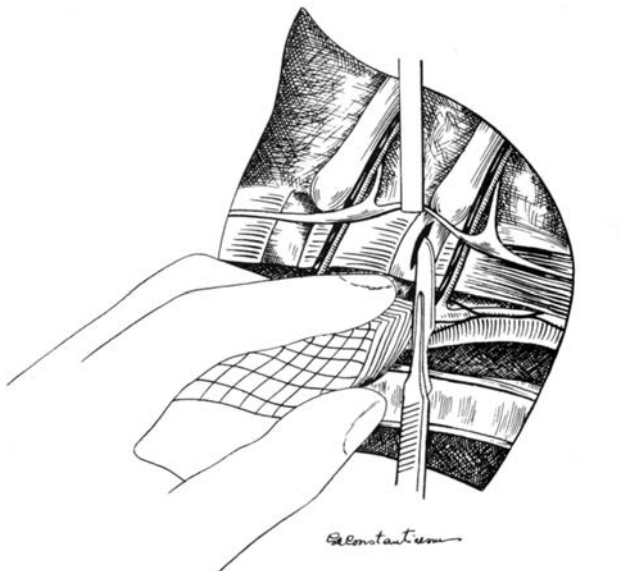


Figure 48-10. The aorta is protected and depressed with a gauze sponge, and the thoracic disc is incised with a scalpel.

Postoperative Care

The animal is monitored closely during the anesthetic recovery period. Antibiotics are given, the bladder is kept evacuated, and intensive physical therapy is instituted. Physical therapy includes hydrotherapy and cart walking.

Hemilaminectomy of the Cranial Thoracic Region

James F. Biggart, III

Indications

The most common indication for surgery of the thoracic spinal cord is the removal of extradural masses usually diagnosed by myelography, CT and MRI. Disc herniations in the thoracic spine are rare, and many surgeons ignore the few disc lesions seen there. The intercapital ligaments occupying the floor of the canal between T2-10 help to protect the spinal cord from disc herniation. Neoplasia in the thoracic spine is relatively more common than in other areas of the spine because of the lack of thoracic disc herniation. Therefore, exploration of the thoracic cord is likely to yield a tumor more often than in other areas of the spine.

Thoracic spinal fractures are rare because of the stabilizing influence of the ribs and long dorsal spines that help to prevent rotational deformities as well as flexion extension injuries. The mobile spine anterior and posterior to the thorax suffers more traumatic lesions.

The degenerative changes seen in the cervical and lumbar spine are not so common in the thoracic spine. Disc degeneration occurs as frequently as elsewhere in the spine, but disc herniations into the canal are rare. Redundancy of the ligamentum flavum is rare. Acquired bony stenosis is not often seen. Facet degenerative changes, synovitis, and synovial proliferation seldom cause cord stenosis or cord pressure. Bony stenosis, such as seen in the cervical region of caudal cervical spondylopathies of large dog breeds, has not been reported. Because many of these degenerative changes occur in more mobile segments of the spine, the more rigid thoracic spine is believed to be spared these changes.

Positioning of the Patient

The patient is placed in ventral recumbency. Elevation of the sternum (but not the elbows) by pillows, sandbags, or padding raises the spine in relation to the scapula. Pulling the forelegs forward usually loosens the adduction of the scapula to the spine, thereby allowing lateralization of the scapula. However, positioning the forelimbs posterior or crossing them under the sternum may aid in spinal visualization, so experimentation with foreleg positioning may be helpful.

Surgical Approach and Anatomy

A midline incision is made through the skin, subcutaneous fat, and fascia to the midline over the dorsal thoracic spinous processes. Just off the midline, the approach continues ventral alongside the dorsal spines to the dorsal lamina, which forms the base of the dorsal spines. The cutaneous trunci, trapezium, and cleidocephalicus are the first muscles encountered and are incised along their attachment to the dorsal spine processes on the midline. The latissimus dorsi and rhomboideus muscles are likewise incised, allowing lateralization of the scapula by self-retaining rib, Gelpi, or Weitlaner retractors. The cranial serratus dorsalis insertions are incised, as are the insertions of the thoracic spinalis and semispinalis muscles on the dorsal spines. The spinalis thoracis muscles are elevated by periosteal elevators to expose the lateral dorsal spines. The longissimus muscles are lateralized with retraction and do not require incision. The thoracic multifidus muscles are elevated with periosteal elevators or are incised at their origins. The supraspinatus ligament and interspinales muscles are left intact. The longi and breves rotatores muscles are incised at their origins exposing the dorsal lamina (Figure 48-11). The levator costae muscle can be spared unless rib head exposure is needed.

Once the lamina is exposed, a high-speed drill is needed to remove the dorsal lateral lamina. For right-handed surgeons, a left-sided hemilaminectomy is preferred (Figure 48-12). The

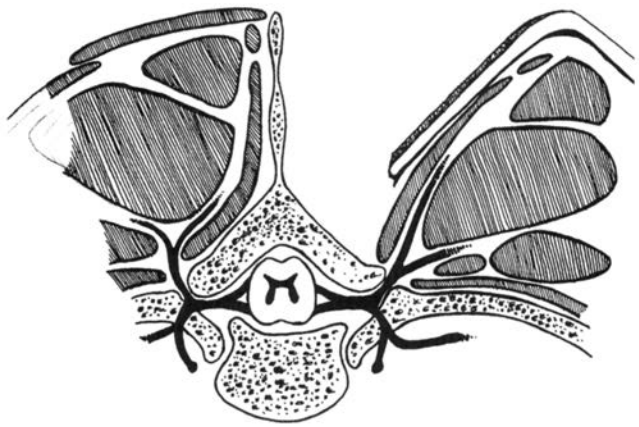


Figure 48-11. Exposure of the dorsolateral lamina.

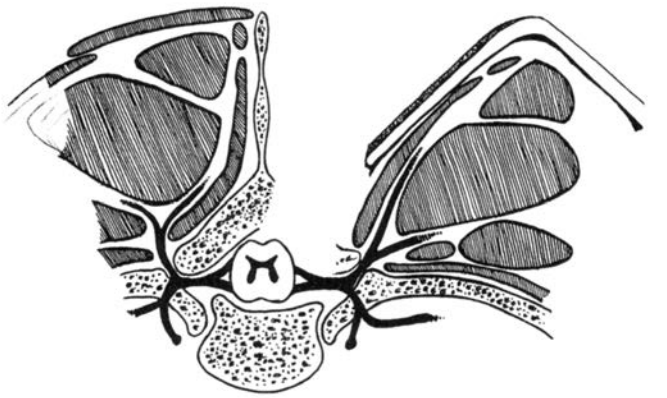


Figure 48-12. Hemilaminectomy exposing the spinal cord.

dorsal spine can be undercut to the off side of the spinal canal. The ventral 1 to 2 cm of the dorsal spine can be removed, allowing wide lateral exposure to the off side (Figure 48-13). The resultant floating dorsal spine, suspended by interspinous muscles and supraspinous ligament, produces no noticeable effect. Likewise, the rib head, neck, and tubercle can be removed as needed for lateral cord exposure on the near side. The resultant floating rib seldom causes problems because it is supported by adjacent ribs through the intercostal muscles. As the surgeon moves forward in the thoracic spine, the ribs articulate higher in the interdiscal space and may necessitate rib head, neck, and tubercle resection. Resection of the proximal rib head, neck, and tubercle allows adequate spinal cord visualization. Care must be taken to avoid dissection below the rib that could allow penetration into the chest cavity, thereby creating a pneumothorax.

The length of the dorsal spines in some breeds may create a deep surgical field. Proper instrumentation and lighting allow careful cord evaluation. The arteries encountered are the dorsal branches of the intercostal arteries. The spinal branches supply the spinal cord through the foramen just above the rib neck. These vessels can be avoided by staying close to the midline along the dorsal spines. The veins encountered parallel the arteries and join the azygos posterior to the heart and the costocervical-vertebral trunk anterior to the heart.

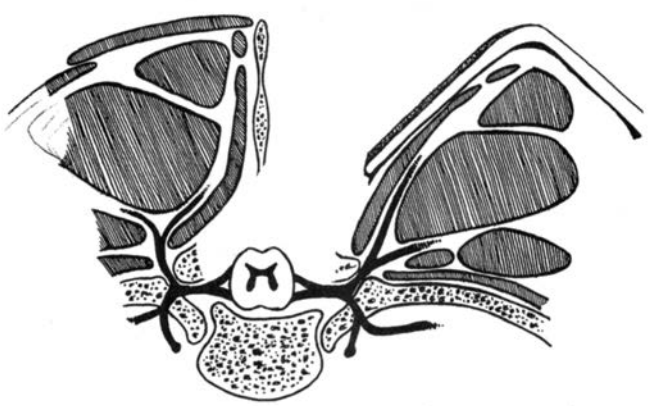


Figure 48-13. Dorsal laminectomy necessitating removal of the dorsal spine.

Wound closure is similar to that of lumbar or cervical hemilaminectomy. A free fat graft harvested from the subcutaneous tissue is placed into the hemilaminectomy defect. Careful cord hemostasis lessens the hemorrhage under the fat graft that increases scar invasion of the graft. The more graft that undergoes revascularization, the less restrictive scar forms above the cord.[1-3] The trapezius, rhomboideus, serratus dorsalis, and cranialis muscles should be reattached to preserve scapular function. The rest of the epaxial muscles reattach to the spine without direct suturing.

Postoperative care is similar to that after other spine approaches. Lameness is common for a few days until the scapular sling muscles lose their tenderness.

Benefits

Inclusion of this approach to the thoracic spine with well-known approaches to the neck and lumbar spine allows the surgeon to explore any lesion in the spinal canal from the foramen magnum to the coccygeal vertebrae. Most extradural lesions can be removed from the spinal canal, especially if undercutting the dorsal lamina or removal of the base of the dorsal spine is used to gain access to the far side of the spinal cord.

Limitations

Long, wide laminectomies over many disc spaces entail removal of the bases of many dorsal spines. The need for stabilization of these spines to prevent their ventral collapse into the laminectomy site adds additional hardware, expertise, and complexity to an already challenging approach. In addition, visualization, especially under the spinal cord, is sometimes poor.

The scapula prevents a lateral view of the cord in the cranial thoracic spine. Instruments have to be placed from a dorsal aspect. This necessitates using right-angled instruments that are not used in cervical and lumbar spine operations. Removal of the rib head and neck, especially over many disc spaces, adds complexity.

A surgical headlamp and 2x loop magnification are helpful in visualizing the spine especially in deep surgical fields. Bipolar cautery and fine tip suction are essential in providing hemostasis. The added visual acuity gained by hemostasis is more beneficial than the more obvious benefit of preventing blood loss and shock.

Because of the stabilizing influence of the adjacent dorsal spines and ribs, the destabilizing effects of wide deep laminectomy over the thoracic spine are less than those of the cervical or lumbar spine. Wider exposure of the spinal cord is possible, allowing a greater amount of adjacent tissue excision for biopsy or tumor removal. However, the close proximity to the aorta, azygos vein, and chest cavity makes exposure ventral to the cord or rib head hazardous. Damage to the nerve roots exiting the foramen cause some loss of forelimb function as well as loss of intercostal function affecting respiration.

Variations: First and Second Thoracic Cord Exposure

The first and second thoracic vertebral cord can be approached as a posterior extension of a seventh cervical dorsal laminectomy.[4,5] The thoracic dorsal spines can be exposed anteriorly without disturbing the ligamentum nuchae or supraspinous muscles, which are retracted laterally. The drill is angled from anterior to posterior, with the right-handed surgeon positioned on the right side of the patient that has been placed in sternal recumbency. Removal of the lamina between the base of the dorsal spine and first rib head exposes the spinal cord and canal over one side. Care must be used to leave enough of the base of the first dorsal spine to maintain the strength necessary to support the head and neck through its attachment of the nuchal ligament. This limits the exposure of the first thoracic spinal cord. If complete removal of the base of the first dorsal thoracic spine is needed, then enough of the base of the spine should be removed to prevent downward pressure of the spine stump on the exposed cord. Support of the head by the nuchal ligament, which attaches to the first three dorsal spines, pushes the remaining spine ventrally when its lower base is removed.

Approaching the anterior thoracic cord in this way avoids the disruption of the musculature along the dorsal spine and attachments to the scapula. The scapula influences the approach to the thoracic spine only anterior to T6 or T7. Posterior to these areas, the approach is similar to that of the lumbar spine.

References

1. Biggart JF III. Laminectomy membrane: etiology and prevention. In: Proceedings of the American College of Veterinary Surgeons Annual Meeting. Denver, CO: American College of Veterinary Surgeons, 1981.

2. Biggart JF III. Prevention of laminectomy membrane by free fat grafts after laminectomy in dogs with disc herniations. Vet Surg 1988;17:29.

3. Gill GG, Sakovich L, Thompson E. Pedicle fat grafts for the prevention of scar formation after laminectomy. Spine 1979;4:176.

4. Piermatei DL, Greeley RG. An atlas of surgical approaches to the bones of the dog and cat. 2nd ed. Philadelphia: WB Saunders, 1979:46-49.

5. Parker AL. Surgical approach to the cervico-thoracic junction. J Am Anim Hosp Assoc 1979;9:374-377.

Hemilaminectomy of the Caudal Thoracic and Lumbar Spine

Karl H. Kraus and John M. Weh

Hemilaminectomy of the Caudal Thoracic and Lumbar Spine

Hemilaminectomy of the caudal thoracic and lumbar spine is used to gain access to the vertebral canal for the removal of offending masses, often impinging on or involving the spinal cord. These masses include intra and extradural tumors, granulomas, bone fragments resulting from vertebral fracture, and (by far most common) intervertebral disk extrusions and protrusions. The term "hemilaminectomy" may be a misnomer, since the lamina of the vertebrae is the boney structure which is dorsal to the vertebral canal, dorsal to the articular facets. The pedicle, or root, is the boney structure lateral to the vertebral canal between the vertebral body and articular facets. It is the pedicle, more than the lamina that is removed during what is commonly referred to as a hemilaminectomy. Some authors do refer to removal of sections of the pedicle as pediculotomy, however the term hemilaminectomy is used to describe the common surgical procedure for removal of part of the vertebral arch on a single side of the spinous process to gain access to the vertebral canal.

The timing of surgical intervention and the urgency of spinal cord decompression has been explored in several clinical studies. Though there is some disagreement in interpretation of the clinical studies, and hospitals have different capabilities for after hours imaging and surgery, a general consensus regarding the triage of patients with spinal cord compression is available. In cases of thoracolumbar spinal cord compression resulting from presumed intervertebral disk extrusions or protrusions the recommendations are as follows:

1. No deep pain less than 12 hours. Emergency operation should be recommended. The prognosis is 50% for ambulating. At present, there are no clinical studies that demonstrate efficacy of any glucocorticosteroid including methylprednisolone sodium succinate, therefore the administration of these medications in not indicated.
2. No deep pain over 24 hours. Operate when practical. "Practical" is defined as in the morning if presented at night, as soon as possible if presented during the day, but do not wait until the next day. There is no reported correlation between duration of paralysis prior to surgery, and clinical outcome.
3. Acute, less than 12 hours with no motor function but deep pain is present. Offer emergency operation contingent on personnel, progression of neurologic signs and how long to morning (e.g. is it 3:00am? Then wait.) These cases may loose deep pain as the pathophysiology is not static. Prognosis is therefore guarded but not poor.
4. Deep pain present, no motor function, over 24 hours. Operate when practical. Prognosis is good with 96% of dogs becoming ambulatory. It will take an average of two weeks for these dogs to walk.
5. Non-ambulatory, purposeful motor movement. If admitted in evening, then operate in am. Perform serial neurologic exams to assure patient's neurologic status does not worsen. Some facilities will delay day admitted cases if the neurologic examination is static and noninvasive imaging (CT,MR) is available in the morning, therefore avoiding a myelogram. Prognosis is good for ambulating. It will take an average of one week for these dogs to walk.
6. Ambulatory paretic. Operate the next day. Of course sooner if patient is stable and facilities and personnel are available. Prognosis is excellent for ambulating. Cage rest can be considered if cost is a factor, but owners should be warned about worsening of neurologic status including paralysis.

A majority of disk extrusions occur near the thoracolumbar junction; rostral to the lumbar intumescence of the spinal cord

and caudal to the thoracic intumescence. Therefore the neurologic signs are normal sensation, proprioception and motor function to the thoracic limbs and loss of proprioception, motor function, and pain sensation (in that order) to the pelvic limbs. The common neurologic localization and clinical diagnosis is a T-3 to L-3 (third thoracic to third lumbar spinal cord segment) myelopathy. Disinhibition from compromise of the upper motor neurons to the femoral and sciatic nerves results in hyper-reflexia or upper motor neuron signs to the patellar and cranial tibial reflexes. The progression of signs from loss of proprioception, to loss of motor function, to loss of superficial then deep pain, is most often a function of compression on the descending and ascending spinal cord axons. The larger axons, such as those that carry proprioceptive information, are affected first. Deep pain sensation, or spinal thalamic pathways are not discrete in domestic animals as they are in humans. Instead they are diffuse, multisynaptic and bilateral within the spinal cord. Loss of deep pain perception reflects a functional transection of the spinal cord. Though a functional transection does not necessarily mean an irreversible condition, the loss of deep pain sensation is a negative prognostic indicator. The alpha motor neurons to the femoral nerve are located above the interbertebral disk between the third and fourth lumbar vertebrae. The alpha motor neurons to the sciatic nerve are located roughly above the fourth and fifth lumbar vertebra. For this reason compressions of the spinal cord in these locations can result in lower motor neuron signs to the segmental reflexes in these areas. Offending masses can impinge on vertebral nerve roots and can result in pain and hyperesthesia due to the radiculopathy. Hyperesthesia in descrete areas as assessed by the paniculus reflex can give a more precise indication of the location of an offending mass.

Because the neurologic examination often does not give an exact localization of the area of compression or side of the mass if it is lateralized, imaging should be performed to define the pathology of the mass (tumor or disk, size) and location (vertebral segment, left, right, midline). Myelography with conventional radiographs has classically been used to localize the lesion. Though sufficient in most cases, a discrete lesion my not be apparent if there is considerable spinal cord swelling. In addition it may be difficult to differentiate disk extrusions from other pathologies. Computed tomography (CT) can be used since many disks are partially calcified. The soft tissue resolution of newer CT scanners is very good and can image most masses. Spiral CT scanners are very fast and can noninvasively localize a lesion in less than 10 minutes in most cases. Magnetic resonance imaging (MRI) scanners provide the best resolution of both soft and boney tissues and are becoming the standard of care for neurologic imaging in veterinary medicine.

Once a lesion is localized with either modality, identifying the proper location for a surgical approach to perform hemilaminectomy can be troubling for inexperienced surgeons. Several strategies can be employed. First, the surgeon should count the number of lumbar vertebrae. This is obvious with myelograms and most CT scans, but a scout image must be taken with MR scans. Though in most cases there are seven lumbar vertebrae, in some patients there are transitional vertebrae. Vestigial ribs may arise from the first lumbar vertebra, or the most caudal rib may be present on one side only. Since ribs are not always imaged with MR, a dorsal plane scout film (dorsal plane localizer) from the sacrum to the twelfth thoracic vertebra will demonstrate rib anatomy. Hemi-vertebra may be present at the lumbosacral junction. These anatomic variations must be noted and kept in mind. With MR, a scout film (sagittal localizer) will image the celiac and cranial mesenteric vessels along with the lumbar vertebrae. The vessels arise below the thirteenth thoracic or first lumbar vertebrae. These vessels serve as land marks for more focal MR images.

Palpation of the spinous processes can usually give the proper location in the lumbar area. The spinous process of the seventh lumbar vertebra may be palpated between the cranial aspects of the wings of the ilium. The spinous processes are usually palpable and the surgeon can count cranially to find the proper surgical site. In some cases where lumbar fat is very thick, the surgeon may need to make an approximate surgical approach through the skin and lumbar fat, then palpate the spinous processes surgically. In the thoracolumbar area, the ribs serve as landmarks for localization. Again, confirm the anatomy of the patient, as transitional vertebrae and small vestigial ribs can confuse localization. After an initial surgical approach through the skin and fat is made, a small incision in the lumbar fascia lateral to the longissimus and iliocostalis muscles is made by the thirteenth rib just large enough to accommodate one's index finger. The thirteenth rib can be palpated. This rib attaches to the cranial aspect of the thirteenth thoracic vertebra. The spinous process of the thirteen thoracic vertebra is also often the first that can be distinctly palpated as those of the ninth to twelfth tend to be very close to each other. Once the thirteenth thoracic spinous process can be identified with certainty, the location for laminectomy can be accurately determined. Matching the shape of the spinous processes seen during a surgical approach with pre-operative imaging is also helpful.

Some surgeons use other techniques to localize the proper location for the hemilaminectomy. Specifically a hypodermic needle (such as 22 ga.) can be pressed into a spinous process prior to surgery, then a lateral radiograph taken to define which spinous process the needle is in. The hub of the needle is then cut off leaving the shaft of the needle beneath the skin. The needle is then found during the surgical approach, defining the proper surgical location. It is not uncommon, however, for a surgeon to loose the needle and spend some time finding it during the surgical approach. Another similar technique is to use Methylene blue. Instead of leaving the shaft of the needle under the skin, a needle is pressed into a spinous process then a lateral radiograph is taken. A small amount of sterile methylene blue 1% (0.1 ml) is injected into the area of the spinous process then the needle removed. The area of staining is found during the surgical approach defining the proper location. However, the staining may not be as discrete as desired, especially in the lower thoracic area, and therefore the surgeon may not be absolutely certain about anatomic localization.

It is a standard of care in surgery on humans to take an intra-operative radiograph during the surgical approach to confirm localization. Many veterinary surgical hospitals have equipment

for intraoperative radiographs such as C-Arms and fluoroscopy. Intraoperative radiographs are probably the best technique to assure and document surgical localization, and should be used when available.

Deciding on Approach

A hemilaminectomy is often chosen over a dorsal laminectomy for several reasons. It is a rapid operation that gives good exposure to the dorsal, lateral and ventral spinal canal on one side. Though a dorsal laminectomy gives exposure to both sides of the vertebral canal, this approach does not allow direct exposure of the ventral floor of the vertebral canal and the intervertebral disk. In the lower lumbar area essential nerve roots are in the area of a hemilaminectomy and can be avoided with a dorsal laminectomy. However, if carefully performed, a hemilaminectomy can be utilized throughout the thoracic and lumbar spine.

Surgical Prep and Positioning

A hemilaminectomy is performed by a dorsal approach close to the midline. The hair should be clipped in the area of the lesion, extending about 5 cm laterally on each side. A more liberal clip should be performed both cranially and caudally to assure that the surgeon has enough flexibility to extend the incision if needed. The skin of the dorsum of dogs and cats is quite movable allowing some flexibility if the skin incision does not exactly match the approach to the vertebrae. The patient is placed on the operating table in ventral recumbency. It is very important to make sure the patient's spine is straight and placed straight on the table, and also that the patient is not leaning to the left or right. Errors can be easily made during the hemilaminectomy when the orientation of the patient makes anatomic perspective confusing. Patient postitioners such as vacuum bags are very useful to stabilize the patient and keep them steady during the operation. Rolled towels and orthopedic tape are also helpful.

Goals of Surgical Decompression

A hemilaminectomy is simply the approach made by the surgeon to decompress the spinal cord. The overall goal should be to remove the offending mass without manipulation of critical neurologic structures. With this in mind, the principles of proper surgical decompression are as follows:

1. The approach should be made aseptically and atraumatically.
2. The hemilaminectomy should be performed so that the offending mass can be removed without manipulation of the dural sac.
3. The offending mass must be removed completely without residual compression.
4. Hemorrhage must be minimal as postoperative hematoma can act as a compressive mass.

These principles of decompression dictate the instrumentation needed and the surgical techniques employed to properly perform the surgical procedure.

Instrumentation

A surgical pack with basic high quality instruments is needed. In addition, several other instruments are very helpful. Visualization of the surgical field is very important. Proper surgical lights should have at least 5,000, and preferably closer to 10,000 Foot Candles at 36 inches. Two light heads are important to prevent shadowing. Many surgeons use a head light which is very helpful, especially if the surgical lighting is questionable. Surgical loupes are also important for magnification (Figure 48-14). Custom built loupes for inter-pupillary distance, frame size, corrective lenses, and working arm distance (focal distance) should be used so that the surgeon is not distracted by improper fit. Usually 2.5x magnification is sufficient. Higher amounts of magnification give a smaller field of view.

Hemostasis is essential to prevent blood loss, provide better visualization, and prevent postoperative hematoma which can act as a compressive mass (Figure 48-15). A high quality electrocoagulation unit should be available. Usually about 35 watts of power are used for both cutting and coagulation. Bipolar cautery should be available as this tends to localize current and prevent inadvertent stimulation of nervous structures and heat damage. With bipolar cautery the power is reduced to 15 Watts. Bone wax is very helpful in stopping hemorrhage from cancellous bone. Other hemostatic agents such as absorbable gelatin sponge and oxidized cellulose are useful in stopping hemorrhage and encouraging coagulation.

Elevating and retracting the axial muscles are performed with periosteal elevators and retractors (Figure 48-16). Besides either ASIF or Keyes periosteal elevators, Freer elevators are very helpful for fine elevation. Gelpi retractors are used by many veterinary surgeons and several sizes should be available.

Historically different instruments have been successfully used to perform the laminectomy including trephines and ronguers. However, a principle of surgical decompression is to remove the offending mass without manipulation of the dural sac and other eloquent neurologic structures. It is difficult, if not impossible



Figure 48-14. A head light and prescription 2.5X loops provide a surgeon with illumination and magnification which is very helpful in neurosurgery.



Figure 48-15. Different techniques and agents are used to establish hemostasis. Shown here from left to right are cellulose, collagen, bone wax, bipolar, and monopolar cautery.



Figure 48-16. Retraction of the axial musculature is frequently performed with Gelpi retractors. Having several sizes is helpful. Elevation of muscle from the vertebrae can be performed with several different types of periosteal elevators.

to chip away the lamina or pedicle of a vertebra with a rongeur without placing one tip of the rongeur into the vertebral canal and therefore pressing on the dural sac. Currently, most surgeons will use a high speed drill with a variety of burrs to remove bone. Air (nitrogen) powered drills are most useful as they stay cool and are durable (Figure 48-17).

Suction is essential for removal of the bone swarf (particles of bone material produced during drilling), blood and saline. Small Frazier suction tips are best. The area can be lavaged using a 10 cc syringe with a needle or canulla (Figure 48-18).

Removal of the offending mass requires a variety of different instruments depending on the specific situation. These include dental instruments, pituitary curettes, wire loops, nerve root retractors, probes, biopsy forceps, etc. (Figure 48-19). Different surgeons have their own preferences regarding which instruments work best. A very versatile and inexpensive instrument is small gauge wire (24 or 26 ga,) which can be fashioned into many different shapes and held with a mosquito hemostat or small needle holder.



Figure 48-17. Making an aperture in the vertebrae is principally performed with a high speed drill (left) and various sizes and shapes of Burs. Rongeurs such as Kerrison, Ruskin, or Lempert (right) may also be used, or used in conjunction with a high drill.

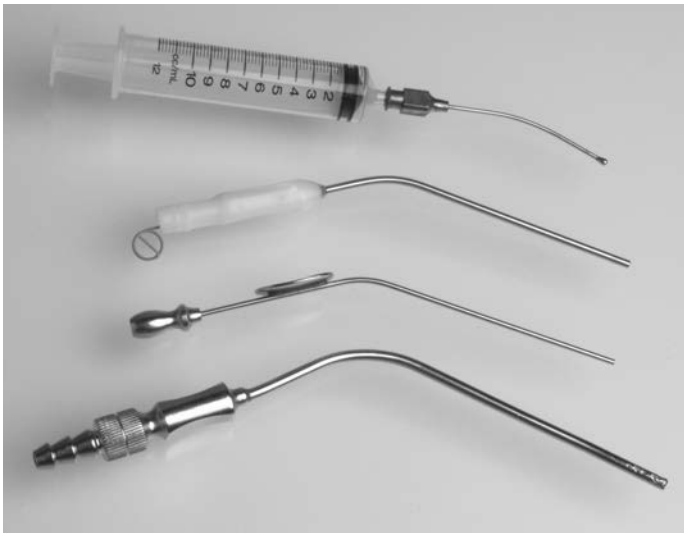


Figure 48-18. Precise lavage can be performed with a syringe and cannula (top). Different small sizes of Frazier suction tips provide suction and visualization of the surgical field.



Figure 48-19. Once the hemilaminectomy has been performed, disk material or other masses can be removed with a variety of different instruments depending on the situation or surgeon's preference. These include probes, nerve root retractors, curettes, dental instruments, or orthopedic wire.

Technique

A skin incision about four vertebra in length is made, and the approach advanced to the lumbar fascia. Many surgeons will towel or drape the incision for added sterility. An incision through the lumbar fascia using a scalpel or electroscalpel is made on the dorsal midline between the spinous processes and just to the side of the hemilaminectomy around the spinous processes in a scalloped like shape. Then a periosteal elevator is used to elevate each (usually four) spinous process. In the lumbar area, the elevation is carried to the transverse processes. In the thoracic vertebra the elevation is carried to the costal fovea or articulation with the rib. A scissor is then used to cut the interspinous ligament, lengthwise between the spinous processes, allowing the transversospinalis muscles to be retracted laterally. Gelpi retractors are commonly used with one tip deep in the musclulature and the other in the interspinous ligament over the area of the laminectomy. At this point, many surgeons will remove the tendinous attachments of the lumbar musculature from the articular facets of the vertebrae. This will provide further retraction of the axial musculature, however it will also result in a small arterial hemorrhage which must be controlled. The hemilaminectomy can be performed without this dissection and as the facet is removed with a bur, the muscles will retract laterally and carry the small arteriole laterally as well.

Though some surgeons still use rongeurs to perform laminectomies, the use of a high speed burr allows better exposure with less manipulation of the dural sac. Burring must be performed carefully, but a few simple techniques make this technically simple. The most common mistake in burring is to try to breach the vertebral canal as quickly as possible with a large burr. This results in a limited exposure to the vertebral canal (Figure 48-20). This small hemilaminectomy with sharp bone edges is not helpful as it provides limited exposure, and can make decompression without spinal cord manipulation difficult. In addition, extending a small approach with rougeurs requires one tip of the rongeur to be placed inside the vertebral canal which can result in manipulation of the dural sac. The preferred approach utilizes smaller burr size for more precise bone removal. The compressive lesion can be relieved from the spinal cord without manipulation of the spinal cord. The burring is begun in two separate locations, at the level of the accessory process (dorsolaterally) in the center of the vertebral pedicle on either side of the offending disk space, until cancellous bone is exposed. The key to careful and efficient burring is to locate the layer of cancellous bone (red in appearance) between the outer cortex of the vertebra and inner cortex (white in appearance), beyond which lies the vertebral canal and spinal cord. Burring is continued until the inner cortical bone is exposed, but stopped before the vertebral canal is entered. The bur is directed ventrally and burring continues ventrally removing the lateral cortical wall of the vertebral pedicle. The burr is not directed toward the vertebral canal, but safely in the direction of bone to be removed (Figure 48-21). A sharp, properly sized burr will progress through cancellous bone quickly and safely. The dorsal extent of the hemilaminectomy of the two vertebrae is connected longitudinally across the articular facets (Figure 48-22). Since the facets are cortical bone, it is much more difficult to gauge the appropriate burr depth. That is why burring is begun at the center of a vertebra where outer cortex (white), cancellous bone (red), and inner cortex (white) can be more easily discerned. The surgeon can then extend the bone aperture at the correct depth across the articular facets.

Ventrally, bone is removed to the level of the ventral aspect of the vertebral canal. The bur is then directed from either direction toward the vertebral foramen. Removing bone from either side of the ventral aspect of the vertebral foramen is the

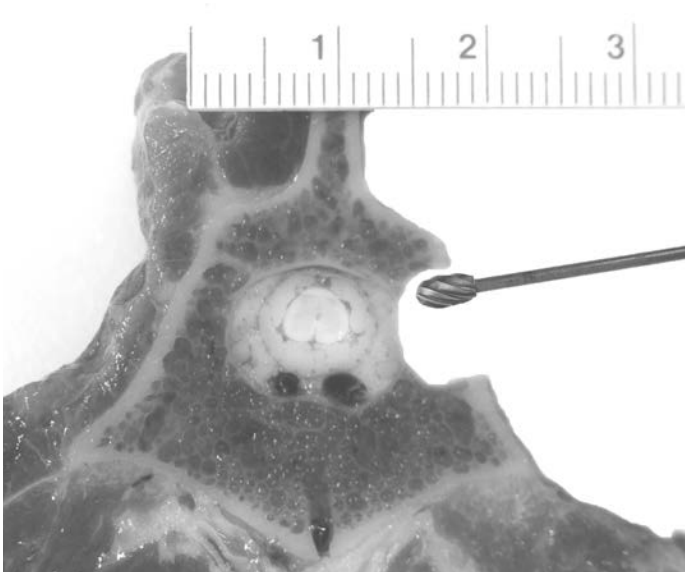


Figure 48-20. An approach with a larger burr that enters the vertebral canal directly will result in a small aperture, limiting exposure and the surgeon's ability to remove an offending mass without manipulation of the spinal cord.

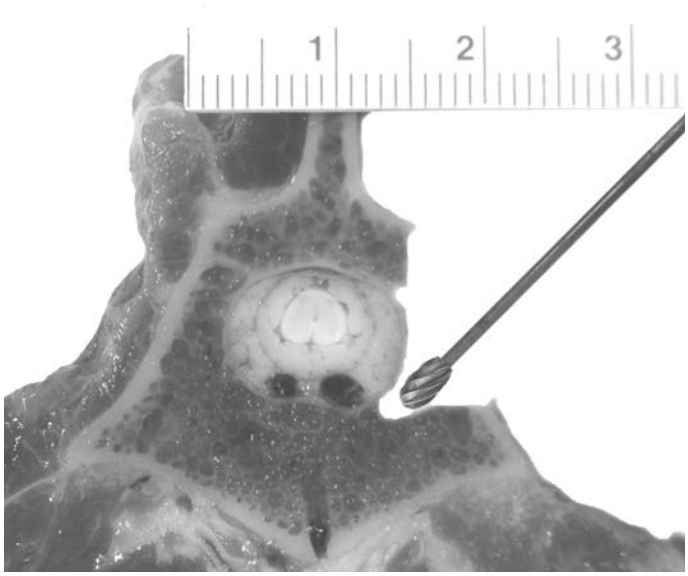


Figure 48-21. Burring is started at the level of the dorsal aspect of the vertebral canal, in the center of a vertebra. The bur will progress through the outer cortical bone (white in appearance), then through cancellous bone (red), then to inner cortical bone (white again). The outer cortical bone and cancellous bone is removed progressing ventrally.

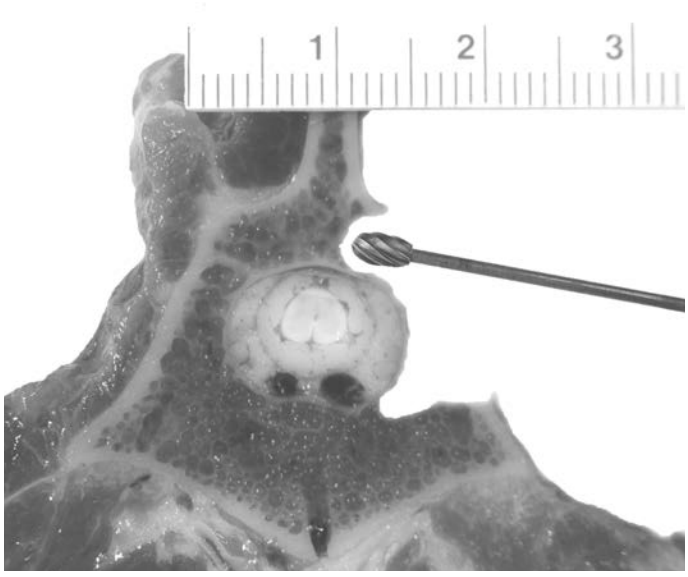


Figure 48-22. The hemilaminectomy can extend dorsally. The handle of the high speed drill is directed such that the surgeon is always pushing toward bone, not the vertebral canal, to prevent accidentally entering the vertebral canal.

most difficult aspect of this operation and should be performed most carefully as the arterial and venous supply to the vertebral canal, and nerves or nerve roots can be damaged. However, carefully preformed, the end result is an oval to almost rectangular aperture with dorsal and ventral extents at the levels of the vertebral canal. At this point a smaller bur is chosen to enter the vertebral canal. The smaller bur is then used to remove bone around the perimeter of the hemilaminectomy. The bur should not be directed straight toward the vertebral canal, but rather toward the perimeter of the bone window to prevent inadvertent penetration of the vertebral canal (Figure 48-23). Usually the side of the bur us used to remove bone from the vertebral canal and the bur can be subtly felt to "give way" when the inner cortical bone is removed. If skillfully and carefully performed, the inner cortical bone can be removed without breaching the inner periosteum of the vertebral canal. If the inner periosteum is kept in tact, the vertebral canal can be entered dorsally with a dental or other instrument. This periosteum can be retracted ventrally, exposing the vertebral canal and spinal cord and in addition avoiding and even occluding the ventral vertebral sinuses.

Once the laminectomy is complete, the offending mass can be seen and removed. It is important to relieve the mass without manipulation of the spinal cord. Rounded instruments are used rather than sharp to avoid lacerating the venous sinuses. The spinal cord should be completely decompressed. Hemorrhage should be controlled with collagen sponge or other techniques.

If there is a significant amount of disk material adhered to the dura mater, or in cases of Hanson Type II, it may be impossible to remove the disk material without manipulation of the spinal cord. In these cases the laminectomy is extended under the spinal canal leaving the dorsal annulus of the disk intact. A small bur removes disk and bone until a small cavity exists (Figure 48-24). This can extend well over 50% of the distance to the opposite side. The dorsal annulus and disk material can then be pushed down into this cavity thereby relieving spinal cord compression without manipulation of the spinal cord.

Closure

There is some controversy regarding placement of fat or other materials over the laminectomy site. Laminectomy membranes and resultant pain are not as frequent in veterinary medicine as in humans. If a hemilaminectomy is performed as described, the

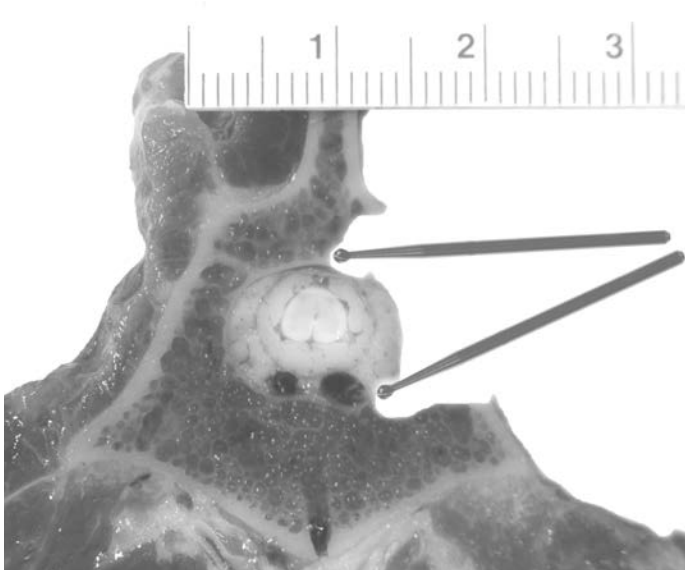


Figure 48-23. A smaller bur is used to enter the vertebral canal. The bur, again, is held so that the surgeon is not pushing toward the vertebral canal. The side of the bur is used to enter the vertebral canal, preferably without breaching the inner periosteum.

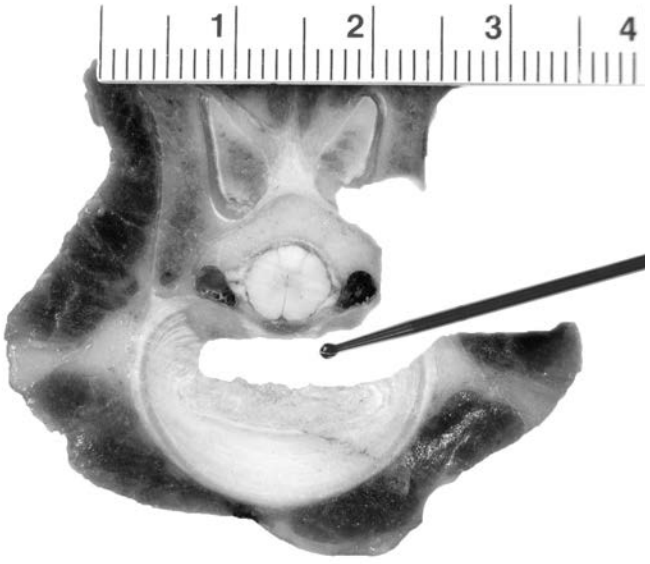


Figure 48-24. In some situations, such as adherent disk material or Hanson type II disks, the mass cannot be removed without manipulation of the dura, which must be avoided. In these cases the disk and vertebral end plates beneath the dorsal annulus are removed. The disk can then be pulled into the cavity that is formed, thereby decompressing the spinal cord.

resulting scar and fibrous tissue do not result in compression of the spinal cord or nerve roots. A small amount of fat placed in the laminectomy aperture will prevent some scar tissue from forming. Fat grafts are frequently used in veterinary surgery. However, the surgeon should use a small amount of fat as too much can result in spinal cord compression when the hypaxial musculature swells post operatively. The deep lumbar fascia is closed with a monofilament absorbable suture material in a simple continuous pattern. The subcutaneous tissues and skin are closed routinely.

Post operative Care

Steroids and antibiotics are not used post operatively. If the spinal cord is decompressed, there is no rational for continued administration. Complications associated with steroid use in neurosurgical patients are severe and well reported. Incisional infections are very rare. The main consideration for postoperative care is micturition. If the patient recovers with purposeful motor movement, they can usually urinate on their own. However, if the patient does not have purposeful motor movement, the bladder must be cared for until motor function returns, or the bladder converted into an automatic bladder that the owner can care for at home. An indwelling urinary catheter can be used for several days, but will often result in a urinary tract infection. In many cases the bladder can be expressed several times a day without catheterization. The bladder must never be allowed to overfill, because this results in stretching of the detrusor muscle and an atonic bladder. In male dogs it may be necessary to administer medications that relax the urethral spincters. The internal urethral spincter can be relaxed with phenoxybenzamine and the external urethral sphincter with Diazepam.

Those patients requiring several weeks to recover will require physical therapy. The goal of physical therapy is to frequently move the limbs in physiologic walking motions. Resolution of spinal cord swelling and remyelination of damaged axons will result in complete return of neurologic function if axons are intact. However, more severe spinal cord damage with axonal loss and gliosis will require establishment of new synaptic connections and central plastic reorganization. Physiologic motion enhances the speed and degree of these processes. Swimming is excellent if tolerated, and should be begun as soon after the sutures are moved as possible. The patient's limbs should be moved in walking motions for at least fifteen minutes three times a day. The patient should be encouraged to stand, support weight, and walk as much as possible.

Suggested Readings

Davis GJ, Brown DC: Prognostic indicators for time to ambulation after surgical decompression in nonambulatory dogs with actue thoracolumbar disk extrusions: 112 cases Veterinary Surgery 31:513-518, 2002.

Kraus KH. Medical managment of acute spinal cord injury. In Kirk RW and Bonagura JD. (eds). Current Veterinary Therapy XIII: Small Animal Practice. W.B. Saunders Co., Philadelphia, 2000. Pp. 186-190.

Moissonnie P, Meheust P, Carozzo C; Thoracolumbar lateral corpectomy for treatment of chronic disk herniation: Technique description and use in 15 dogs. Veterinary Surgery 33:620-628, 2004.

Scott HW, McKee WM: Laminectomy for 34 dogs with thoracolumbar intervertebral disc disease and loss of deep pain perception. J Sm Anim Pract 40: 417-422, 1999.

Slocum B, Slocum Devine T: Pediculotomy in the thoracolumbar vertebra In Bojrab MJ, ed: Current Techniques in Small Animal Surgery, 4th ed, Baltimore: Williams and Wilkins, 1998, p 853.

Modified Dorsal Laminectomy

Eric J. Trotter

Introduction

A variety of surgical procedures have been described for decompression of the spinal cord in the thoracolumbar region of dogs. The procedures differ in the amount of bone removed, and thus, are referred to as hemilaminectomy, mini-hemilaminectomy, pediculotomy, pediculectomy, dorsal laminectomy, modified dorsal laminectomy, and laminectomy modifications, including laminotomies and laminoplasties. Each technique has its own indications, inherent advantages and disadvantages, and most, if performed properly, satisfy the two basic tenets of spinal cord surgery, *i.e.*, spinal cord decompression and mass removal. There is no one best technique for all patients.

Hemilaminectomy, mini-hemilaminectomy, and pediculectomy are particularly well-suited to the removal of extruded or protruded intervertebral disc material from the vertebral canal without fear of laminectomy membrane formation. Bone removal and resultant exposure of the vertebral canal and spinal cord are minimal in comparison to dorsal decompressive techniques. Vertebral column stability is less compromised with these procedures, even with concurrent prophylactic intervertebral disc fenestration than with dorsal laminectomy techniques which require bilateral exposure and partial facetectomies.

Objective comparison of the many decompressive techniques, at least in intervertebral disc disease, has been clouded by the many variables associated with spontaneous extrusion or protrusion of intervertebral discs in the thoracolumbar region. Personal preference and the individual surgeon's training have all too frequently determined the type of decompressive procedure utilized. Previously, severely-limited imaging modalities, *i.e.*, flat films and myelography, also made rational, logical selection of the most appropriate technique for the individual patient difficult, if not impossible. With the increased availability of CT and MRI, selection of the most appropriate decompressive technique based on the precise location of the extradural mass became far more objective, and allowed for minimally invasive surgical techniques. For these reasons, although performed for many years with excellent results at this hospital, dorsal or modified dorsal laminectomy are only infrequently performed for uncomplicated thoracolumbar intervertebral disc extrusion or protrusion in chondrodystrophoid or non-chondrodystrophoid dogs. However, in many cases, *i.e.*, vertebral column fractures, luxations, congenital vertebral malformations, synovial cysts, arachnoid cysts, vertebral or spinal cord neoplasms, or syrinxes, and in some cases with intervertebral disc disease, laminectomy will be the procedure of choice to allow for expansive spinal cord exposure, decompression, and mass removal when these other techniques would prove to be inadequate.

Surgical Technique for Modified Dorsal Laminectomy

Following confirmation of the neuroanatomic lesion by either myelography, CT, or MRI, the anesthetized patient is placed in sternal recumbency, without pressure on the abdomen, and prepared for aseptic surgery of the thoracolumbar spine. Prophylactic antibiotics (cefazolin, 22 mg/kg IV at time of surgery, then 22 mg/kg PO BID, G.C. Hanford Manufacturing Co., Syracuse, NY 13201) are administered intravenously at the time of surgical intervention, and may be continued in the early postoperative period. Corticosteroids (methylprednisolone sodium succinate, 30 mg/kg IV, Solu-Medrol, Pharmacia & Upjohn, Kalamazoo, MI 49001) may be administered at the time of surgery in patients who have not already been treated with steroids. Gastric protectants (Pepcid, Famotidine, 0.5-1mg/kg QD or BID, Bedford Laboratories, Bedford, OH 44146; and sucralfate, medium and large dogs 1 gm TID, toy dogs (< 7 kg) 0.5 gm TID, Major Pharmaceuticals, Livonia, MI 48150) are administered preoperatively when possible, and continued postoperatively.

The skin incision, centered over the area of involvement, is made slightly lateral to the dorsal midline. Length of this incision is determined by the specific pathology in the individual patient. Moistened laparotomy tapes or surgical paper towels are clipped to the reflected subcutaneous tissue and/or superficial fascia on each side of the incision to cover any exposed skin. The thoracolumbar fascia is incised bilaterally immediately lateral to the spinous processes. Periosteal elevators are utilized to lever or reflect the epaxial muscles bilaterally to a level just ventral to that of the accessory processes (Figure 48-25). Utilization of self-retaining retractors (Gelpis or Beckmans) allows for relatively atraumatic dissection under tension, which is most easily performed from caudal to cranial. Maceration of the epaxial musculature contributes to delayed wound healing, postoperative pain, and laminectomy membrane formation. Small branches of either the paired lumbar or intercostal arteries are cauterized by means of bipolar cautery as they are exposed both cranially and caudally to the cranial articular processes of each adjacent vertebra. Care must be exercised during both periosteal elevation and the cauterization of small bleeders around the articular processes to avoid exacerbation of spinal cord ischemia by interruption of the, at best, tenuous spinal cord blood supply through the varying intervertebral foramen (dorsal and ventral radicular branches).[1-3]

For laminectomy at the thoracolumbar junction, the 13th rib and first lumbar transverse process are readily identifiable landmarks to confirm the appropriate site for laminectomy. The 13th rib arcs dorsocaudally and is located far more superficially than the cranioventrally directed first lumbar transverse process. Particularly in obese patients, some surgeons prefer to place a sterile hypodermic needle into one of the dorsal spines during preoperative films to confirm anatomic location, especially in the mid lumbar spine, since localization by palpation of the dorsal spine of the seventh lumbar vertebra may be difficult. The spinous processes of the vertebrae cranial and caudal to the disc space (in a two level laminectomy) are removed by means of bone rongeurs (Figure 48-26). This is preferable to the utilization of a bone cutter which can result in excessive torque being applied to the vertebral column of small breed dogs.

By means of a high-speed air drill with a new 4 mm egg-shaped bur with notched flutes, the remainder of the dorsal spine is removed. Meticulous hemostasis, and irrigation with sterile saline or lactated Ringer's solution and fluid removal by suction maintains a clear field, removes the bone dust produced by the air drill, and dissipates the minimal amount of heat produced by a new bur. Old dull burs should not be used for this technique because they generate significant heat by sanding rather than cutting away the bone of the laminae. In cases of thoracolumbar disc disease, the laminectomy defect is centered over the area of involvement and most often extends cranially and caudally almost to the adjacent interarcuate ligament unless significant spinal cord compression and edema necessitate extension of the defect until normal amounts of epidural fat are visualized surrounding the spinal cord in the epidural space. Length of the defect in other cases is determined by the specific pathology encountered. Width of the defect is determined by the joint spaces between the cranial and caudal articular processes at the involved interspaces (Figure 48-26, arrow). Complete facetectomy at multiple locations has been shown experimentally to result in some vertebral column instability, although this has not been problematic in clinical cases other than vertebral

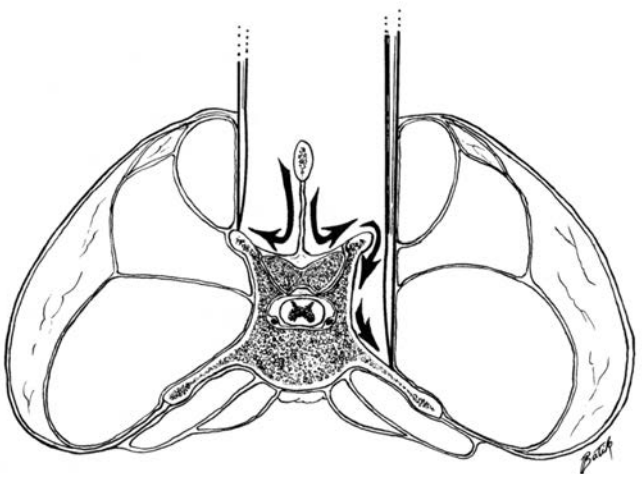


Figure 48-25. Periosteal elevation of the epaxial musculature for dorsal laminectomy. Arrows indicate the direction of force applied to the elevator for atraumatic periosteal elevation.

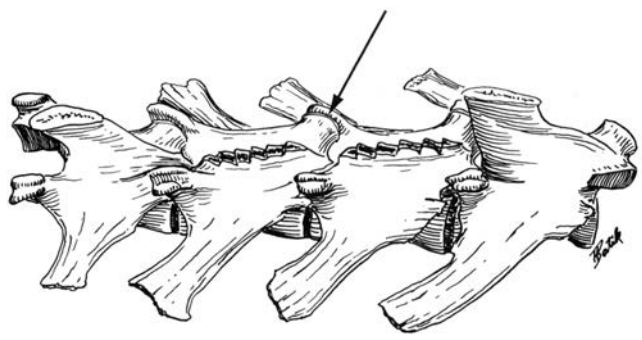


Figure 48-26. The arrow indicates the joint space between the cranial and caudal articular processes, which is used as a guideline for the lateral extent of the laminectomy.

column fractures/luxations in which this induced instability is compensated for by the vertebral column instrumentation which had been planned.

The bone structure and color are reliable indices of the depth of drilling: (1) outer cortical bone is dense and white; (2) middle cancellous bone is spongy and reddish-brown; (3) the inner cortical bone is dense, white, and very thin. Only cortical bone is present at the attachments of the interarcuate ligament. Once the limits of the laminectomy defect have been defined, drilling continues to completely remove the outer layer of cortical bone and then the middle layer of spongy cancellous bone (Figure 48-27). Hemorrhage from the cancellous bone is easily controlled with bone wax.

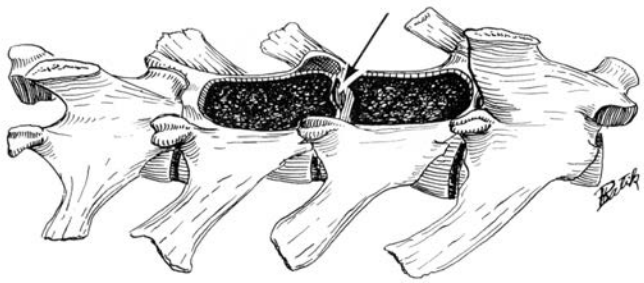


Figure 48-27. The outer cortical bone and most of the middle layer of cancellous bone, including that of the caudal articular processes, have been removed. The arrow indicates the dense cortical bone at the intervertebral space and the interarcuate ligament.

The surgeon must remember that he or she is removing the top of a horizontally-oriented cylinder while maintaining bone at the pedicles at a level dorsal to the dorsal tangent of the spinal cord. The inner layers of the laminar-pedicle junctions are excavated bilaterally to provide complete exposure of the epidural space (Figure 48-28). When the thin layer of inner cortical bone begins to sag under the pressure of the drill, a 2.3 or 1.6 mm round carbide-tip bur is substituted for the large bur

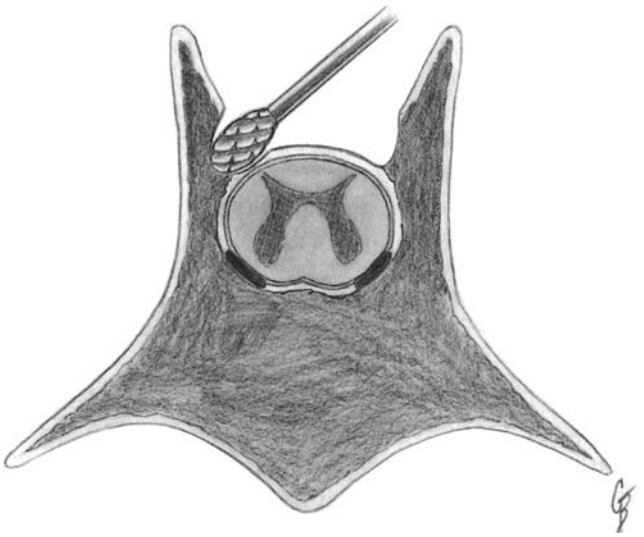


Figure 48-28. After excision of the middle layer of cancellous bone, excavation of the pedicles is begun with a 4-mm-diameter bur.

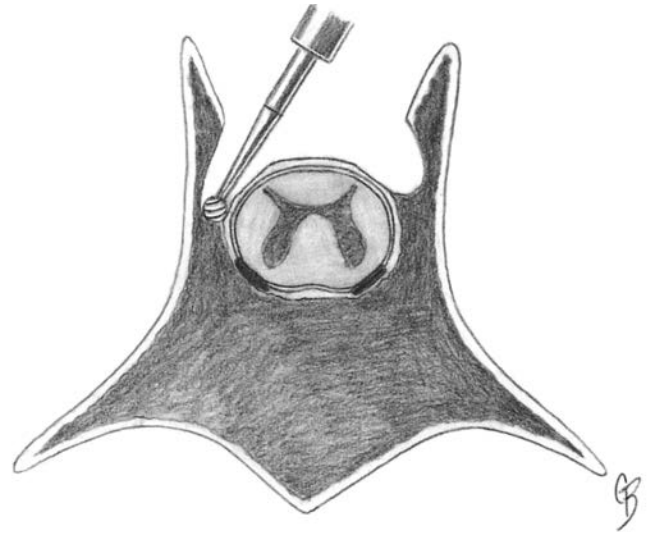


Figure 48-29. Further excavation of the middle layer of cancellous bone of the lateral laminae is performed with on of the small round burs.

(Figure 48-29). A thin plate of inner cortical bone remains in all areas of the defect to protect the spinal cord during the majority of the drilling, or "brushing away" of the bone. This thin plate of inner cortical bone is isolated by drilling around the periphery of the laminectomy defect with a small drill with approximately a 45 degree angle away from the spinal cord (Figure 48-30). The angled drilling into the pedicles avoids drilling directly over the spinal cord and results in smooth, deeply undercut edges of the laminectomy with excellent exposure of the full width of the vertebral canal. Some additional undercutting is necessary to remove portions of the cranial articular processes of the more caudal of the two vertebrae which are located somewhat in the frontal plane, deep to the caudal articular processes of the more cranial of the two vertebrae. Complete excision of the caudal articular processes and undercutting in this region results in impressive exposure of the full width of the spinal cord for resection of intra- or extramedullary mass lesions and sufficient access to the vertebral canal for the removal of extradural mass lesions, even those located ventral to the spinal cord. Excavation of the pedicles, *i.e.*, removal of the inner cortical and middle layers of cancellous bone of the pedicles, while preserving the outer layer of cortical bone of the pedicles, dramatically increases exposure without predisposing to the phenomenon of constrictive fibrosis (Figure 48-31).[4-7] Removal of extruded intervertebral disc material, even if located bilaterally or ventral to the spinal cord is uncomplicated, in spite of the minimal epidural space of chondrodystrophoid dogs with relative vertebral

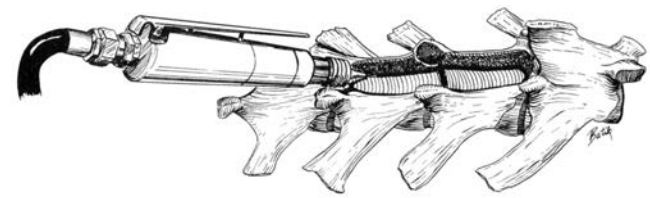


Figure 48-30. Angled drilling into the cancellous bone around the periphery of the thin plate of inner cortical bone avoids drilling directly over the spinal cord and results in smooth, deeply undercut edges. This technique increases both exposure and decompression and facilitates removal of extradural mass lesions.

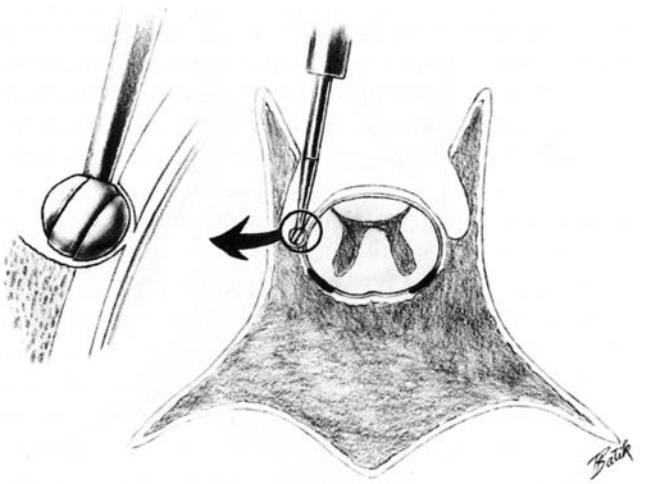


Figure 48-31. The inner cortical bone shelf is cut around the periphery with the smallest bur.

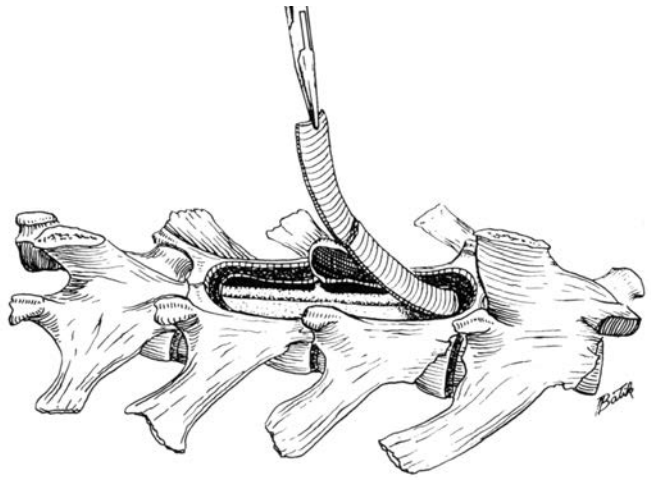


Figure 48-32. The thin shelf of inner cortical bone is grasped with a hemostat and is removed as a unit.

canal stenosis. Minimal spinal cord manipulation is necessary. The spinal cord may be gently retracted by means of a small suture placed in a relatively avascular area of the dura mater. Rhizotomy in appropriate locations releases the dural tube for additional retraction or "rolling". Fine-tipped suction and various ophthalmic and dental instruments have proven useful for the removal of mass lesions from the vertebral canal. Bleeding from the internal vertebral venous plexus is controlled by means of bipolar cautery, macerated muscle, or absorbable gelatin sponge (Gelfoam, Upjohn Co., Kalamazoo, MI 49008). It is imperative that the bone of the remaining pedicles on both sides of the defect be maintained at a level dorsal to the dorsal tangent of the spinal cord to prevent the occurrence of secondary spinal cord flattening during healing of the laminectomy defect (laminectomy membrane formation, epidural scar, laminectomy scar, postlaminectomy stenosis, or constrictive fibrosis). For the same reason, a hemilaminectomy, with complete excision of the facets, or articular processes, should never be converted to a dorsal laminectomy, nor should facet or laminar fragments be indiscriminately removed in vertebral column fractures unless appropriate (and as yet somewhat unproven) measures are taken to prevent secondary spinal cord compression due to formation of the laminectomy membrane. When the thin remaining layer of inner cortical bone has been completely isolated (See Figure 48-32), it is grasped with a hemostat and "peeled off", or removed as a complete boney shelf with the periosteum lining the vertebral canal. Because laminectomy scar formation and secondary spinal cord compression increase with an increase in not only defect width, but length, the length of the defect should be limited to only what is necessary to decompress the involved segments of spinal cord or resect the offending mass lesion.

Durotomy may be performed for the removal of intradural mass lesions or may be utilized to establish a more definitive prognosis in paraplegic, analgesic cases in which acute focal, segmental spinal cord necrosis, malacia, thrombosis, blanching, or chronic loss of cord substance with glial scarring is suspect. Dorsal midline myelotomy is only performed in paraplegic, analgesic patients in which the prognosis is in question. Continued leakage of cerebrospinal fluid has not been a problem with durotomies. A mild, transient neurologic deficit has been demonstrated in normal dogs following durotomy. The dura mater appears to heal rapidly by neomembrane formation.[5]

Durotomy is performed with either Potts-Smith 60 degree angled cardiovascular scissors or a bent disposable 20 to 25 gauge needle. The dura mater is usually incised on the dorsal midline for the full length of the laminectomy defect. Incision of the inelastic, and often opaque (loss of the normal translucent appearance) dural sheath and frequently the underlying pia mater may result in greater intramedullary decompression of the spinal cord and associated vasculature. Neither hypothermic or normothermic perfusion are utilized routinely.

Torn or devitalized epaxial musculature is excised prior to closure. This also appears to limit the infolding or collapse of the epaxial musculature into the laminectomy defect, a factor in the formation of laminectomy membrane. A section of absorbable gelatin sponge, creased on the midline to resemble a tent, and shaped to conform as closely as possible to the margins of the laminectomy defect is carefully placed in direct apposition with the remaining pedicles (marginal fitting). With this particular technique in the thoracolumbar region of dogs, the healing pattern following implantation of absorbable gelatin sponge is predictable and relatively innocuous.[5] Other implants such as absorbable gelatin film (Gelfilm, Upjohn Co., Kalamazoo, MI 49008), muscle, and free or pedicle fat grafts have met with variable and unsatisfactory or even disastrous results. Although highly successful in other locations, subcutaneous fat grafts in this location, with this laminectomy technique actually increase spinal cord compression postoperatively.[7,8] Cosmetically unacceptable scars, structural defects, or vertebral column instability have not been problems with this technique.

Postoperative Care

Postoperative analgesia, predominantly with opioids, is usually indicated for the first 12 to 24 hours. Corticosteroid therapy is no longer continued in the postoperative period due to the limited benefits confirmed by experimental studies and the possibility of gastrointestinal complications. Nonsteroidal anti-inflammatories are rarely used since most patients have been treated with corti-

costeroids either pre- or intraoperatively. Their concurrent or sequential use would increase the risks of catastrophic gastrointestinal bleeding or perforation. Postoperative therapy includes manual expression of the urinary bladder or urinary tract catheterization, tail walking, whirlpool hydrotherapy, exercise carts, and general supportive care. Patients are discharged from the hospital as soon as conscious control of micturition is regained. Early return to familiar surroundings seems to promote enthusiasm on the part of the patient and owner, more rapid return of urinary continence, and an early return to full function.

References

1. Caulkins SE, Purinton PT, Oliver JE. Arterial supply to the spinal cord of dogs and cats. *Am J Vet Res* 50:425, 1989.

2. Parker AJ. Distribution of spinal branches of the thoracolumbar segmental arteries in dogs. *Am J Vet Res* 34:1351, 1973.

3. Parker AJ, Park RD, Stowater JL. Traumatic occlusion of lumbar segmental arteries. *J Trauma* 14:330, 1974.

4. Funkquist B, Schantz B. Influence of extensive laminectomy on the shape of the spinal canal. *Acta Orthop Scand Suppl* 56:1, 1962.

5. Trotter EJ, Crissman J, Robson D, et al. Influence of nonbiologic implants on laminectomy membrane formation in dogs. *Am J Vet Res* 49:634, 1988.

6. Trotter EJ. Dorsal laminectomy for treatment of thoracolumbar disc disease. In: Bojrab MJ ed. Current techniques in small animal surgery. 3rd ed. Philadelphia: Lea & Febiger, 608, 1990.

7. Trevor PB, Martin RA, Saunders GK, *et al.* Healing characteristics of free and pedicle fat grafts after dorsal laminectomy and durotomy in dogs. Vet Surg 20:282, 1991.

8. Trotter EJ. Unpublished data.

Suggested Readings

Biggart JF, III. Prevention of laminectomy membrane by free fat grafts after laminectomy in dogs with disk herniations. *Vet Surg* 17:28, 1988.

Cook S, Prewett A, Dalton J, *et al.* Reduction in perineural scar formation after laminectomy with Polyactive membrane sheets. *Spine* 19:1815, 1994.

Einhaus SL, Robertson JT, Dohan FC, Jr., *et al.* Reduction of peridural fibrosis after lumbar laminotomy and discectomy in dogs by a resorbable gel (ADCON-L). *Spine* 22:1440, 1997.

Geisler FH. Prevention of peridural fibrosis: current methodologies. *Neurol Res* 21;Suppl 1:S9, 1999.

Gill G, Sakovich L, Thompson E. Pedicle fat grafts for the prevention of scar formation after laminectomy. An experimental study in dogs. *Spine* 4:176, 1979.

LaRocca H, Macnab I. The laminectomy membrane. Studies in its evolution, characteristics, effects and prophylaxis in dogs. *The Journal of Bone and Joint Surgery – British volume* 56B:545, 1974.

Olby N. Current concepts in the management of acute spinal cord injury. *J Vet Int Med* 13:399, 1999.

Robertson J, Meric A, Dohan FJ, *et al.* The reduction of postlaminectomy peridural fibrosis in rabbits by a carbohydrate polymer. *J of Neurosurg* 79:89, 1993.

Schulz KS, Waldron DR, Grant JW, *et al.* Biomechanics of the thoracolumbar vertebral column of dogs during lateral bending. *Am J Vet Res* 57:1228, 1996.

Shires PK, Waldron DR, Hedlund CS, *et al.* A biomechanical study of rotational instability in unaltered and surgically altered canine thoracolumbar vertebral motion units. *Prog Vet Neurol* 2:6, 1991.

Smith GD, Walter MC. Spinal decompressive procedures and dorsal compartment injuries: comparative biomechanical study in canine cadavers. *Am J Vet Res* 49:266, 1988.

Songer MN, Rauschning W, Carson EW, *et al.* Analysis of peridural scar formation and its prevention after lumbar laminotomy and discectomy in dogs. *Spine* 20:571, 1995.

Viguier E, Petit-Etienne G, Magnier J, *et al.* Mobility of T13-L1 after spinal cord decompression procedures in dogs (an in vitro study). *Vet Surg* 31:297, 2002.

Yovich JC, Read R, Eger C. Modified lateral spinal decompression in 61 dogs with thoracolumbar disc protrusion. *J Sm An Pract* 35:351, 1994.

Surgical Treatment of Cauda Equina Syndrome

Guy B. Tarvin and Timothy M. Lenehan

Introduction

A definitive preoperative diagnosis of cauda equina syndrome can be difficult to make. Not all practitioners have access to magnetic resonance imaging, the best modality for defining problems in the lumbosacral region. Access to computed tomography (CT) is equally limited, and often myelography or epidurography is required in concert with a CT scan to demonstrate soft tissue lesions such as nerve root entrapment. Epidurography alone is difficult both to perform and to interpret if conducted only on occasion. Electrodiagnostic testing and electromyography require special equipment and expertise to perform and to evaluate, and not all dogs with cauda equina syndrome have electrophysiologically demonstrable signs of lower motor neuron disease. Myelography is incapable of defining many pathologic processes involving the nerve roots of the cauda equina in the lumbosacral area of the dog. Stressed radiographs (hyperextension-flexion) of the spine demonstrate hypermobility, but they are not necessarily diagnostic of neurologic involvement even when used in conjunction with myelography. In fact, many animals affected by cauda equina syndrome have normal spinal radiographs. Hence, a veterinarian must use clinical acumen along with one or more of these diagnostic modalities to establish a diagnosis of cauda equine syndrome before recommending surgical intervention. In many cases only an exploratory laminectomy can provide both a diagnosis of and cure for cauda equina syndrome. The purpose of the surgery is to decompress the conus medullaris or those nerve roots of the cauda equina that are causing clinical symptoms. The surgeon should be vigilant to remove only as much bone as needed to accomplish this task, especially when dealing with cauda equina syndrome secondary to lumbosacral instability. The removal of portions of discs or facets progressively destabilizes the spine and may predispose the patient to adverse postoperative sequelae.

Surgical Procedure

The animal is placed in ventral recumbancy with the stifles and hips flexed and the hocks extended. If extensive foraminal exploration is anticipated, then placement of the patient's hind legs in the forward extended position combined with padding

placed under the belly in the lumbosacral region will accentuate lumbosacral kyphosis to more widely open the foramina at the lumbosacral junction.

A dorsal midline approach to the lumbosacral spine is performed. Several large Gelpi or hinged Weitlaner retractors facilitate muscle retraction (Figure 48-33). Suction is essential for good visualization, and most typically a No. 10 or 12 Frazier suction tip is adequate. Electrocautery, surgical sponge (Gelfoam), bone wax and small pieces of epaxial muscle placed on small bleeders are essential for adequate hemostasis in large breed dogs.

A modified dorsal laminectomy is performed over the affected interspaces (generally L7 to S1-2), initially leaving the caudal pedicles of L7 intact. If the compression is due to either midline disc bulging or hypertrophy of the interarcuate ligament, then this surgical approach alone should result in decompression. If the surgeon is unsure of complete decompression, then extradural fat and fibrous connective tissue are removed from the spinal canal as needed to facilitate visualization of the various nerve roots and ganglia of the cauda equina. A nerve hook helps to isolate and trace individual nerves as they enter their respective foramina to exit the spinal canal. Unilateral or bilateral pediculectomy is performed as needed to gain further exposure and decompression of the involved nerves. In some cases, foraminotomy without pediculectomy is possible and preferred. Tethered nerve roots are freed from any fibrous connective tissue constraints. In the case of a Hansen type I disc rupture, the ruptured nuclear material is removed (generally by suction). If a Hansen type II disc rupture is present, the location of the bulging annulus in relation to a compressed nerve determines the surgical procedure. Disc material that is entrapping a nerve root is either cut away or, alternatively, is left alone and the nerve decompressed by facetectomy, pediculectomy, or foraminotomy.

Once decompression has been achieved and hemostasis is complete, an autologous free fat graft is harvested from the subcutaneous region and placed over the laminectomy site to minimize cicatrix formation. Muscle, fascia and subcutaneous layers are closed, respectively, with synthetic absorbable suture material. Inaccurate closure of the muscle results in a palpable midline defect, whereas inattention to subcutaneous closure results in seroma formation. The application of a compression bandage is optimal, yet difficult to apply and maintain, given the location of the operative site, especially in male dogs.

Postoperative Care

Postoperative recommendations include strict confinement to house and leash walking activity only for 8 weeks' time, before a return to moderate function. This confinement allows time for the musculature to adhere to the lamina and for the spine to adjust to the added instability imposed by the surgical procedure.

In most cases, a modified dorsal laminectomy is sufficient to gain good visualization of the problem and to effect decompression. Removal of the dorsal spinous processes and dorsal laminectomy minimally destabilize the lumbosacral motion unit in four point flexion/extension tests in vitro. Hence, one may expect resolution of nerve root symptoms without significant subsequent clinical deterioration if successful mechanical decompression has been achieved (and if mechanical compression alone was the source of the pain). Osteoarthritic symptoms may be expected to persist however (i.e. morning and exercise induced stiffness with occasional episodes of low back pain lasting several days). The addition of discectomy, foraminotomy or facetectomy further destabilizes the spine. Clinically significant sequelae such as facet fracture, lumbosacral subluxation, cicatrix formation and ongoing clinical symptomatology can result. It is therefore important to use a minimalistic approach in one's decompression technique.

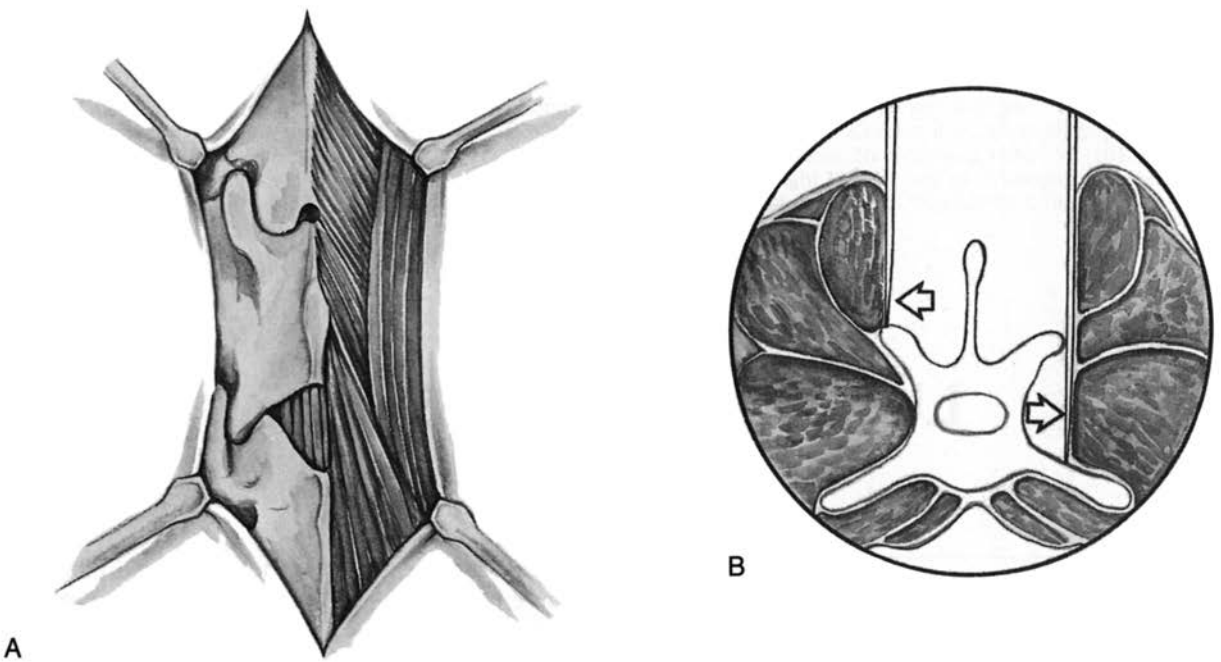


Figure 48-33. Muscle elevation for dorsal laminectomy.

Decompressive laminectomy in a hypermobile lumbosacral segment should be undertaken with caution, particularly if discospondylitis is suspected. In such instances, laminectomy only further destabilizes an already unstable situation and may have orthopedic and neurological sequelae, if the infection is not brought under control quickly.

The literature would indicate that on average 85% of the animals operated on demonstrate initial improvement. However, subsequent deterioration occurs in up to 1/3 of patients resulting in an overall longterm success rate of around 55%. Approximately 25% of cases are improved by surgery but not symptom free, and there is on average a 25% failure rate. Persistent postoperative clinical symptoms most probably relate to ongoing lumbosacral instability, attendant discogenic pain, epidural scarring, arachnoiditis, facet arthritis or fracture, insufficient decompression at the operative site, alternate segment disease, iatrogenic conus or nerve root trauma, infection, etc. Preoperative conditions predisposing to surgical failure seem to include advanced age, chronicity of symptoms, concurrent hind limb problems, and urinary or fecal incontinence. Favorable preoperative conditions include young age and mild clinical symptoms.

If there is a recurrence of symptoms in the early postoperative phase, a second exploratory surgery is justified in selected cases.

Bony or soft tissue disease at any of the L5-6 to S1-2-3 vertebral interspaces potentially can result in clinical signs of cauda equina syndrome (sciatic or sacral nerve root involvement) (Figure 48-34). The clinician must attempt to localize the lesion to a specific area of the spinal cord or nerve roots preoperatively. A "routine" dorsal laminectomy at the L7-S1 interspace may miss the underlying disorder entirely, if the signs of the cauda equina syndrome are, for example, due to an intramedullary tumor affecting the L6 segment of the spinal cord.

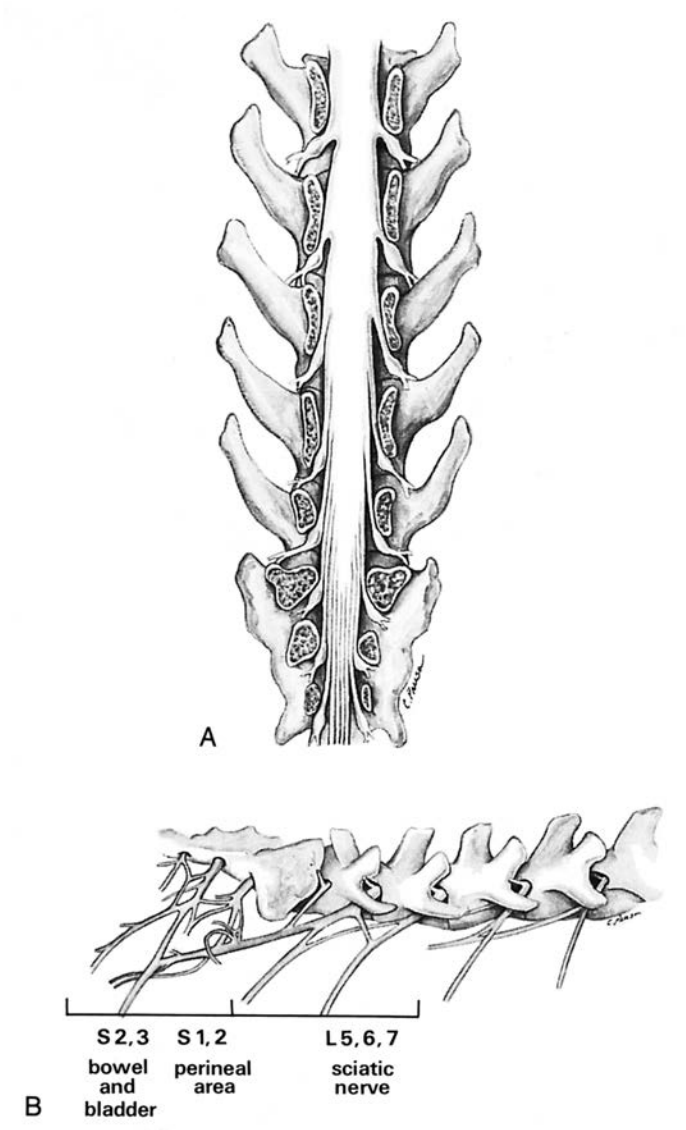


Figure 48-34. A. Dorsal view of the cauda equina. **B.** Nerve distribution of the cauda equina.

Suggested Readings

Danielson F, Sjostrom L. Surgical Treatment of Degenerative Lumbosacral Stenosis in Dogs. Vet Surg 28: 91, 1999.

Dr. Risiol, Sharp NJH, Olby NJ, et al. Predictors of outcome after dorsal decompressive laminectomy for degenerative lumbosacral stenosis in dogs: 69 cases (1987-1999). J. Am Vet Med Assoc 219: No5: 624, 2001.

Janssens LAA, Moens Y, Coppens P, et al. Lumbosacral Degenerative Stenosis in the Dog. Vet Comp Orthrop Traumatol 13:97, 2000.

Linn LL, Bartels KE, Rochat MC, et al. Lumbosacral Stenosis in 29 military working dogs: Epidemiologic findings and outcome after surgical intervention (1990-1999). Vet Surg 32:21, 2003.

Moens NMM, Runyun CL. Fracture of L7 vertebral articular facets and pedicles following dorsal laminectomy in the dog. J Am Vet Med Assoc. 221: No 6: 807, 2002.

Smith MEH, Bebchuk TN, Shmon CL, et al. An invitro biomechanical study of the effects of surgical modification upon the canine lumbosacral spine. Vet Comp Orthrop Traumatol 17:17, 2003.

Surgical Treatment of Fractures, Luxations and Subluxations of the Thoracolumbar and Sacral Spine

Karen L. Kline and Kenneth A. Bruecker

Introduction

The thoracolumbar and lumbar spine are relatively common locations for spinal fractures, luxations and subluxations in the dog and cat. As previously mentioned, it appears that the higher incidence of fracture/luxations at certain sites along the vertebral canal may not correlate to differences in muscular or ligamentous attachments, but rather to areas of the vertebral column with a static/kinetic relationship (ie. thoracolumbar and lumbosacral junction).[1,2,3,4] As mentioned also in the previous chapter on cervical spine injury, the history, physical and neurologic examinations are crucial to the determination of prognosis and surgical outcome.

Technique Selection

There are numerous techniques that have been developed to stabilize thoracolumbar and lumbar spinal fractures, luxations and subluxations in dogs and cats.[5-19] As mentioned previously, the technique chosen is dictated by the location of the fracture, size, age, and disposition of the patient, equipment available and experience of the surgeon.

Surgical Techniques

Dorsal spinous process plating requires exposure of the dorsal spinous processes and articular facets.[5] The supraspinous and interspinous ligaments should be preserved if possible. A minimum of three spinous processes on each side of the fracture/luxation should be exposed. Metal or plastic plates are available for dorsal spinous process plating. When using plastic plates, a plate is used on each side of the exposed dorsal spinous processes (2 plates total)[6,8] (Figure 48-35). The roughened side of the plate is placed against the dorsal spinous processes. The plates are attached with appropriate size nuts and bolts placed between the dorsal spinous processes. It is important to keep the plates as close to the base of the dorsal spinous processes as possible. Grooves can be created in the lamina at the base of the spine using a high speed bone burr or rongeurs to help keep the plates low on the spine. This will allow maximal purchase of the spinal plates to the dorsal spinous processes. Metal plates are used in a similar fashion however the nuts and bolts are placed through the dorsal spinous processes (Figure 48-36).

The advantage of dorsal spinous process plating is preservation of the inherent stability provided by the articular facets, supraspinous and interspinous ligament. The major limiting factors of dorsal spinous process plating are the age and size of the patient. The dorsal spinous processes must be large enough and the bone compact enough to support the stresses that are encountered by an unstable spine. This technique is commonly used in combination with other stabilization techniques (ie. pins and polymethyl methacrylate, vertebral body plating). The most common postoperative complications are fracture of the spinous processes and plate slippage.

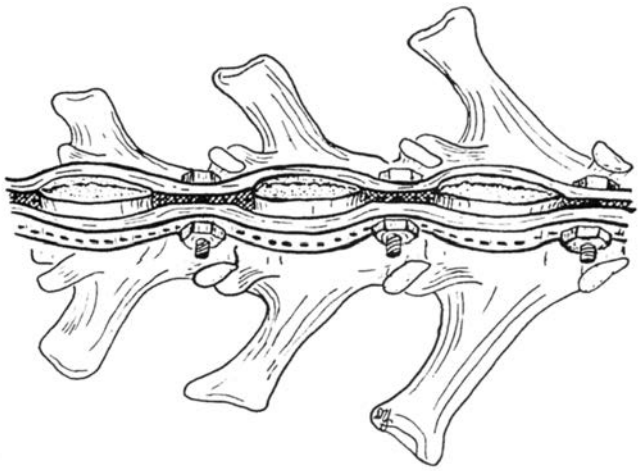


Figure 48-35. Dorsal spinal plating using plastic plates. (From Lumb WV and Brasmer TH. Improved spinal plates and hypothermia as adjuncts to spinal surgery. J Am Vet Med Assoc 1970;157:338-342.)

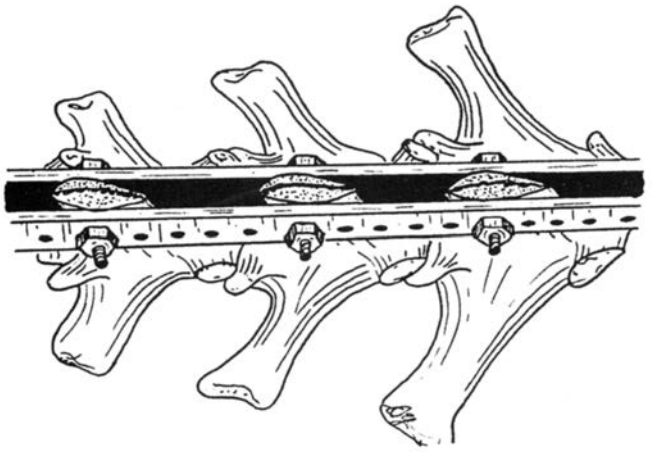


Figure 48-36. Dorsal spinal plating using metal plates. (From Lumb WV and Brasmer TH. Improved spinal plates and hypothermia as adjuncts to spinal surgery. J Am Vet Med Assoc 1970;157: 338-342.)

Spinal stapling also requires exposure of the dorsal spinous processes and facet joints. An intramedullary pin is placed through a dorsal spinous process, bent 90 degrees, laid along the lamina between the base of the spinous processes and articular processes, and secured to the base of the dorsal spinous processes with orthopedic wire (Figure 48-37). Added security can be accomplished by wiring the pin around the base of the transverse processes in the lumbar spine or around the rib heads in the thoracic spine (Figure 48-38) or by incorporating multiple pins and wires in a modified segmental spinal instrumentation technique (Figure 48-39).[9] At least two interspaces on each side of the fracture/luxation should be included in the repair.

Vertebral body plating (dorsal body plating) requires dorsolateral exposure of the articular facet, vertebral body and transverse process of the lumbar vertebrae or the articular facet, vertebral body and rib head of the thoracic vertebrae[10] (Figure 48-40). Care should be taken to protect the spinal nerve roots encountered cranial and caudal to the fracture/luxation. The spinal nerve and vessels at the involved space must be severed. The proper length and size plate is selected and placed on the dorsolateral aspect of the vertebral bodies. There should be at least four cortices engaged cranial and caudal to the involved fracture/luxation. Use of locking plates and screws may permit monocortical screw placement. If a luxation, subluxation or fracture close to the interspace exists, stabilization of the two adjacent vertebrae is adequate, however if a mid body fracture exists, three vertebral bodies should be spanned. The holes are drilled and screws are placed in a ventral and medial direction, being careful to avoid entering the spinal canal dorsally or the abdominal cavity ventrally. Placement of the plate on the thoracic vertebrae is more difficult due to the presence of rib heads. The rib heads must be removed and the transverse process contoured so the plate lies flat against the vertebral body. It is recommended that an anatomic specimen be available for visualization during placement of plates and screws. The need for rhizotomy precludes the use of vertebral body plating caudal to the fourth lumbar vertebra.[10,a,b]

[a]Lubra¨ plate, Lubra Co, 1905 Mohawk, Fort Collins, CO 80521 [b]Auburn spinal plate, Richard Manufacturing Co, Memphis, TN 38101

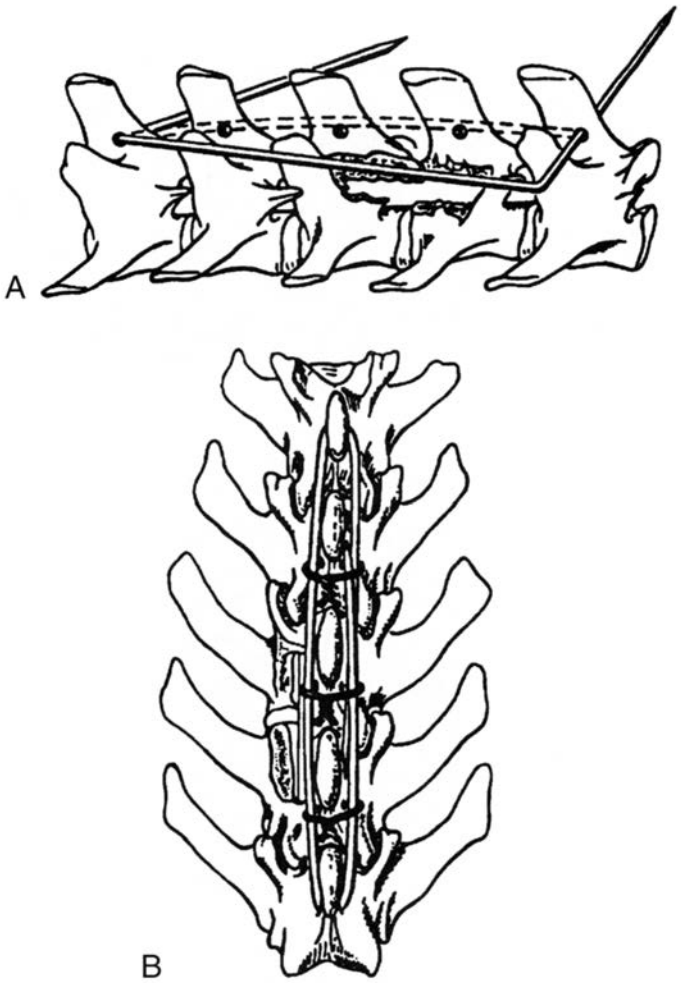


Figure 48-37. A. and **B.** Spinal stapling using single pin, doubled on the contralateral side of the dorsal spinous processes. (From Bruecker KA, Seim HB: Spinal Fractures and Luxations in Slatter DH (ed): Textbook of Small Animal Surgery, 2nd ed, WB Saunders Co., Philadelphia 1993)



Figure 48-38. Added stability can be achieved to the spinal stapling if rib heads and/or transverse processes are incorporated into the repair (From Helphrey M and Seim HB. Spinal trauma in Bojrab MJ (ed): Current Techniques in Small Animal Surgery. 3rd edition, Lea and Febiger, Philadelphia, 1990.)

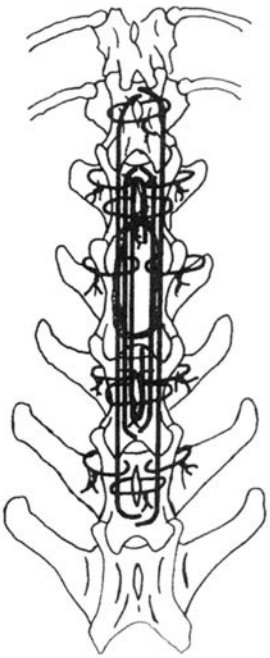


Figure 48-39. Modified segmental spinal instrumentation using multiple Steinmann pins and orthopedic wire. (From McNaulty JF, Lenehan TM, Maletz LM. Modified segmental spinal instrumentation in repair of spinal fractures and luxations in dogs. Vet Surgery 1986;15:143-149.)

Stabilization techniques utilizing pins (or screws) and polymethyl methacrylate require exposure of the dorsal spinous processes, articular facets and transverse processes bilaterally.[11,12] A minimum of two appropriate sized endthreaded, knurled acrylic pins are placed into the vertebral bodies on each side of the fracture/luxation. In the thoracic vertebrae, the pins are inserted into the pedicle and driven into the vertebral bodies, using the tubercle of the ribs and the base of the accessory processes as landmarks. In the lumbar vertebrae, pins are inserted directly into the vertebral bodies using the accessory processes and transverse processes as landmarks. Because pin placement is critical and landmarks vary considerably, depending on the level of the spine, a skeleton should be available for reference. The pins are directed cranioventral and from lateral to medial in the vertebral body cranial to the fracture/luxation, and caudoventral and from lateral to medial in the vertebral body caudal to the fracture/luxation. The Steinmann pins are power driven so they exit 2 to 3 mm from the ventral aspect of the vertebral body and are cut leaving 1.5 to 2 cm exposed dorsally. The polymethyl methacrylate forms around the knurled shaft of the pin and helps prevent pin migration. The surgical field is lavaged and dried in preparation for application of polymethyl methacrylate. If a laminectomy is not performed, polymethyl methacrylate is simply applied as a spherical mass, incorporating the Acrylic pins as well as the articular facets and adjacent dorsal spinous processes (Figure 48-41A and B). If a laminectomy is performed, the exposed spinal cord is covered with an autogenous fat graft and the polymethyl methacrylate is molded into the shape of a doughnut (Figure 48-42). Care is taken not to allow the polymethyl methacrylate to contact the spinal cord. The polymethyl methacrylate is lavaged with cool saline to dissipate the heat of polymerization. Portions of the epaxial muscles adjacent to the polymethyl methacrylate may

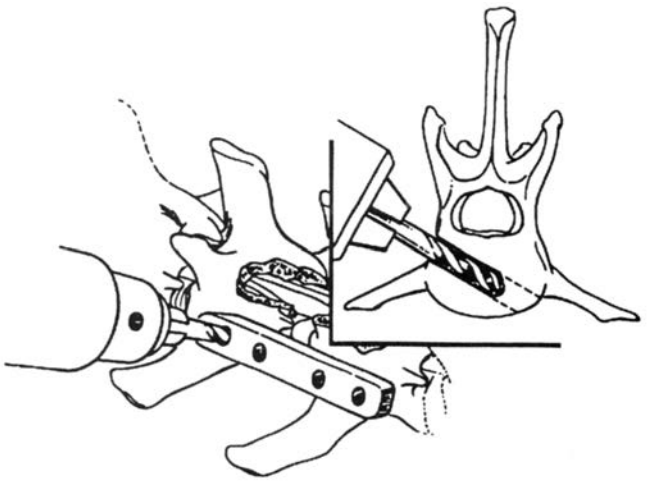


Figure 48-40. Application of a vertebral body plate. (From Swaim SF. Vertebral body plating for spinal stabilization. J Am Vet Med Assoc 1971;158:1653-1695.)

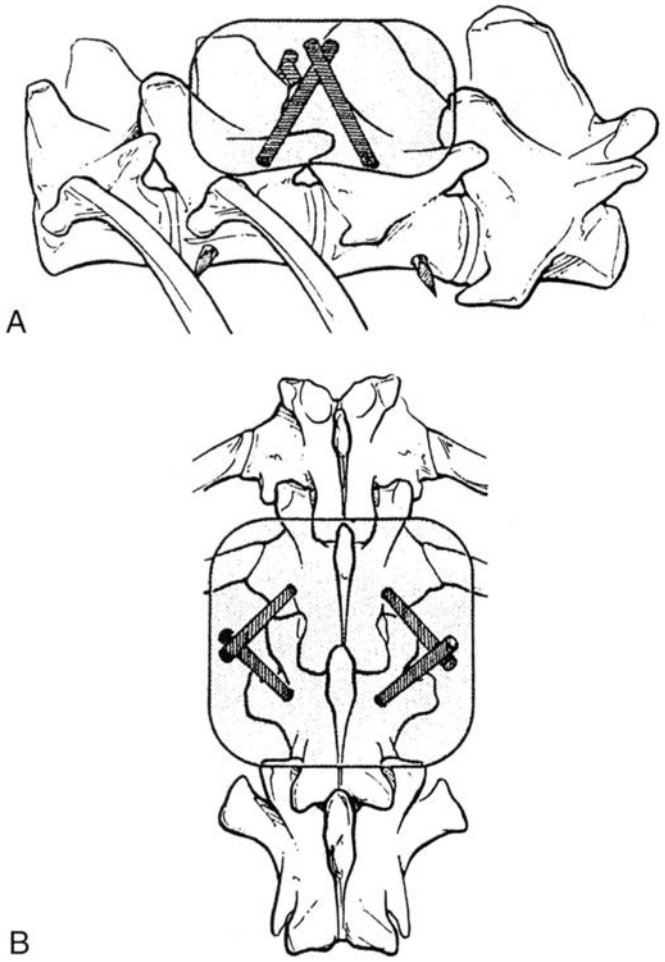


Figure 48-41. A. and **B.** Dorsal placement of Steinmann pins and polymethyl methacrylate to stabilize lumbar fracture/luxations. (From Blass CE and Seim HB. Spinal fixation in dogs using steinmann pins and methyl methacrylate. Vet Surgery, 1984;13:203-210.)

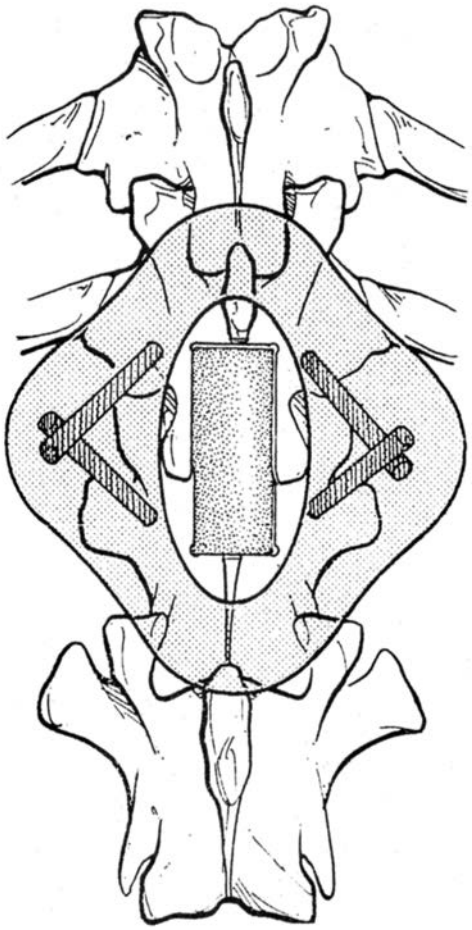


Figure 48-42. Dorsal placement of Steinmann pins and polymethyl methacrylate to stabilize lumbar fracture/luxations following laminectomy. Note that the polymethyl methacrylate is not placed over the laminectomy site (From Blass CE and Seim HB. Spinal fixation in dogs using steinmann pins and methyl methacrylate. Vet Surgery, 1984;13:203-210.)

have to be excised to facilitate closure. Rarely, relief incisions in the lumbodorsal fascia lateral to the polymethyl methacrylate are necessary to allow closure of the primary incision.[11,12]

The major disadvantage of this technique is the exposure necessary for pin placement, however, in a series of dogs treated with this technique, there were no failures associated with stress fatigue.[11] The technique is relatively straightforward, requires minimal special equipment, though a thorough knowledge of anatomy and constant reference to an appropriate anatomic specimen are recommended.

In some instances (generally T-L fractures or luxations in large breed dogs with hyperactive personalities), a combination of the above described techniques should be considered. Combinations such as pins and polymethyl methacrylate with dorsal spinous process plating, cross pins with dorsal spinous process plating, or body plating with dorsal spinous process plating have proven successful.[a]

[a]Lubra¨ plate, Lubra Co, 1905 Mohawk, Fort Collins, CO 80521

Fractures of L6, L7 and S1

Fractures and luxations of the caudal lumbar and sacral vertebrae are relatively common due to the static-kinetic relationship of the sacral and lumbar segments, respectively. Neurologic signs occurring secondary to trauma of the cauda equina, result in varying degrees of femoral, sciatic, and sacral nerve dysfunction. Because the spinal cord ends cranial to L7, patients with 60 to 70% displacement of the spinal canal may still have a favorable prognosis.[1]

Due to the increased shearing forces present in the lumbosacral region, caudal lumbar and lumbosacral fracture/luxations are difficult to stabilize. Techniques used to successfully treat L7-S1 fracture/luxations include transilial pinning, transilial pinning with plastic plate support, pins and polymethyl methacrylate, transilial pinning with external skeletal fixation, and spinal stapling.[6,9,13,14,15,16,17]

Surgical Techniques

In cases of L7-S1 luxations or subluxations, manipulation of L7-S1 during reduction involves grasping towels clamps or bone forceps placed on the wings of the ilium and pulling caudally and slightly dorsal. A non-sterile assistant can place counter traction on the head or front legs and this can help to lever the sacrum against the lamina of L7 while pressing ventrally on L6. Also, a small Hohmann retractor can be used to aid reduction of an L7 fracture or luxation by hooking the jaws of the forceps under the cranial lamina of the sacrum and lower the jaws against the caudal lamina of L7. Transilial pinning requires exposure of the dorsal L7-S1 region.[17] The caudal segment is most often displaced ventrally and cranially. Bone forceps are placed on each ilial wing to help elevate the ilium and sacrum dorsally to align the articular processes of L7 with the cranial articular surface of the sacrum. An appropriate sized trocar tip pin (1/8" or smaller) is driven through the wing of the ilium, across the laminae of L7 and through the opposite wing of the ilium (Figure 48-43). The most common problem associated with this technique is migration of the Steinmann pin. A more stable technique is generally recommended. To help prevent migration of the Steinman pins, bending the ends of each pin at a 90 degree angle can be done, as well as connecting the pins on each side with a double Kirschner clamp (see below) or notching the pins' ends with a pin cutter and incorporating them with bone cement.

The use of plastic dorsal spinous process plates and transilial pins has been reported[6,13] This requires a similar approach and reduction as previously described. Plastic dorsal spinous process plates are placed on each side of the three dorsal spinous processes cranial to the fracture/luxation and secured with nuts and bolts as previously described for plastic dorsal spinous process plating. The plastic plates extend caudad to S2-3. A 3/32" or 1/8" trocar tip pin is driven through one ilial wing, through the plastic plate at the level of L7-S1, and through the opposite ilial wing. A second pin is placed caudal to the first pin. The ends of the pins are bent craniad at a 90° angle and cut to leave 5 mm protruding (Figure 48-44). Postsurgical complications include fracture of the dorsal spinous processes or migration of the transilial pins. Pin migration may be decreased by application of polymethyl methacrylate to notched pins. Transilial pinning and external skeletal fixation with a Kirschner-Ehmer[c] apparatus has been described.[15,16] In this technique the transilial pins are placed percutaneously. In addition, one pin is inserted percutaneously through the vertebral body cranial to the fracture/luxation. Kirschner clamps attach the pins to a connecting bar on each side of the spine (Figure 48-45).

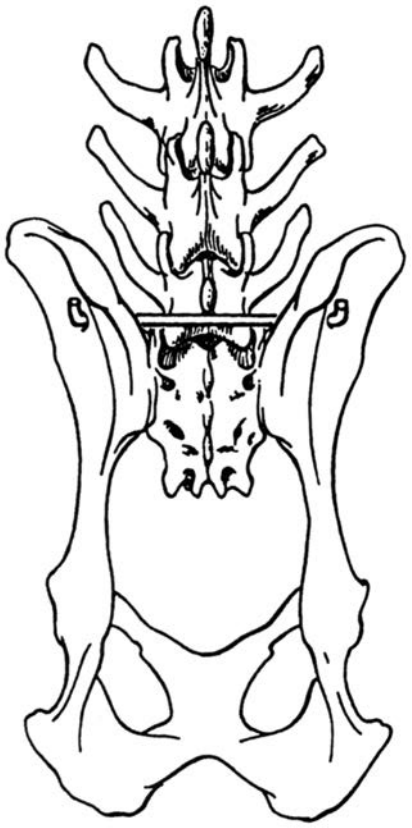


Figure 48-43. Transilial pin used to stabilize a fracture of the body of L7 or lumbosacral luxation. (From Bruecker KA, Seim HB: Spinal Fractures and Luxations in Slatter DH (ed): Textbook of Small Animal Surgery, 2nd ed, WB Saunders Co., Philadelphia 1993)

Pins and polymethyl methacrylate can also be utilized to stabilize lumbosacral fracture/luxations. The approach and reduction is as previously described. Two pins are placed in the vertebral body cranial to the fracture/luxation and two pins are placed in the wings of the ilium. The pins are incorporated with polymethyl methacrylate as previously described. The disadvantage of this technique is the large amount of polymethyl methacrylate needed for adequate stabilization, making closure difficult. Modified segmental spinal instrumentation has been used successfully to stabilize lumbosacral fractures. Pins are prebent 90°, placed through holes drilled in the wings of the ilium, laid alongside the dorsal spinous processes of at least two vertebra cranial to the fracture/luxation, and wired in place to the adjacent articular facets, dorsal spinous processes and lamina (Figure 48-46). Combinations of the above techniques may be utilized in large breed dogs with hyperactive personalities.

[c]Kirschner-Ehmer apparatus, Kirschner Co

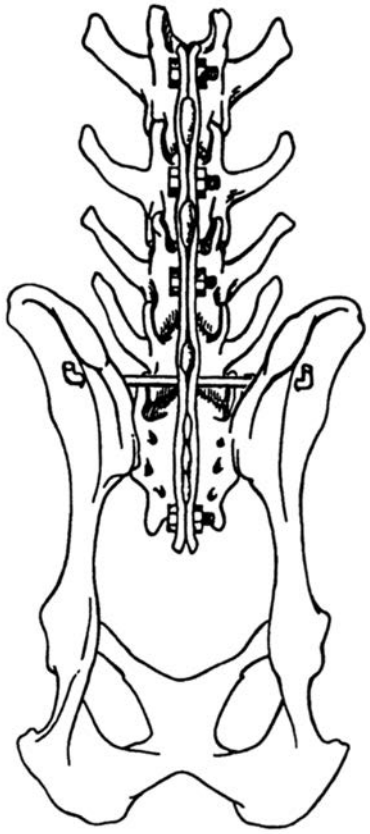


Figure 48-44. Transilial pin used in conjunction with plastic dorsal spinal plates provides additional support for lumbar or lumbosacral fractures. (From Bruecker KA, Seim HB: Spinal Fractures and Luxations in Slatter DH (ed): Textbook of Small Animal Surgery, 2nd ed, WB Saunders Co., Philadelphia 1993)

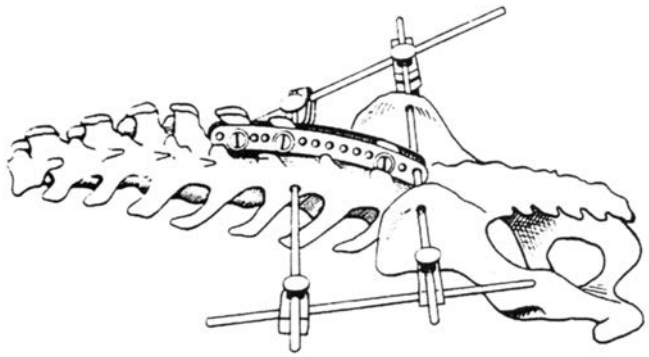


Figure 48-45. Transilial pin with external skeletal fixation also provides additional support for lumbar or lumbosacral fractures. (From Shores A, Nichols C, Rochat M, et al. Combined Kirschner-Ehmer device and dorsal spinal plate fixation technique for caudal lumbar vertebral fractures in dogs. J Am Vet Med Assoc 1989;195:335-339.)

Sacral and Sacrococcygeal Fractures

Special attention to the S2-S3 dermatomes and evaluation of bowel and bladder function should be considered when performing a neurologic examination on patients with sacral and sacrococcygeal fracture/luxations. Fracture of the sacral wings generally occurs through the sacral foramina, damaging the S1, S2 and S3 nerve roots. Sacroiliac luxation however, rarely effects

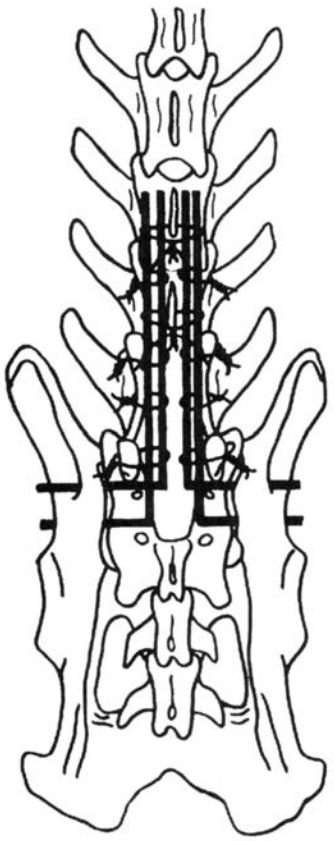


Figure 48-46. The use of modified segmental spinal instrumentation for the repair of lumbosacral and caudal lumbar fracture/luxation. (From McNaulty JF, Lenehan TM, Maletz LM. Modified segmental spinal instrumentation in repair of spinal fractures and luxations in dogs. Vet Surgery 1986;15:143-149.)

the nerve roots. A dorsal approach to the sacroiliac junction can be utilized to expose fractures of the sacral wing. Careful periosteal elevation of the paraspinal musculature allows visualization of the fracture fragments. Once reduced, the fracture can be stabilized with a lag screw inserted through the ilium and sacral fragment and into the sacral body.[18] A parallel trocar tip pin or wire may be inserted to provide rotational stability (Figure 48-47). If the neurologic examination reveals severe nerve root damage (shearing of the S1-S3 nerve roots), laminectomy and exploration of the cauda equina should be considered. Patients sustaining sacral or sacrococcygeal fracture/luxation may present with an anesthetic tail. If the tail remains anesthetic at 2 to 3 weeks post trauma, an amputation may be necessary to eliminate associated fecal matting, urine scalding (cats), and self-mutilation.[14] Traumatic injury of the sacrococcygeal area frequently occurs in cats.[4,19] Avulsion of the nerve roots of the cauda equina is a frequent sequela to injuries causing sacrococcygeal fracture/luxations. The prognosis is good for return of normal urinary function in cats that have anal tone and perineal sensation at the time of initial examination.[19] Cats that are unable to urinate normally within 4 to 6 weeks after the injury are not expected to recover normal urination habits.[19]

Coccygeal fractures

Coccygeal fractures may result in various neurologic deficits to

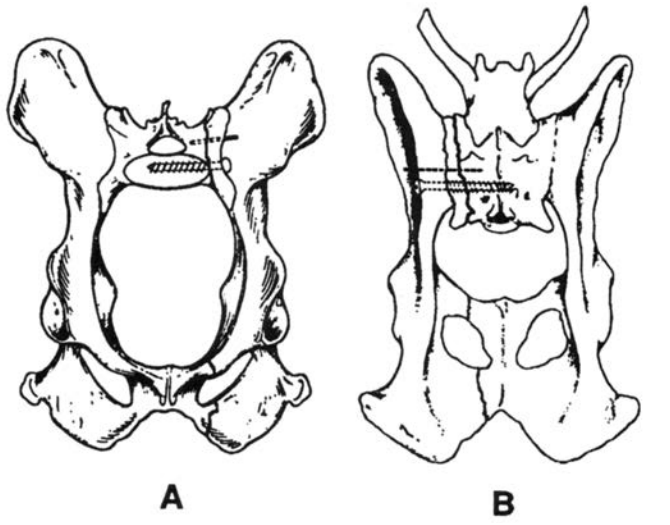


Figure 48-47. Stabilization of sacral fracture using lag screw and Kirschner wire; cranial **A.** and **B.** dorsal views. (From Bruecker KA, Seim HB. Spinal Fractures and Luxations in Slatter DH (ed): Textbook of Small Animal Surgery, 2nd ed., WB Saunders Co., 1993)

the tail. Rarely should they be treated surgically. If anesthesia of the tail persists, amputation may be the only feasible alternative.

New Horizons

One new spinal fixation technique has been described in the literature and involves the use of closed fluoroscopic-assisted spinal arch external skeletal fixation (ESF) for the stabilization of traumatic vertebral column injuries in 5 dogs. In this study, the fixator configuration consisted of pins placed bilaterally in 2 contiguous vertebral bodies cranial and caudal to the fracture. The protruding portion of the pins were incorporated into an external connecting system (IMEX Veterinary Inc., Longview Texas) for spinal stabilization. Results of this study were initially encouraging and this device may prove to be useful in the future.[20,d]

Post-operative Management

Post-operative management of spinal fracture patients is generally divided into ambulatory or non-ambulatory convalescence. Patients with an ambulatory status postoperatively are generally managed in the following manner: cage confinement, brief exercise 2 to 3 times a day for 2 to 3 weeks, serial neurologic and radiographic examinations and home on restricted exercise and/or passive range of motion exercises until radiographic evidence of healing is present. Non-ambulatory patients are managed in the following manner: elevated padded cage rack or waterbed, turned every 2 to 4 hours, bladder expressions 4 to 5 times a day or intermittent sterile catheterization in the male patient 2 to 3 times daily, passive range of motion exercises 3 to 4 times a day, electrical stimulation (if available), serial neurologic and radiographic evaluations and frequent hydrotherapy until return to an ambulatory status is achieved. Complications as described for the recumbent cervical injury patient have been described and apply to these patients as well. The use of back braces or splints is somewhat controversial. If the brace is comfortable, light weight and tolerated by the patient they are helpful. However, most braces are heavy, nonconforming, result in pressure sores and are not well tolerated by the patient.[3] Heavy reliance on a back brace, especially in large breed, hyperactive dogs should be avoided unless surgical intervention is not an option.

[d]IMEX Acrylic pins, IMEX Veterinary Inc., Longview, TX

References

1. Feeney DA and Oliver JE. Blunt spinal trauma in the dog and cat: neurologic, radiologic and therapeutic correlations. J Am Anim Hosp Assoc 1980;16:664-668.

2. Swaim SF. Biomechanics of cranial fractures, spinal fractures, and luxations, in (ed) Bojrab, Pathophysiology in Small Animal Surgery. 1981:774-778.

3. Carberry CA, Flanders JA, Dietze AE, et al. Nonsurgical management of thoracic and lumbar spinal fractures and fracture/luxations in the dog and cat: a review of 17 cases. J Am Anim Hosp Assoc 1989;25:43-54.

4. Feeney DA and Oliver JE. Blunt spinal trauma in the dog and cat: insight into radiographic lesions. J Am Anim Hosp Assoc 1980;16:885-890.

5. Piermattei DL. An atlas of surgical approaches to the bones and joints of the dog and cat. 3rd ed. WB Saunders, 1993;45-89.

6. Dulisch ML and Nichols JB. A surgical technique for management of lower lumbar fractures: case report. Vet Surgery 1981;10:90-93.

7. Sharp NJ and Wheeler SJ: Trauma. In Small Animal Spinal Disorders. Philadelphia; Elsevier, 2005, 282-305.

8. Lumb WV and Brasmer TH. Improved spinal plates and hypothermia as adjuncts to spinal surgery. J Am Vet Med Assoc 1970;157:338-342.

9. McNaulty JF, Lenehan TM, Maletz LM. Modified segmental spinal instrumentation in repair of spinal fractures and luxations in dogs. Vet Surgery 1986;15:143-149.

10. Swaim SF. Vertebral body plating for spinal stabilization. J Am Vet Med Assoc 1971;158:1653-1695.

11. Blass CE and Seim HB. Spinal fixation in dogs using steinmann pins and methyl methacrylate. Vet Surgery, 1984;13:203-210.

12. Rouse GP and Miller JI. The use of methyl methacrylate for spinal stabilization. J Am Anim Hosp Assoc 1975;11:418-425.

13. Lewis DD, Stampley A, Bellah JR, et al. Repair of sixth lumbar vertebral fracture-luxations, using transilial pins and plastic spinous-process plates in six dogs. J Am Vet Med Assoc 1989;194:538-542.

14. Matthiesen DT. Thoracolumbar spinal fractures/luxations: Surgical management. Comp Cont Ed 1983;5:867-878.

15. Shores A, Nichols C, Koelling HA. Combined Kirschner-Ehmer apparatus and dorsal spinal plate fixation technique of caudal lumbar vertebral fractures in dogs: biomechanical properties. Am J Vet Res 1988;49:1979-1982.

16. Shores A, Nichols C, Rochat M, et al. Combined Kirschner-Ehmer device and dorsal spinal plate fixation technique for caudal lumbar vertebral fractures in dogs. J Am Vet Med Assoc 1989;195:335-339.

17. Slocum B and Rudy RL. Fractures of the seventh lumbar vertebral in the dog. J Am Anim Hosp Assoc 1975;11:167-174.

18. Taylor RA. Treatment of fractures of the sacrum and sacrococcygeal region. Vet Surgery 1981;10:119-124.

19. Smeak DD and Olmstead ML. Fracture/luxations of the sacrococcygeal are in the cat: a retrospective study of 51 cases. Vet Surgery 1985;14:319-324.

20. Wheeler JL, Lewis DD, et al. Closed Fluoroscopic-Assisted Arch External Fixation for the Stabilization of Vertebral Column Injuries in 5 Dogs. Vet Surg 2007, 36: 442-448.

Section L

Fracture Fixation Techniques and Bone Grafting

Chapter 49

Fixation with Pins and Wires

Application of Cerclage and Hemi-cerclage Wires

Sharon C. Kerwin

Definition and Indications

Cerclage refers to a wire used to encircle a bone. Cerclage wire typically is used to provide interfragmentary compression in a manner similar to that of interfragmentary screws, and is useful in situations where space is limited and screw application would be difficult, or when screws of the correct type or size are not available. Properly applied cerclage wires have been shown not to interfere with the blood supply to bone,[1,2] and may be used in the immature as well as the mature animal.[3,4] Types of cerclage wire application include full cerclage, where the wire completely encircles a complete cylinder of bone, and hemicerclage, where wire is passed through a hole or holes drilled through bone.

For the vast majority of fractures, cerclage wire is used as adjunctive, rather than primary, fixation. The surgeon should keep in mind that while properly applied cerclage wire in selected cases is very effective, errors in application or case selection can be disastrous. Careful attention to detail in fracture repair planning, fixation and post-operative assessment is critical. Cerclage wire is typically applied to long spiral or oblique fractures where the length of the fracture is roughly two and one-half to three times the diameter of the bone (Figure 49-1), and a single cerclage wire is avoided as it acts as a stress concentrator and becomes a fulcrum for motion of the fracture fragments. Cerclage wire may be used both as a temporary reduction device, for example, to hold the fracture in reduction while applying a plate, external skeletal fixator, or interlocking nail, or as a permanent device, often in combination with one of the above or with an intramedullary pin. Although some investigators have commented that cerclage wire may inhibit the surgeon's ability to accurately contour a plate to bone, in practice properly applied cerclage wires are commonly left under plates and mechanical performance in one study showed that cerclage wires used under the plate performed as well as lag screws and were easier to apply.[5]

In certain circumstances, cerclage wire can also be used over a plate,[5,6] although mechanically they may not perform as well as they do under the plate.[7]

An exception to the single cerclage wire rule for long bones may be made if the intent is to prevent a non-displaced fissure fracture from propagating or fracturing further during manipulation of the fracture ends during open reduction (Figure 49-2).

Cerclage wire is made of relatively soft (usually annealed) 316L stainless steel that is available on spools, in coils or as preformed loops. Sizes of cerclage wire typically used in cats and dogs include 22, 20 and 18 gauge. On rare occasions, it may be appropriate to use 24 gauge wire in very tiny patients and 16 gauge wire in very large dogs. A special type of cerclage wire, cable cerclage, uses large diameter braided titanium alloy or stainless steel along with a special clamp system. Cable cerclage is designed for use over total hip replacements or for fixation of trochanteric osteotomies in humans. Successful use of cable cerclage after total hip revision in the dog has been reported.[8]

Wire diameter can exponentially increase load to failure (a 50% increase in diameter may increase load to failure by up to 169%),[9] and the largest diameter wire that the surgeon can apply to the bone without technical difficulty is recommended.[10] The area moments of inertia ($I = \pi r4/4$) of the various common wire sizes are listed in Table 49-1 and give the user an indication of how strength is greatly decreased as the size of the wire decreases, and also why the use of stainless steel suture material (eg, 30 gauge stainless steel wire) in any configuration is strictly contraindicated for fracture repair. Method of wire application and type of knot have been extensively studied in both the human and veterinary literature in order to maximize both initial tightness of the wire and identify configurations that will stand up to cyclic load and maximize load to failure. When reviewing the literature, one should be aware that some studies are designed to evaluate cerclage wire used for spinal or tension band applications rather than for long bone applications, and be cautious when trying to apply results of those studies toward applications which they were not designed to evaluate.

Types of Knots and Types of Twisters

Cerclage wire in veterinary surgery is generally applied either as a twist wire or loop wire (single or double loop). Clinical advantages of twist wires include ease of application with a simple wire twister (Figure 49-3), the ability to tighten and fasten the wire at the same time, and the ability to retighten the wire if it loosens during fracture reduction,[11] as frequently occurs during the placement of multiple cerclage wires. Loop wires have the advantage of better initial tension or tightness when properly applied, and do not have a protruding twisted end that may irritate soft tissues. Loop wires that loosen during fracture reduction must be removed and replaced.

There are many different types of wire tighteners available which have been reported in the literature. They fall into categories of twist tighteners, loop tighteners and there are instruments available that can actually tie a square knot in stainless steel cerclage wire (Table 49-2)

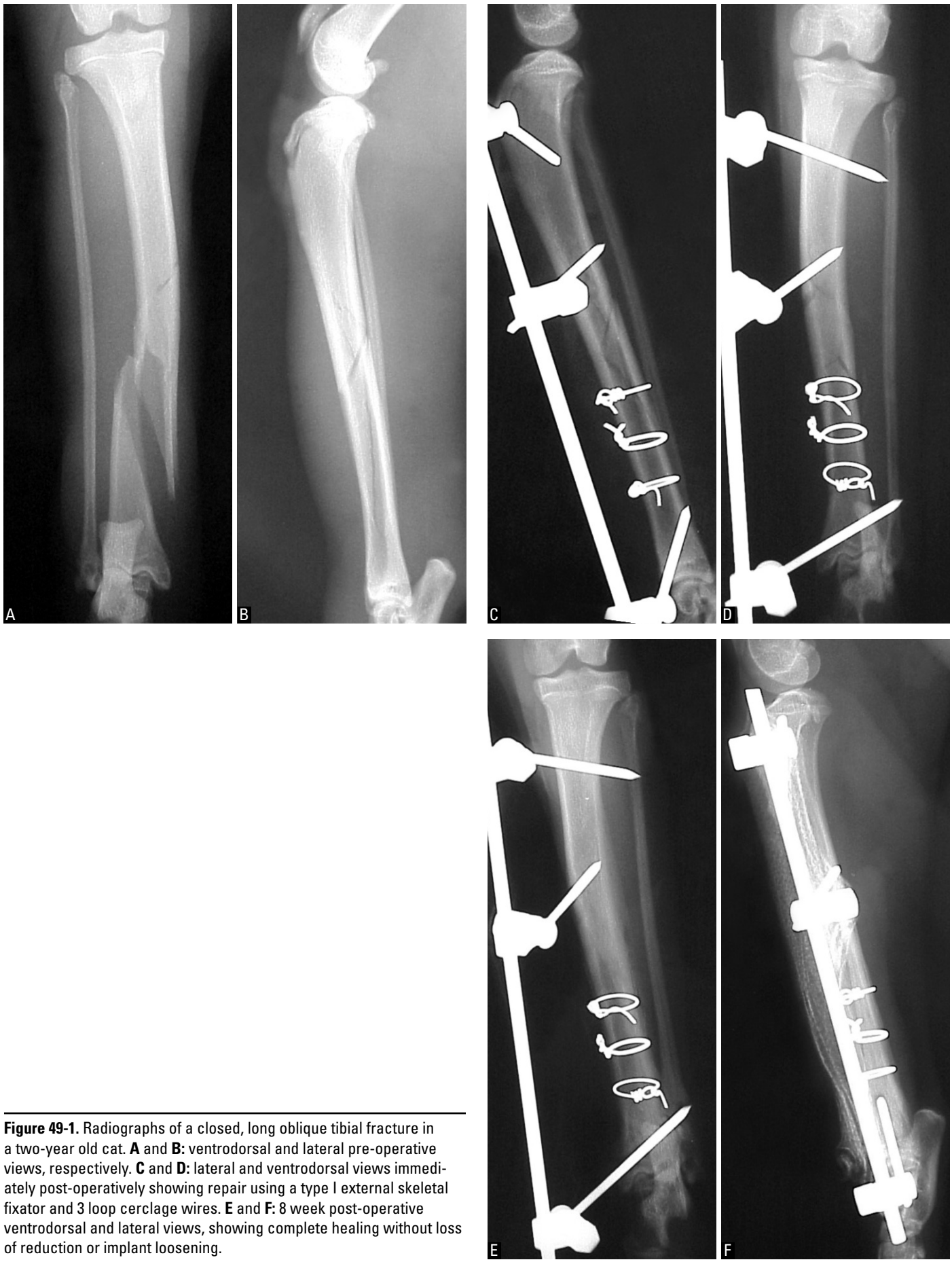


Figure 49-1. Radiographs of a closed, long oblique tibial fracture in a two-year old cat. **A** and **B:** ventrodorsal and lateral pre-operative views, respectively. **C** and **D:** lateral and ventrodorsal views immediately post-operatively showing repair using a type I external skeletal fixator and 3 loop cerclage wires. **E** and **F:** 8 week post-operative ventrodorsal and lateral views, showing complete healing without loss of reduction or implant loosening.



Figure 49-2. A. Lateral view of a comminuted, short oblique femur fracture in a 6 month old female mixed breed dog. **B.** Usage of a cerclage wire distal to the major fracture line for prevention of fissure propagation. The fissure is not obvious on the pre-operative radiograph. **C.** Fracture is healed 8 weeks post-operatively.

Table 49-1. Area moment of Inertia for Cerclage Wires

Wire Diameter (gauge/diameter in mm)	Area Moment of Inertia [I] (mm^4)
16 g/1.2	0.1018
18 g/1.0	0.0491
20 g/0.8	0.0201
22 g/0.6	0.0064
24 g/0.5	0.0031

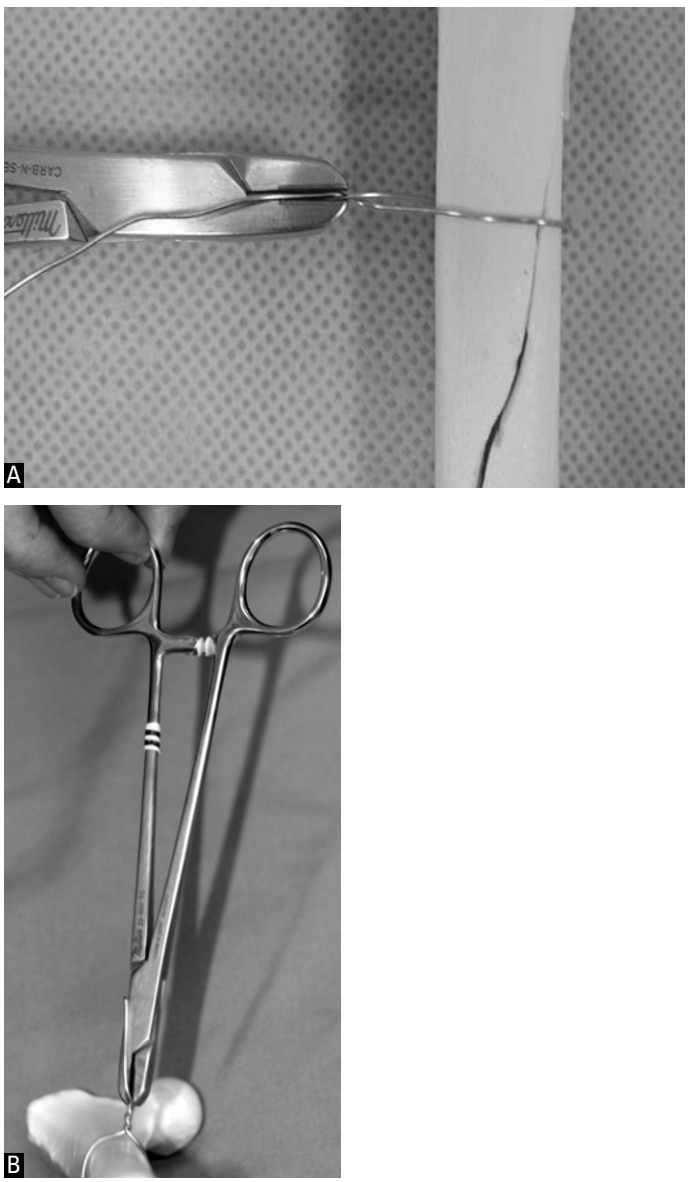


Figure 49-3. A wire twister is used to form twisted full cerclage wire. **A.** The wire is grasped where it crosses and pulled and twisted at the same time. **B.** A locking wire twister is always used to prevent loss of tension during wire twisting and tightening.

Table 49-2. Types of Wire Tighteners (reference listed has a picture of each tightener)

Twist
Wire twister (see Figure 49-3)
Rhinelander wire tightener twister (with strain gauge)[19]
Bowen twister cutter[14]
Ochsner wire twister[10]
Kirschner wire twister[20]
Modified ASIF wire tightener[9]
"Jet Twister" Smith & Nephew[11]
Single Loop
Richards standard wire twister[19]
Richards loop wire tightener[19]
Osteo systems (through Richards) wire tightener with strain gauge[19]
ASIF wire tightener[10]
Double Loop
ASIF wire tightener[10]
Knot Twist
Kirschner "Bow Twister"[11]
Square knot
Harris knotter[21]

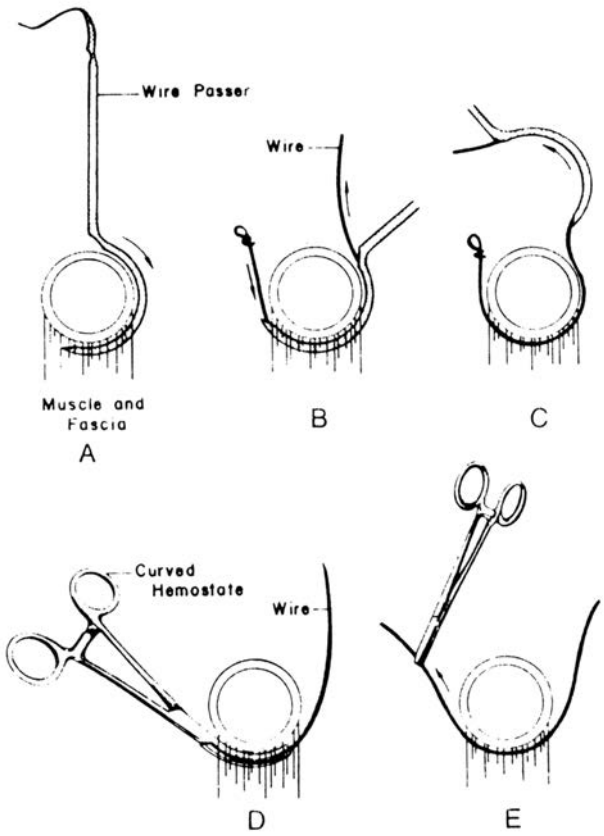


Figure 49-4. Usage of a cannulated cerclage wire passer and hemostat.

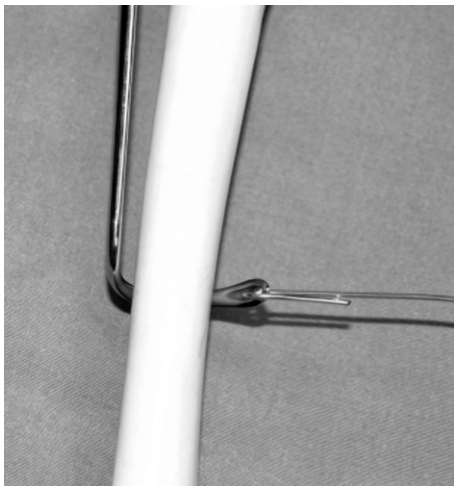


Figure 49-5. Usage of an aneurysm needle as a cerclage wire passer.

Application of Full Cerclage Wire

For fixation of a long bone fracture, cerclage wire should only be used where the fracture can be anatomically reconstructed to complete the original, 360° cylinder of bone. Although wire can keep bone fragments compressed, it cannot keep them apart as a plate and screw construct can. If even a tiny piece of bone is missing, the fracture will collapse as the wire is tightened and a loose wire with loss of reduction will result. In general, cerclage is reserved for two-piece fractures, although occasionally a third piece may be successfully incorporated. It is important to minimize dissection and soft tissue trauma to the musculature attached to the bone while applying cerclage wire. Cerclage wire may be passed around the bone either directly or using an instrument such as a cerclage wire passer (Figure 49-4) or aneurysm needle (Figure 49-5). Soft tissue inadvertently trapped under the wire will undergo necrosis and this will subsequently lead to wire loosening, however, there is no need to attempt to place the wires subperiosteally.[4] Wires are generally placed approximately 1 cm apart and at least 5 mm from the ends of the fracture. Some surgeons recommend that cerclage wires should be placed no nearer that one bone diameter away from the ends of the fracture.

After the cerclage wire has been carefully passed around the diaphysis of the bone and the fracture reduced, it must be tightened while maintaining reduction. For twist wire application, the wire may be twisted by hand for the first one or two twists loosely, leaving about 0.5 to 1 cm between the bone and the twist. A locking wire twister should be used for applying cerclage wire, as use of an ordinary pair of pliers allows loss of tension as the wire is being twisted. Using a locking wire twister, both wire ends should be grasped where they intersect (See Figure 49-3), and the wire pulled firmly up while twisting at the same time to avoid the complication of one wire wrapping around the other, which will drastically weaken the construct. It is of critical importance that the wire be tight. The surgeon should watch as the gap between the wire and the bone disappears, and should periodically check the wire for looseness by pushing firmly on it with a Freer periosteal elevator or other suitable instrument. If the wire is loose, tightening should continue. With practice, the operator will develop a "feel" for the mechanics of stainless steel

cerclage wire, as a rule, it is common to break wires as they are being applied, particularly for the inexperienced surgeon. If the wire breaks between the 2nd and 3rd twist or higher and is tight, it may be left in place, otherwise, it is removed. The wire should be left without cutting or otherwise manipulating the ends until all cerclage wires have been placed, and then checked again for tightness. Care should be taken not to notch or otherwise damage the wire that is going to stay in the animal as even a small notch will greatly decrease the fatigue resistance of the wire.[12] Loose wires should either be retightened or removed and replaced. If the wires were placed for temporary fixation, for example to hold the fracture in reduction while applying a bone plate, they may be removed prior to final tightening of the plate screws.

Twist wires should be cut to preserve at least 2 to 3 twists. It has been shown that wiggling the wire during cutting can substantially decrease the tension in the twist wire.[13,14] Wire ends should not be bent over with twist wires utilized for full cerclage (as opposed to hemicerclage or wire used in pin and tension band fixations).

Loop wires may be applied using either commercially available or hand-made loops. The cerclage wire is placed as described above for twist wires, and the free end passed through the eye of the loop. The loop wire tightener is passed over the free end of the wire, which is passed through the crank of the tightener. The wire is tightened by turning the crank until it can no longer be moved. Tightness of the wire can be checked with a periosteal elevator or other suitable instrument. The wire is then bent over until the free end folds back on itself, maintaining tension on the wire during this step. The crank is then reversed until enough length of wire is exposed so that it can be cut, and the arm is pressed flat to the bone. A double loop wire is made by taking a suitable length of wire, folding it in half, passing it around the bone as described above, and passing the two free ends through the loop. A double loop tightener with two cranks is used to tighten the wire as described above for the single loop wire.[15]

For all types of wire, it is important that they are tightened perpendicular to the long axis of the bone, rather than perpendicular to the fracture line as they will slip down perpendicular to the bone when exposed to weight-bearing forces and become loose. In an area where the bone diameter is changing and wire slippage may occur, the use of a Kirschner wire to prevent slippage as a "skewer pin" may be indicated (Figure 49-6). The K-wire is placed perpendicular to the fracture line, and the cerclage wire is placed around it and tightened so that the ends of the K-wire prevent it from slipping. Skewer pin configurations are not as strong as lag screw fixations, but may be considered for the treatment of short oblique fractures if supported by another device.[16]

Cerclage wires should be placed at least one-half of the diameter of the bone apart. Multiple cerclage wires should always be used unless they are being used to prevent propagation of fissures. In the author's opinion, the operator should also keep in mind that if more than four or five cerclage wires are being placed, that the possibility for excessive stripping of the soft tissues exists and another type of fixation should be considered (See figure 49-6).

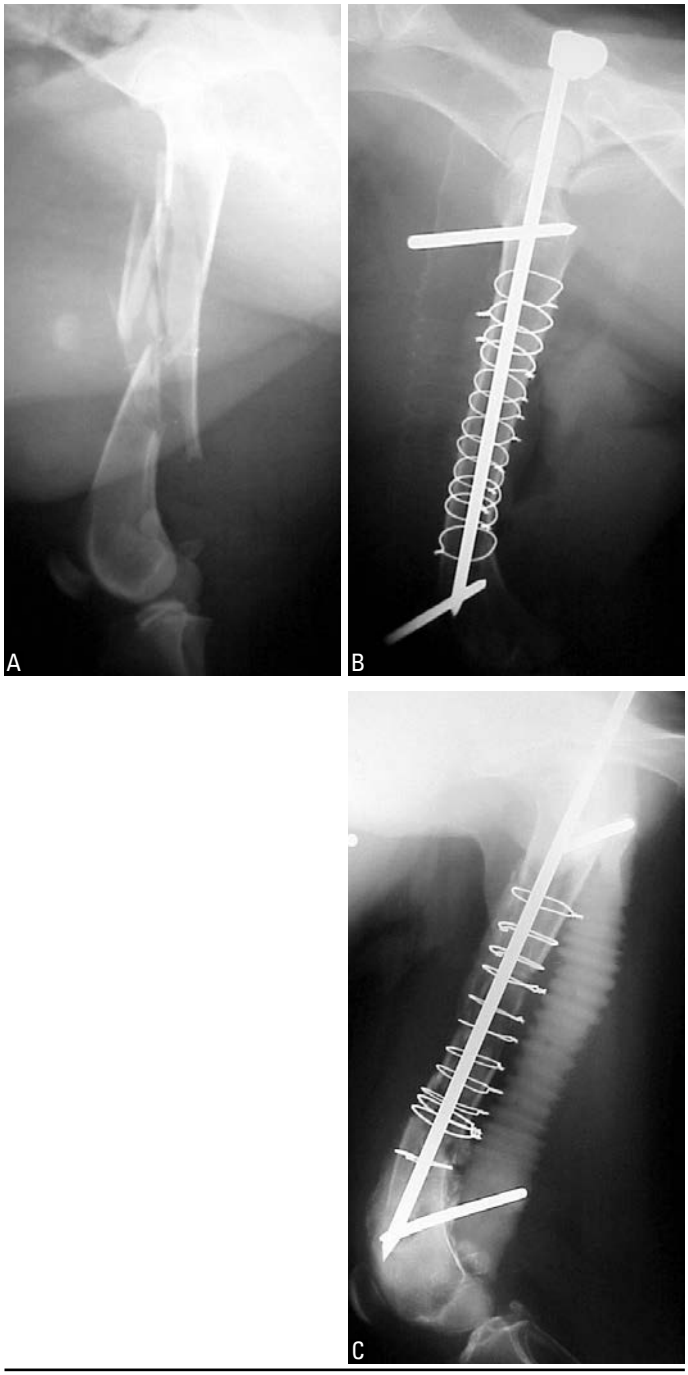


Figure 49-6. A. Comminuted femoral fracture in a 5 year old FS German Shepherd Dog. **B.** Post-operative repair with external fixation and cerclage. **C.** Eight weeks post-operative, osteomyelitis and sequestrum formation likely exacerbated by loss of blood supply due to extensive approach required to apply 12 cerclage wires.

Contraindications

Full cerclage wires are contraindicated in the treatment of transverse, short oblique (with the possible exception of a skewer pin configuration), segmental or multi-fragmented fractures. When evaluating preoperative radiographs of fractures, all of the fragments, even tiny ones, should be counted and if there are more than three, another method of fixation should be considered. Full cerclage are also contraindicated if, for any reason, the full 360 degrees of the shaft cannot be reconstructed, or the shape of the bone is such that wires cannot be applied so that they will sit

perpendicular to the long axis of the bone without slipping. Loose or damaged cerclage wires should always be removed. Finally, the surgeon should balance the risk of damage to the blood supply and potential for a nidus of infection in high-velocity, open or infected fractures and as a general rule, cerclage wire fixation is contraindicated for these types of fractures.

Complications and their Prevention

Properly applied cerclage wires rarely cause problems, however, improperly applied wires are almost always problematic. Loose wires, the most common complication, usually occur either as a result of failure to completely reduce the fracture or because of improper tightening techniques. In the author's experience, cerclage wire failure most frequently occurs when wires are utilized inappropriately on short-oblique or multi-fragmented femur fractures, usually combined with an intramedullary pin in large breed dogs. Loose wires very effectively prevent revascularization of the area around the fracture, and sequestration of dead bone fragments with collapse and rotational instability of the fracture are the end results (Figure 49-7). Prevention of complications depends upon careful case selection and proper application techniques, as described above. A failed pin and cerclage wire fixation can be devastating for the animal and in some cases may be irreparable, even if referred to a specialist with access to all types of orthopedic equipment.

Hemicerclage wire

Hemicerclage wire refers to wire that has been passed through at least one hole drilled through the bone. Although hemicerclage configurations have been reported for the treatment of rotational instability in long bone fractures, in practice they are very weak,[17] reaching only about 3% of the load in Nm of an intact construct and absorbing only 2% of the energy that an intact construct can absorb prior to failure during mechanical testing.[18] Hemicerclage wire applied to long bone fractures may also only be effective if rotational instability occurs in only one direction. Biomechanical testing of a variety of interfragmentary wire designs, either with hemicerclage wire, or combined cerclage wire and K-wire applications showed that a biplanar 90° configuration with wire and cross pin configuration had the highest torsional yield load and safe load,[18] however, this configuration would be difficult to apply clinically and has yet to be tested in vivo.

Hemicerclage is primarily used where applied loads are low, for example in the treatment of mandibular, maxillary and some skull fractures. Considerations for applying these wires include avoiding tooth roots and angling drill holes such that it is easy to grasp the wires and pull them through the bone to allow tightening. Holes drilled for application of hemicerclage wires should be at least 2 implant diameters away from the fracture line to prevent them pulling through or fracturing the fragment as they are carefully tightened. Unlike full cerclage wire, hemicerclage wire is not prone to loosening after being tightened down to the bone and it is acceptable to bend the wire ends over. Overtightening of hemicerclage wire will cause bone failure and pull-out of the wire. Attention should be paid to pulling as much "slack" from the wire prior to tightening, and also to twisting the wire halfway between two points of fixation so the twist does not sit at the level of the drill hole and prevent further tightening.



Figure 49-7. A. Lateral radiograph of a comminuted, closed diaphyseal humeral fracture in an 11 month old German Shepherd Dog. **B.** Lateral post-operative radiograph of repair with intramedullary pins and 4 loop cerclage wires. Note that the distal-most wire is very close to the fracture line. **C.** Rotational instability evident at 8 weeks, distal wire has loosened.

References

1. Blass CE, van Ee RT, Wilson JW. Microvascular and histological effects on cortical bone of applied double-loop cerclage. J Am Anim Hosp Assoc 27:432,1991.

2. Rhinelander FW, Wilson JW. Blood supply to developing, mature and healing bone. In: Sumner-Smith G, ed. Bone in clinical orthopedics. Philadelphia: WB Saunders, 1979, p.162.

3. Ellison GW, Piermattei DL, Wells MK. The effects of cerclage wiring on the immature canine diaphysis: a biomechanical analysis. Vet Surg 11:44, 1982.

4. Wilson JW. Effect of cerclage wires on periosteal bone in growing dogs Vet Surg 16:299, 1987.

5. Nye R, Egger E, Huhta J, Histand M, Mallinckrodt C. Acute failure characteristics of six methods for internal fixation of canine femoral oblique fractures. Vet Comp Orthop Traum 9:106, 1996.

6. Kanakis TE, Cordey J. Is there a mechanical difference between lag screws and double cerclage. Injury 22:185, 1991.

7. Willer RL, Schwarz PD, Powers BE, Histand ME. Comparison of cerclage wire placement in relation to a neutralization plate: a mechanical and histological study. Vet Comp Orthop Traum 3:90, 1990.

8. Blaeser LL, Cross AR, Lanz OI. Revision of aseptic loosening of the femoral implant in a dog using cable cerclage. Vet Comp Orthop Traum 12:97, 1999.

9. Meyer DC, Ramseier LE, Lajtai G, Notzli H. A new method for cerclage wire fixation to maximal pre-tension with minimal elongation to failure. Clin Biomech 18:975, 2003.

10. Wilson JW. Knot strength of cerclage bands and wires. Acta Orthop Scand 59:545, 1988.

11. Bostrom MPG, Asnis SE, Ernberg JJ et al. Fatigue testing of cerclage stainless steel wire fixation. J Orthop Traum 8:422, 1994.

12. Oh I, Sander TW, Treharne RW. The fatigue resistance of orthopaedic wire. Clin Orthop Rel Res 192:228, 1985.

13. Roe SC. Evaluation of tension obtained by use of three knots for tying cerclage wires by surgeons of various abilities and experience. J Am Vet Med Assoc 220:334, 2002.

14. Rooks RL, Tarvin GB, Pijanowski GJ, Daly B. In vitro cerlage wiring analysis. Vet Surg 11:39, 1982.

15. Roe SC. Mechanical characteristics and comparisons of cerclage wires: introduction of the double-wrap and loop/twist tying methods. Vet Surg 26:310,1997.

16. Smith BA Kerwin SC, Hosgood G, et al. Mechanical comparison of two methods for interfragmentary fixation in a short oblique fracture model. Vet Comp Orthop Traum. 9:4, 1996.

17. Blass CE, Caldarise SG, Torzilli PA, Arnoczky SP. Mechanical properties of three orthopedic wire configurations. Am J Vet Res 46:1725, 1985.

18. Metelman LA, Schwarz PD, Hutchison JM, et al. A mechanical evaluation of the resistance of various interfragmentary wire configurations to torsion. Vet Surg 25:213, 1996.

19. Willer R. Cerclage wiring. In: Bojrab MJ (ed): Current techniques in small animal surgery 4th ed. Baltimore, Williams & Wilkins, 1998, p. 921.

20. Blass CE, Piermattei DL, Withrow SJ, Scott RJ. Static and dynamic cerclage wire analysis. Vet Surg 15:181,1986.

21. Cheng SL, Smith TJ, Davey JR. A comparison of the strength and stability of six techniques of cerclage wire fixation for fractures. J Orthop Traum 7:221,1993.

Intramedullary Pins and Kirschner Wires

Sharon C. Kerwin

Definition and Indications

Devices used in the medullary cavity of long bones, such as intramedullary rods or nails, are designed to act as non-compressing splints. A gliding splint allows compression caused by physiologic loading conditions, while a non-gliding splint incorporates features that prevent fragment compaction, for example an interlocking nail. The terms "rod" and "nail", while sometimes interchanged, are not equivalent. A rod is loosely applied, so that contact with endosteal bone is limited. Examples of use of a rod would be a rod suspending a roll of paper towels, allowing free movement between the paper towel tube and the rod, or typical veterinary use of an intramedullary Steinmann pin. In the veterinary literature, the term "pin" is often used interchangeably with "rod". A nail is tightly applied to the endosteal bone to the point of firm wedging, just like a carpenter's nail driven into a board, displacing wood and becoming firmly wedged.[1]

Types of Implants Available

Intramedullary pins (IM pins) used in animals range from ¼ inch diameter (6.3 mm) down to 5/64 inch diameter (2.0 mm). Intramedullary pins in this size range are called Steinmann pins. Smaller pins are usually referred to as Kirschner wires (K-wires), and although they may be used as intramedullary devices in very tiny animals, they are generally used as interfragmentary devices. K-wires are available in .035, 0.045, .054 and .062 inch diameters. Intramedullary pins and K-wires can be obtained as fully threaded, partially threaded or nonthreaded. Although some surgeons use partially (end) threaded pins for intramedullary pins with the intention of increasing rotational stability, in fact those pins do not provide additional rotational stability (Figure 49-8) and are at risk for breakage at the thread-shaft interface or in the weaker threaded portion (Figure 49-9). In addition, fully or partially threaded Steinmann pins and K-wires are more difficult to remove as the bone tends to grow into the threads. For these reasons, the use of threaded pins as intramedullary devices is not recommended.

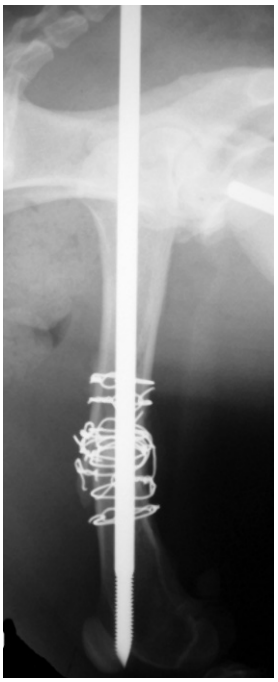


Figure 49-8. Use of a partially threaded intramedullary Steinmann pin and cerclage wires for the treatment of a comminuted femoral fracture in a 5 year old male Labrador retriever. The fracture collapsed within days due to the inability of the pin and wires to sustain rotational forces. In addition, the intramedullary pin has migrated into the joint.

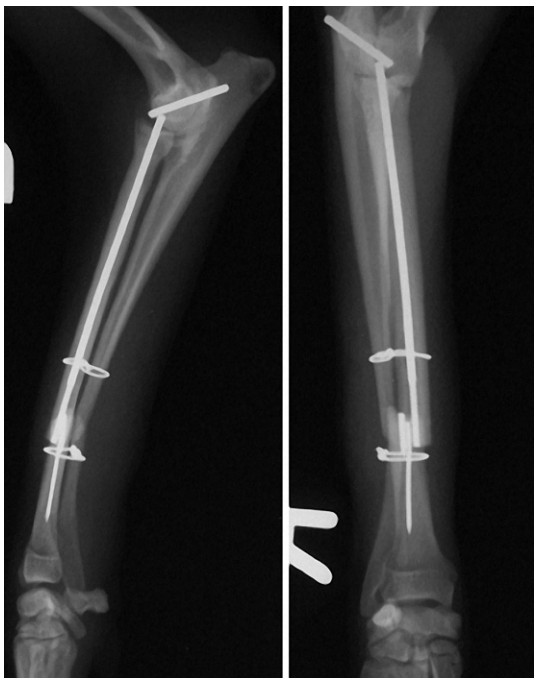


Figure 49-9. Lateral and ventrodorsal view of a radial fracture repair with a threaded Steinmann pin. The pin has broken in the weaker threaded portion at the level of the fracture line. An additional K-wire is present but was unable to control rotational stability. Note also that the Steinmann pin has broken proximally where it was normograded through the articular surface of the radius.

Steinmann pins and Kirschner wires are available in a variety of lengths, usually from 6 to 12 inches long, and may have points on one or both ends. Although most are manufactured from surgical grade 316L stainless steel, pure titanium K-wires are also available. The pins are easily cut, and there is no advantage to the veterinary surgeon in purchasing single pointed pins.[2] Pins may be manufactured with a trocar, chisel, diamond, or bayonet point (Figure 49-10). Trocar points are by far the most commonly used and consist of a three-sided tip with a long bevel and good ability to penetrate cortical bone. Chisel points (also called diamond points) are broad, flat two-sided points with a short bevel and are designed to deflect the pin away from the cortex during drilling rather than engage the opposite cortex. Some pins are available with a trocar point on one end and a chisel point on the other: the starting hole through the cortex can be drilled using the trocar point, and then the pin can be reversed if the surgeon desires for it to deflect off the far cortex. Bayonet points are "single-lipped" or "free cutting" points found on pins designed for transfixation pins for circular external fixators. The ends are such that they can easily penetrate soft tissues and can be tapped through cortical bone with a hammer after being partially drilled through the bone in an attempt to preserve blood supply. These pins also come with "stoppers" in the middle and may be called "olive wires", which may be used to pull a fragment into alignment or allow decreased translation of a bone segment within an external fixator frame (Figure 49-11).

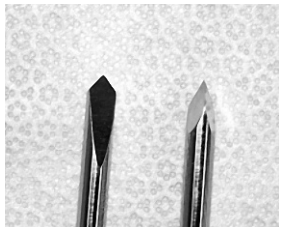


Figure 49-10. Different types of points available on Steinmann pins and Kirschner wires. The pin on the left has a chisel point, while the pin on the right has a trocar point.

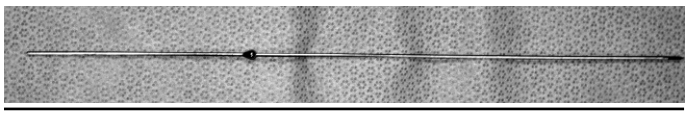


Figure 49-11. Olive or stopper wire. Note the "stopper" placed about 2/3 of the length of the pin away from the cutting tip.

Intramedullary pins excel in resisting bending forces in 360 degrees, can be placed with relatively little in the way of specialized equipment, and often can be placed with a limited approach. Intramedullary pin placement, unless a very large pin is placed or reaming of the medullary cavity is performed, has limited impact on the intramedullary blood supply. Intramedullary pins are relatively easy to remove, in contrast to fixation devices such as lag screws or plates. Intramedullary pins do not prevent rotation or counteract axial forces, and therefore are rarely used alone but combined with other types of fixation, for example cerclage wires, external fixators, plates, and lag screws. From a mechanical standpoint, use of the largest pin possible will result in the stiffest construct and most resistance to bending (Table 49-3). However, use of an excessively large pin has several disadvantages: difficult placement in a curved bone, for example the canine tibia and femur, damage to the intramedullary blood supply, and risk of creating additional fractures if the pin exceeds the diameter of the bone at its' narrowest point, or isthmus. In general, a pin that is approximately 70% of the diameter of the long bone at the isthmus is chosen. If the surgeon anticipates combining the pin with another type of device, such as an external fixator, lag screw or plate, a slightly smaller intramedullary pin is chosen. Use of a pin that is too small may

Table 49-3. Area Moments of Inertia for Steinmann pins and Kirschner Wires[12]

Diameter (inches)	Diameter (mm)	Area Moment of Inertia (mm^4)
1/4	6.3	80
3/16	4.8	24
5/32	4.0	12
9/64	3.5	8
1/8	3.2	5
7/64	2.8	3
3/32	2.4	1.5
5/64	2.0	0.8
0.062 (1/16)	1.6	0.3
0.054	1.4	0.10
0.045	1.2	0.12
0.035	0.9	0.05

result in failure by pin bending or breakage (Figure 49-12). Use of multiple small pins to fill the medullary cavity, also called "stack pinning" to increase resistance to rotational stability, has been shown not to increase rotational stability significantly more than single intramedullary pinning.[3]

In addition to using ancillary devices to control rotational and axial forces on the bone with IM pins, modifications to the pins themselves, including placement of screws through holes across the pin (interlocking nail construct) and modification of the pin itself can be used. A recent example of this in the veterinary literature is the Trilam nail, a stainless steel intramedullary device designed with three "lamellae" extending down its length to counteract rotational forces. The nail is driven with a mallet into the medullary cavity without reaming, such that the three lamellae cut into the inner cortical bone, making it a true nail. Successful use of the Trilam nail in dogs and cats for the treatment of femoral, tibial and humeral fractures has been reported.[4]

K-wires, while they can be used as intramedullary devices, are usually used as interfragmentary devices, often to maintain temporary fracture reduction while the primary fixation (eg a plate) is applied. K-wires by themselves are relatively weak implants (See Table 49-1) and are not generally used alone. In certain fractures, for example physeal fractures in small dogs and cats, cross-pinning with K-wires can be sufficient when fracture healing is expected to be rapid. K-wires are also commonly utilized in combination with cerclage wire for tension-band fixations and to support full cerclage wires in areas of changing bone diameter ("skewer wires").

K-wires have also been modified to improve their anti-rotational characteristics, for example, the Orthofix self-compressing pin recently reported in the treatment of humeral condylar fractures in small breed dogs.[5] These pins are small diameter (1.2 to 2.2 mm threaded segment, 1.5 to 3 mm shaft) pins are designed for use in cancellous bone. As the pin is drilled, the threaded portion cuts a thread into the cancellous bone. When the pin's chamfer (location of the thread-shaft interface where the diameter of the pin increases) contacts the near cortex, further advancement of the implant partially strips the threads cut in the bone in the near fragment, while the threads in the far cortex maintain purchase, leading to interfragmentary compression.



Figure 49-12. Lateral radiograph of a femoral fracture in a dog repaired with an intramedullary pin and cerclage wire. The intramedullary pin diameter is insufficient and has led to failure in bending (rotational instability is also present).

Application Techniques for Intramedullary Pins and Interfragmentary Wires

Intramedullary pins may be inserted either from the fracture site (retrograde insertion) or from either the proximal or distal end of the bone itself (normograde insertion). The local anatomy of the bone often dictates how the pin is driven, for example, retrograde pin insertion in the tibia often results in damage to the articular cartilage or cruciate ligaments. An estimation of appropriate pin size (60 to 75%)[6] may be made from the post-operative radiographs and may be confirmed by observation of the pin as it is gently introduced into the fracture site, even if normograde insertion is planned. If in doubt, a smaller pin should be used initially and replaced with a larger pin if necessary. The pin may be inserted either open or closed. Although closed pinning, based on palpation, can be performed by the experienced surgeon this can become more difficult in larger animals with soft tissue swelling, or in fractures greater than 72 hours old. The increased use of intraoperative imaging (fluoroscopy) can greatly facilitate IM pin placement in a minimally invasive fashion, with less damage to the soft tissues.

Intramedullary pins may be placed either by hand, using a Jacobs' chuck (Figure 49-13), or with a drill. Hand insertion may allow the surgeon to feel whether or not the pin is advancing down the medullary cavity and whether it is up against or about to penetrate cortical bone. When placing pins by hand with a Jacobs' chuck, the smallest amount of pin possible that will allow the pin to advance should be used, in order to prevent "wobble", particularly when smaller pins are used. The chuck should be firmly tightened with the key in at least two separate places to avoid sudden loosening during pin advancement. Although Jacobs' chucks are sold with protective devices that are designed to protect the surgeon's hand from inadvertent pin penetration resulting from sudden pin loosening, in practice many surgeons place the palm of their gloved hand over the end of the pin to gain mechanical advantage. The tip of the pin should firmly engage bone, and the pin rotated back and forth with quarter



Figure 49-13. Jacob's chuck with appropriate length of pin extending from tightened chuck. Note the protective guard that has been threaded into the main body of the chuck.

turns (rather than driven consistently clockwise or counter-clockwise) while avoiding any "wobble" that may enlarge the proximal hole made by the pin and predispose to pin loosening. In larger animals with hard cortical bone, hand placement can be very difficult. In addition, the smaller the pin the more difficult it is to drill by hand and power insertion is mandatory for inter-fragmentary K-wires.

When using a drill to insert an intramedullary pin or K-wire, a cannulated drill should be used to drive the pin to decrease the amount of wobble and the risk of pin bending or breakage during drilling. A high-torque, low speed drill should be used (as opposed to a high speed drill) to decrease heat generation and subsequent bone necrosis. Saline lavage is also important to decrease heating of the bone, particularly with K-wire insertion. When driving an intramedullary pin, whether by hand or with power, it is important to carefully line up the pin with the shaft of the long bone. During open reduction, the surgeon may find it easiest to drive the pin with one hand and stabilize the fracture segment by using a bone-holding forcep gripped with the non-dominant hand. Having an assistant hold a second pin parallel to the shaft of the long bone may be helpful, or in certain cases, placing an "aiming pin" retrograde just a few cm into the medullary cavity so the surgeon can attempt to drive the normograde pin along the axis provided by the aiming pin. When attempting to seat an intramedullary pin into metaphyseal bone, it is important not to accidentally penetrate the articular surface, for example in the distal femur. The surgeon will note an increase in resistance as the pin begins to seat into the metaphysis. In addition, the fracture fragments may begin to distract apart as the pin over-lengthens the bone as it is driven into the metaphysis. In a comminuted fracture, an IM pin may be used to help distract fracture fragments and assist with fracture reduction. As the sharp tip of the pin passes through the first of the two major fracture segments, it may be cut to help prevent penetration of the pin into the joint and will help distract the fracture. The distance that the pin has advanced may be judged by using a second pin of equal length and lining the two pins up after the Jacobs chuck has been removed. After the pin has been seated, the proximal and distal joints should be put through a complete range of motion, as it is easy to inadvertently place a pin into a joint. If available, intraoperative fluoroscopy is useful and much more efficient than closing the surgical approach, traveling to radiology, and returning to the operating room to redirect an implant. Immediately prior to wound closure, the surgeon should carefully palpate the soft tissues surrounding the bone for evidence of overly long or misplaced pins (Figure 49-14), which can be difficult to feel as they unexpectedly exit cortical bone during drilling.

After the pin is judged to be in the correct position, it is cut using specialized pin cutters. Pin cutters are generally designed only to cut pins of a certain range in diameter, and inadvertent use of small pin cutters to cut a large pin may result in permanent damage to an expensive piece of equipment. The surgeon should check the range of diameters listed on the side of the cutter (Figure 49-15). It is helpful to have an autoclavable pin guide (Figure 49-16) in the pack to determine the size of the pin in surgery. The surgeon should also avoid cutting the pin with



Figure 49-14. Radiographs of repair of a distal femoral fracture in a 2 year old cat taken immediately post-operatively. The crosspin is excessively long medially. Note that the intramedullary pin appears to be in the joint on the craniocaudal view but is not based on the lateral view.



Figure 49-15. Pin cutter with indication of maximum pin size that can be cut printed on the side, in this case, up to 2.2 mm or 0.086 inches (up to a 5/64 inch pin).



Figure 49-16. Autoclavable pin ruler that can be used intraoperatively to measure pin size.

bone cutters, which look very similar to pin cutters but will be irreparably damaged if used to cut stainless steel pins or wires. Autoclaved "hardware store" bolt cutters are acceptable but can be bulky and difficult to get into a surgical approach in some cases. Pins accumulate a lot of energy when cut and have the potential to cause serious injury to the surgeon, assistant or circulating technicians if the free end is not firmly grasped or covered with a Huck towel to prevent it from becoming a

projectile. The fracture should be carefully observed during and after pin cutting to make sure that alignment is not disrupted.

Controversy exists over whether to cut pins short or leave them long to facilitate pin removal. Leaving pins long can lead to problems with iatrogenic nerve damage (proximal femur), damage to nearby articular cartilage or patellar tendon (tibia), or soft tissue irritation with subsequent seroma formation or erosion of the tip of the pin through the soft tissues. The alternative to leaving pins long is to cut them short and countersink them, using a countersink and mallet. Many surgeons accomplish this by retracting the pin approximately 1 cm, cutting the pin as short as possible, and then placing the countersink over the top of the pin and tapping it in approximately 1 cm or until it is level with the proximal aspect of the bone (eg, greater trochanter of the femur).

Pin Migration

Steinmann pins and Kirschner wires can loosen and "migrate" out of the bone over time, and in fact have been reported to migrate large distances and penetrate organs including the brain and heart (noted after the use of DeVita pins for reduction of hip luxations),[7] or into a joint, as after pinning of a proximal femoral epiphyseal fracture. Where possible, it is helpful to bend the pin over using either a pin bender designed specifically for bending pins (Figure 49-17) or if such a device is not available, the Jacobs chuck or a metal Freer suction tip can be used to bend K-wires. The surgeon should be cautious when bending larger pins in soft bone or small fragments as the bone could fracture as the pin is being bent, or loss of reduction could occur if stabilization is marginal. Once the pin is bent, it is impossible for it to migrate towards its point, however, it can still migrate in the opposite direction.

Pin Removal

Pins should be removed if they are loose, irritate soft tissues, are in a joint or are infected. Although many surgeons routinely remove intramedullary pins, it has been our experience that stable pins do not need to be removed after the fracture has healed. In humans, there is controversy over whether or not pins should be removed, with one author noting that orthopedic surgeons with implants did not have their own hardware removed, citing a higher refracture rate after implant removal and no documented downside to leaving implants in.[8]

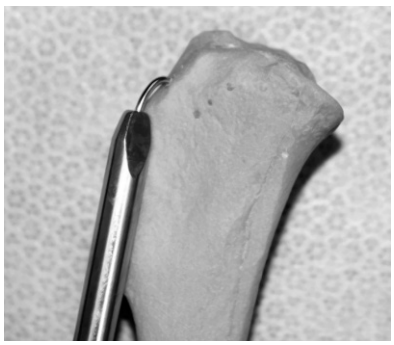


Figure 49-17. Use of a partially cannulated pin bender to bend a K-wire placed in a model of the proximal tibia.

Contraindications

Intramedullary pins alone should never be used for comminuted fractures that will collapse around the pin or fractures that will be rotationally unstable. Pins and cerclage, while effective if properly applied, are useful only for certain types of simple, closed fractures in animals with good healing potential. Although use of an intramedullary pin in an open or infected fracture has been thought to have the potential to spread infection along the medullary cavity, in fact, intramedullary devices can safely be used in infected fractures as long as they are stable.[9]

Complications and their Prevention

Complications associated with intramedullary pinning most frequently include damage to adjacent structures. Bones most amenable to intramedullary pinning include the femur, tibia, humerus and ulna. Pinning of the mandible results in damage to tooth roots and an unstable repair. Pinning of the radius cannot be performed without damaging an articular surface, and bent, broken or migrating pins in the radius are difficult to retrieve. As discussed above, specifics for each bone as to whether the pin should be normograded or retrograded, and how the pin is directed in the medullary cavity, are detailed elsewhere but should be reviewed prior to IM pin fixation.

A common mistake when driving an IM pin is to be slightly off at an angle away from the center of the medullary canal, resulting in the pin penetrating cortical bone prior to crossing the fracture line. If this occurs, the pin must be completely withdrawn and a new entry site drilled, as the pin will tend to fall into the same track that was originally made. If the pin is inadvertently penetrated into a joint, merely withdrawing the pin back into the medullary canal is not sufficient, as once the animal begins to bear weight the pin will migrate into the joint. If possible, the pin may either be withdrawn and replaced with a slightly larger pin, or withdrawn and redriven at a slightly different angle to prevent it from entering the original hole into the adjacent joint.

Post-operative radiographs of the entire bone, in two orthogonal views must always be made post-operatively to confirm pin placement and fracture reduction. Pins that have penetrated a joint should always be removed, as severe damage can occur even within a few days to weeks. If pin migration is noted prior to fracture healing, the fracture is unstable and reinsertion of the implant will not solve the problem. It may lead to infection particularly if a tip of the implant has penetrated the skin. Repeat radiographs should be obtained, and an alternative plan made to address fracture instability with a different form of fixation.

Pulmonary fat embolism is a fairly common complication associated with the introduction of intramedullary devices in humans, and has been reported as a cause of morbidity in dogs during total hip replacement.[10] Although pulmonary fat embolism is not commonly recognized in small animals associated with IM pins, one well-documented case has been reported to cause fatality in a cat,[11] and the surgeon and anesthetist should be aware of the risk and appropriate intra-operative monitoring performed, particularly in animals with pre-existing pulmonary trauma or disease.

References

1. Chandler RW. Principles of internal fixation. In: Rockwood CA, Green DP, Bucholz RW, Heckman JD (eds) Rockwood and Green's Fractures in Adults. Philadelphia, Lippincott-Raven 1996: 165-179.

2. Howard PE. Principles of intramedullary pin and wire fixation. Seminars in Veterinary Medicine and Surgery (Small Animal) 6:52,1991.

3. Dallman MJ, Martin RA, Self BP, Grant WJ. Rotational strength of double-pinning techniques in repair of transverse fractures in femurs of dogs. Am J Vet Res 51:123, 1990

4. Hach V. Initial experience with a newly developed medullary stabilization nail (Trilam nail). Vet Comp Orthop Traum 13:109,2000.

5. Guille AE, Lewis DD, Anderson TP et al. Evaluation of surgical repair of humeral condylar fractures using self-compressing orthofix pins in 23 dogs. Vet Surg 33:314, 2004.

6. Piermattei DL, Flo GL. Brinker, Piermattei and Flo's Handbook of Small Animal Orthopedics and Fracture Repair, 3rd ed. Philadelphia, WB Saunders, 1997: 95.

7. Nunamaker, DM. Fractures and dislocations of the hip joint. In: Textbook of Small Animal Orthopaedics. Philadelphia, J. B. Lippincott, 1985,403.

8. Beadling L. Nancy nailing: a pediatric innovation for contemporary society. Orthopedics Today 25:26, 2005.

9. Muir P, Johnson KA. Interlocking medullary nail stabilization of a femoral fracture in a dog with osteomyelitis. J Am Vet Med Assoc 209:397, 1996.

10. Terrell SP, Chandra AMS, Pablo LS, Lewis DD. Fatal intraoperative pulmonary fat embolism during cemented total hip arthroplasty in a dog. J Am Anim Hosp Assoc 40:345, 2004.

11. Schwarz T, Crawford PE, Owen MR et al. Fatal pulmonary fat embolism during humeral fracture repair in a cat. J Small Anim Pract 42:195, 2001.

12. Muir P, Johnson KA, Markel MD. Area moment of inertia for comparison of implant cross-sectional geometry and bending stiffness. Vet Comp Orthop Traum 8:146,1995.

Tension Band Wiring

Karl H. Kraus

Introduction

Tension banding is a technique by which tensile forces are converted into compressive forces. This principle can be applied to the repair of fractures in which a fragment is distracted from its original position by the pull of a muscle, tendon, or ligament. The area of fracture opposite the pull under tension is termed the tension side of the fracture. If the tension side of the fracture is fixed with a tension device, the device pulls in a vector which counters the distractive force. If the force of the distractive pull is not in a straight line with the tension device, the force of the distractive pull is redirected to a resulting vectoral force which is a compressive force across a fracture or osteotomy (Figure 49-18).

Indications

Indications for use of tension band wires include repair of fractures or osteotomies of the acromion of the scapula, supraglenoid tubercle, greater tubercle of the humerus, olecranon, greater trochanter of the femur, supracondylar epiphysis of the femur, medial malleolus of the tibia, tuber calcis, tibial tuberosity, and attachments of collateral ligaments. This is a commonly used technique because these are frequent sites of fracture and osteotomies for surgical approaches. A tension band wire can be successfully applied in many situations, if principles of application are followed and proper technique is used.

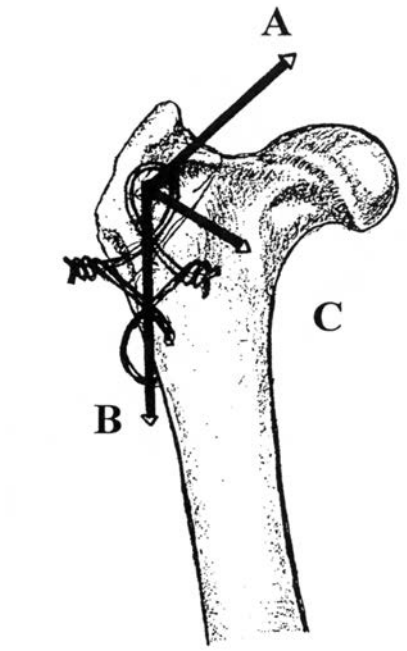


Figure 49-18. The pull of a muscle, tendon or ligament *A.* when countered with the opposing pull of a tension band device *B.* results in a compressive force across the fracture or osteotomy *C.*

Technique

Before a tension band wire is applied, the direction of the distractive forces should be estimated. Because forces can change through the range of motion of a joint, the "average" distractive force should be estimated. The tension band should be applied to the side opposite the distractive forces, the tension side of the fracture or osteotomy.

After the fracture or osteotomy is reduced, two orthopedic pins (Kirschner wires) are inserted from the distracted fragment across the fracture line and into the attaching bone (Figure 49-19A). Two pins are used whenever possible to provide rotational stability. The pins should be applied parallel to the direction of desired compression and so that an orthopedic wire placed over them applies even, undeterred pressure to the tension side of the fracture. These pins should be seated in cortical bone in the opposite cortex to prevent migration.

With a drill or orthopedic pin, a hole is drilled through the cortex to accommodate the tension band wire. The distance of this hole from the fracture line should be such that the figure-of-eight wire does not cross directly over the osteotomy. A section of 0.8 mm, 1.0 mm or 1.2 mm orthopedic wire is looped one-third of the distance from one end. The short end is inserted through the hole in the cortical bone, and the long end with the loop is brought

over the two orthopedic pins in a figure-of-eight pattern, and is twisted to the other loose end (Figure 49-19B). The preplaced loop and twisted ends are tightened alternatively or with the help of an assistant so the wire is evenly tightened (Figure 49-19C). The orthopedic wire should be cut, leaving three to four twists, and bent toward the bone. The Kirschner wires are bent over the tension band wire and are cut to secure it (Figure 49-19D and 49-19E). The ends of the wires are seated against bone. Aftercare of the tension band wire itself is minimal. No more that standard exercise restriction is required.

Complications

Complications are uncommon and are usually the result of improper technique. The six most common technical errors resulting in failure are depicted in Figure 49-20. The first error is having too small a fragment to accommodate an appropriately sized tension band device. Fractures and avulsions can be small, and applying a proper tension band may be difficult. More commonly, however, this error occurs when performing an osteotomy for a surgical exposure, such as an osteotomy of the greater trochanter of the femur or tibial tuberosity. Too small a fragment will break resulting in failure of the tension band. One usually avoidable technical error is the placement of only one pin. Because the vector of the distracting muscle, tendon, or ligament pull may change through a range of motion, there may be a torsional force across the fracture. Two pins prevent rotation. Small avulsion fragments may only accommodate a single pin. However, placing two smaller pins should be used before one larger pin whenever possible. Use of a loop instead of a figure-of-eight wire is an avoidable technical error. A loop tends to center the compression more toward the pin and allows the fracture line on the tension side to distract. Heavy-gauge wire should be used. Although 1.2 mm to 0.8 mm wire may seem difficult to manipulate, smaller wire is rarely appropriate even in

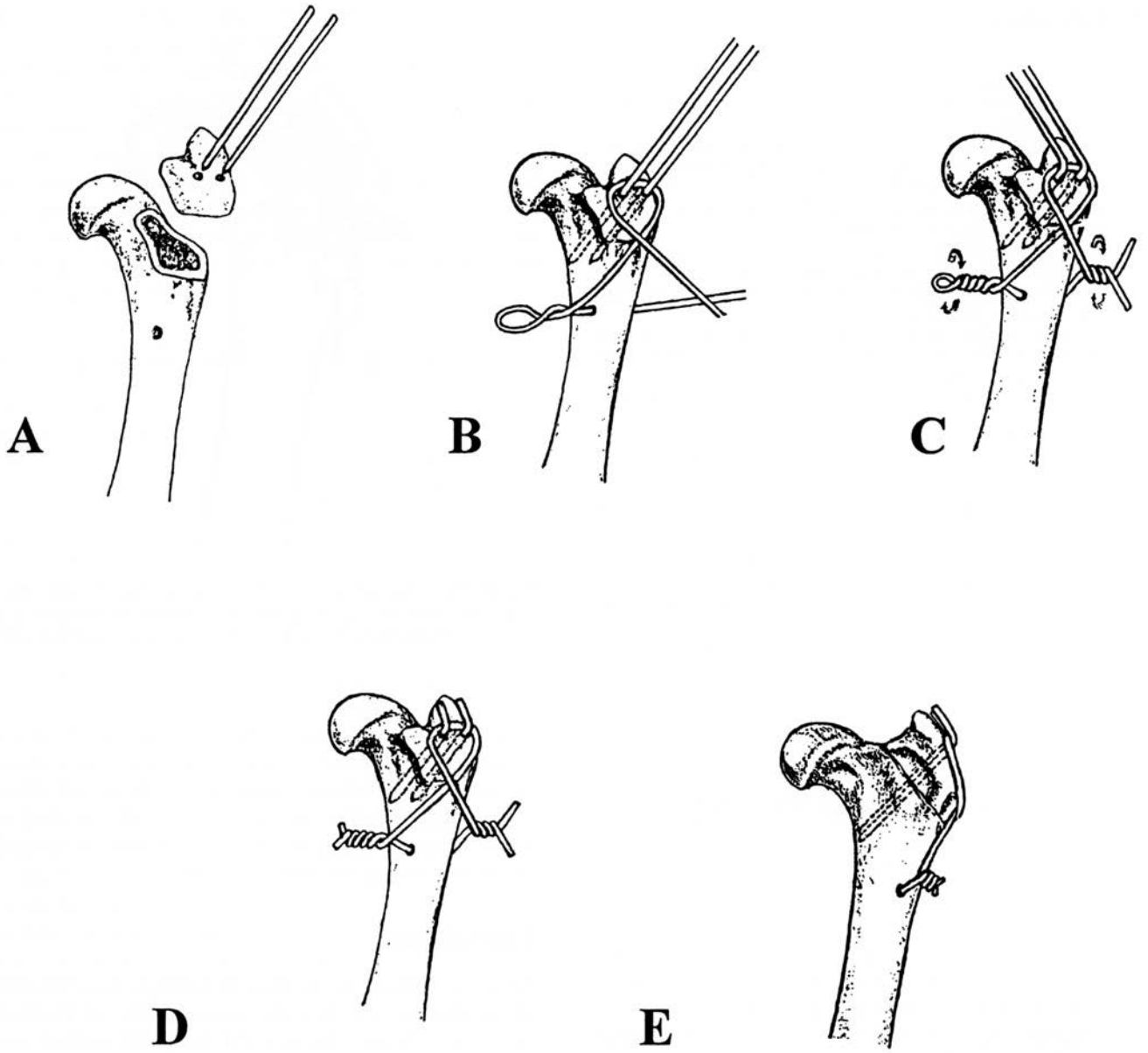


Figure 49-19. Application of a tension band wire. **A.** First the fragment is replaced, and two pins or Kirschner wires are driven perpendicular to the fracture line. **B.** A figure-of-eight wire is placed over the pins and through a hole in the cortex. **C.** The wires are twisted and tightened alternatively. **D.** and **E.** The pins and wires are bent, cut, and seated next to the bone.

small animals. The hole in the bone anchoring the tension band wire should engage enough material to counter the force of the tension device. These forces can be substantial. The pins should be anchored into the opposite cortex. Failure to do so can allow the pin to migrate.

Suggested Readings

Kraus KH. Tension band wiring. In: Bojrab MJ, ed. Current techniques in small animal surgery. 4th ed. Philadelphia: Williams & Wilkins, 1998:925.

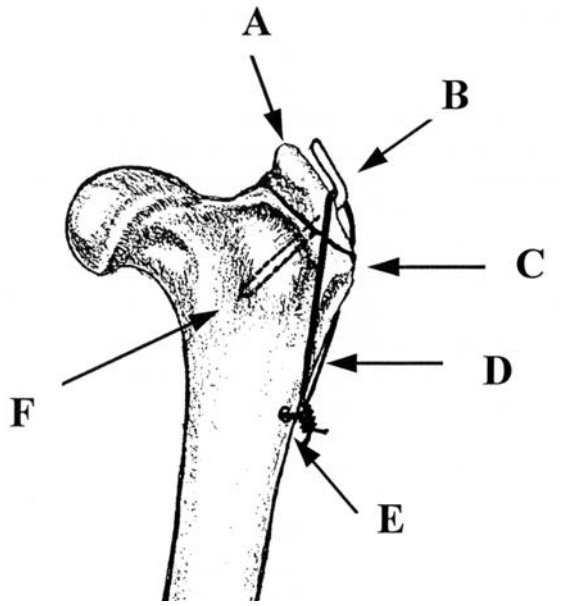


Figure 49-20. Six common errors in placing a tension band wire: *A.* bone fragment is too small; *B.* only one pin is used; *C.* the wire forms a loop and not a figure-of-eight; *D.* too small a gauge of wire is used; *E.* the hole in the cortex does not engage enough bone; and *F.* the pins are not seated in the opposite cortex.

Chapter 50

Interlocking Nailing of Canine and Feline Fractures

Interlocking Nailing of Canine and Feline Fractures

Kenneth A Johnson

This chapter was submitted in 2006 and was based upon the available literature through that year. Other interlocking nail devices have emerged since that time, but are not covered in this chapter.

Introduction

The principles of management of diaphyseal fractures of the femur, tibia and humerus by internal fixation have evolved considerably from the original AO concepts of complete anatomical reduction and rigid stabilization of all the fractured fragments. Nowadays, the concept of biological management of diaphyseal fractures places greater emphasis on less invasive surgical approaches, and preservation of the bone blood supply and the fracture hematoma, especially in cases of comminuted non-reducible fractures. Overall alignment and stabilization of the proximal and distal fragments are obtained without interference with the intermediate comminuted fracture fragments. Interlocking nail fixation is the method of choice for the stabilization of diaphyseal fractures of the femur and tibia in adult humans.[1] In recent years, it has become more widely accepted as a method of treating diaphyseal fractures in small animals as well.[2-8]

Principles of Interlocking Nailing

Interlocking nailing evolved as a modification of intramedullary fixation using Steinmann pins for the stabilization of diaphyseal fractures in small animals. Intramedullary pinning of fractures in animals was first introduced about sixty years ago. While this method often resulted in successful fracture healing, complications due to fracture instability, fracture collapse, pin migration, and sciatic nerve entrapment were not uncommon. Intramedullary pins provide good stability against bending loads during the fracture healing period, provided that the chosen pin is of adequate diameter and stiffness. This is due to the fact that intramedullary pins are located in the neutral axis of loading within the medullary canal, and as such they are more resistant to bending loads than bone plates and other extracortical fixation devices. However, intramedullary pins are quite ineffective at counteracting axial compressive and torsional loads, especially in the case of comminuted fractures. Therefore the basic principle of interlocking nail fixation is that insertion of locking bolts securing the proximal and distal fragments to the nail, counteracts the axial and torsional loads, making the fracture fixation construct much more stable overall.

Types and Sizes of Nails

Several different systems of interlocking nails designed for canine and feline fractures have been developed by surgeons from various countries, world wide.[2-9] In principle, all these interlocking nails function in a similar manner, but they differ somewhat in regard to the instrumentation used for their application. The most widely used interlocking nails in North America (Innovative Animal Products, Rochester, MN) are round in cross section and made from 316L stainless steel that has been cold worked to increase stiffness and fatigue life in vivo. The nails are available in various diameters (4.0, 4.7, 6.0, 8.0 and 10mm) and lengths. An implant of appropriate dimensions (diameter and length) must be selected to match the patient's fractured bone because the nail is not usually cut to length during surgery. One end of the nail has a sharpened trocar point to facilitate insertion into the medullary canal. The other end of the nail is machined with two flanges and an internal thread to allow for precise attachment of the drill-aiming guide during surgery. Typically each nail has two non-threaded transverse holes near to each end, for the insertion of locking bolts. The spacing between these pairs of holes is either 11 mm or 22 mm. The closer hole spacing allows for the insertion of two locking bolts when there is limited metaphyseal bone available. In addition, nails are also available with just one hole proximally or one hole distally for the stabilization of fractures near to the metaphyses, in which case there is less available bone for interlocking (Figure 50-1).

Locking bolts are inserted transversely through the bone and holes in the nail with the aid of a special drilling aiming guide. This instrumentation is described in further detail in the following section about application. The locking bolts have a smooth shaft with four self-tapping threads under the bolt head, to engage the near bone cortex. The shaft of the bolt is almost the same diameter as the nail holes, with just a small under-sized tolerance to prevent jamming during insertion. Prior to the availability of locking bolts, conventional cortical bone screws were used for locking. However, the use of screws for this purpose is no longer recommended, because of their inferior mechanical performance; failure of screws by bending or breakage was occasionally a problem clinically.[10,11] During the course of fracture healing, the locking bolts are mainly loaded by bending or quasi-bending forces. Under these conditions, the stiffness and fatigue life of the locking bolt are determined by its area moment of inertia which is calculated using the formulae of π x radius^4/4. For example, the calculated area moment of inertias for the 2.7 mm diameter locking bolts and cortical screws are 2.61 mm^4 and 0.64 mm^4 respectively.[12] In the case of the cortical screw, this value is much lower because the core diameter of the screw is only 1.9 mm. Under conditions of cyclic bending the fatigue life of the 2.7 bolt is over 140 times greater than that of the 2.7 cortical screw.[13] The diameter of the medullary canal at the level of the locking bolt is also an important factor when considering the mechanical performance of the locking bolt.[14] The bending moment on the bolt is proportional to the unsupported length of the bolt within the medullary canal. Therefore in large breed dogs, the bending load on the locking bolt may be considerable in the metaphyseal region where the bone has a relatively greater diameter. In bones that are ovoid in cross section, it may be possible to reduce the bending load on the locking bolt by orienting it in the direction of the shorter cross-sectional axis of the bone.

Another advantage of using locking bolts instead of cortical screws is that bolts more effectively control torsional instability of the construct. With loading, the threads of cortical screws in the region of contact within the nail hole become deformed and flattened.[15] This effectively reduces the outside diameter of the screw, and allows for greater torsional slack in the construct in comparison to locking bolts.[16,17]

Techniques of Application of Interlocking Nails

Preoperative radiographs of the fractured bone are needed for surgical planning and selection of an appropriately sized nail. The radiographic views need to be true medio-lateral and cranio-caudal projections, with minimal magnification or distortion of bone length. In case of comminuted fractures, radiographs of the contralateral intact bone may be more useful for preoperative planning. The length and diameter of the nail to be inserted can be estimated by overlaying the radiograph with a transparent plastic sheet with the outline of the nail templates printed on it. When using digital radiography, it is necessary to use an internal radiographic marker of known length for calibration of the radiographic magnification, and to import digital templates of the nails for planning.[18]

In case of diaphyseal fractures that are near to the metaphysis, there must be sufficient bone available for seating of the nail and the locking bolt(s), without invading the adjacent joint. Some juxta-articular fractures will not be suitable candidates for interlocking nailing because there is insufficient bone stock for implant fixation. In these cases, alternative means of fixation such as bone plating or hybrid external fixation may provide better stability.

An open surgical approach using appropriate aseptic surgical technique is needed for insertion of the interlocking nail and

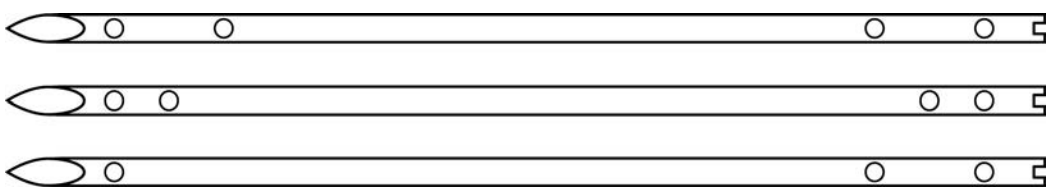


Figure 50-1. Interlocking nails for stabilization of canine and feline fractures have a trocar point for insertion, and one or two holes at each end of the nail for locking.

screws. The extent of the surgical exposure required is influenced by factors such as ease of fracture reduction, the volume of musculature in the region, and how readily the bone can be palpated. Fluoroscopically guided closed nailing of tibial fractures is possible, but closed nailing of femoral fractures in dogs is more challenging. Even if a closed nailing is performed, it will be necessary to make some limited incisions over the proximal and distal ends of the bone for insertion of the nail and locking bolts. Bone holding forceps can be applied to bone through these incisions as well, to allow alignment of the fractured bone. Axial traction is applied to the bone using these bone holding forceps to obtain fracture reduction. For fractures in the metaphyseal region, indirect traction by ligamentotaxis is applied. As far as possible, direct exposure of the fracture hematoma and elevation of the soft tissue attachments of the fractured bone fragments should be minimized.

A small diameter Steinmann pin held in a Jacob's chuck is introduced into the medullary canal to establish axial alignment of the fractured bone. Normograde insertion of the pin is recommended for femoral and tibial fractures. The pin is introduced into the femur through the trochanteric fossa. In the tibia, it is inserted into the proximal end of the bone through a cranio-medial surgical approach, at a point half way between the tibial tuberosity and the medial collateral ligament. In humeral fractures, either retrograde pin insertion from the fracture site or normograde insertion from the greater tubercle is equally appropriate and safe. The opening in the medullary canal can be progressively enlarged by the sequential insertion of Steinmann pins of progressively larger diameter. Alternatively, the medullary cavity can be opened with a reamer. The reamer should only remove cancellous bone from the metaphyseal region. Aggressive reaming of the endosteal cortical bone in the diaphysis should not be performed because cortical bone is much thinner in dogs and cats than in humans. In humans, extensive reaming of the medullary canal is often performed to improve the mechanical performance of an interlocking nail because a large diameter, stiffer nail can be used that is more resistant to fatigue and breakage. However, on the other hand, reaming can cause fracturing of the diaphyseal cortex and damage to the medullary bone blood flow with consequential delayed or nonunion of the fracture.

In preparation for insertion of the nail, an extension piece is attached to the end of the nail (Figure 50-2). The flanges on the end of the nail must interdigitate with those on the extension piece, and the connection is secured by tightening of the threaded, internal spindle with a hexagonal screw driver. The insertion handle is then attached to the extension piece, and used in a manner similar to a Jacobs chuck to drive the nail into the medullary cavity (Figure 50-3). The nail has to be inserted by normograde technique because only one end of the nail has a trocar point. Care should be taken to ensure that the nail is adequately seated into the distal metaphysis of the bone, without accidentally going too far and penetrating the articular cartilage surface of the joint. Depth of penetration is judged by overlying a second nail of the same length, or with intra-operative fluoroscopy. After the nail is inserted, do not attempt to correct any offsets in the fracture reduction by the application of bone holders or cerclage wiring, until after the locking bolts have been inserted. Clamps or cerclage wires placed across the fracture can result in slight bending of the nail which may in turn result in inaccurate drilling and the locking bolts missing the holes in the nail.

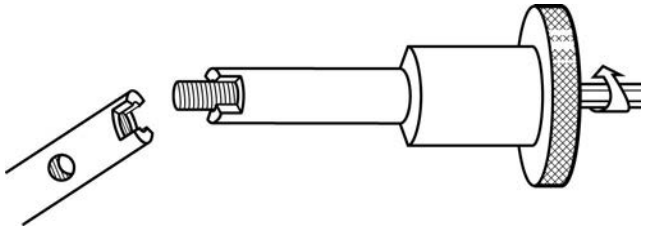


Figure 50-2. The extension piece has flanges that interdigitate with those on the end of the nail, and the connection is secured by tightening of an internal spindle.

After the nail is seated, the insertion handle is removed and the drill aiming guide is attached to the nail extension piece (Figure 50-4). Accurate drilling of the holes is the most technically challenging part of the procedure, and can be the greatest source of intra-operative frustration. Inaccurate drilling can result in the locking bolt being inserted adjacent to the nail, rather than through it. A tissue protection sleeve is inserted into the drill aiming guide in a position that corresponds to one of the distal nail holes. Then the appropriate drill guide is inserted, and a hole is drilled though the bone and the hole in the nail. Sharp drill bits with a "stick-tight" point are used to minimize the risk of the drill migrating to one side of the bone. Particular care is taken when the drill is entering the periosteal surface at an acute angle, as it has a tendency to migrate "down-hill". The diameter of the drill hole is the same as the shaft diameter of the locking bolt. The bone diameter is measured with a depth gauge, and an appropriate length locking bolt is inserted. After the two distal locking bolts have been inserted, the fracture alignment is corrected with respect to bone length and torsion with reference to anatomical landmarks. The proximal locking bolts are then inserted, and the drill aiming guide and extension piece are removed (Figure 50-5). If possible, two locking bolts should be inserted into the proximal and the distal fragments. Careful planning is needed to ensure that there are no empty holes in the nail near the fracture zone because of the risk of nail breakage. Additionally, the minimum distance from the fracture zone to the locking bolts should be 2 cm or more.

Adjunctive fixation is not required unless there are cortical fissures in close proximity to the locking bolts in which case cerclage wire can be applied. Generally comminuted fracture fragments are not disturbed. Autologous cancellous bone graft harvested from the proximal metaphysis of the humerus or tibia should be inserted at the fracture site in adult dogs if an open fracture reduction has been performed. In case of massive bone defects, large quantities of bone graft can be harvested from the wing of the ilium by using an acetabular reamer (BioMedtrix, Boonton, NJ).

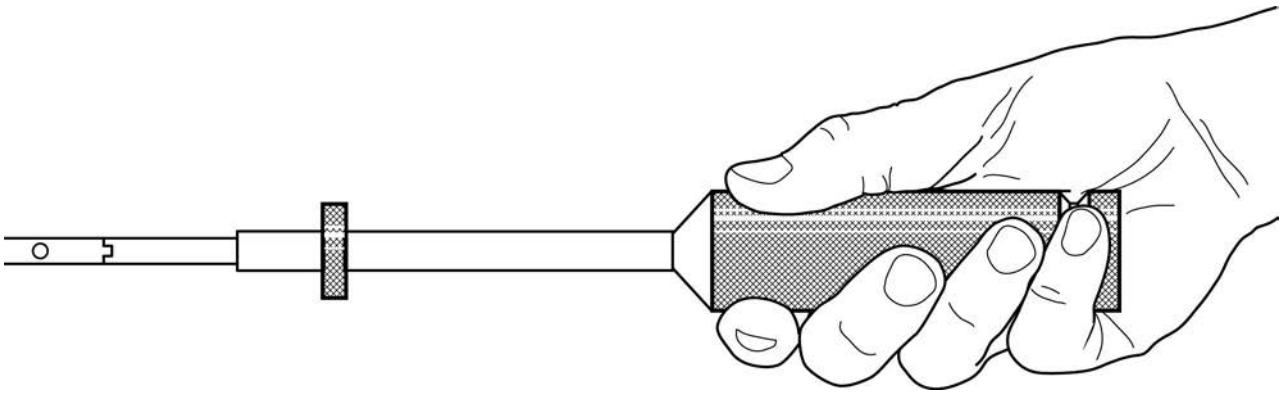


Figure 50-3. The insertion handle is attached to the extension piece, and used to drive the nail normograde into the medullary cavity.

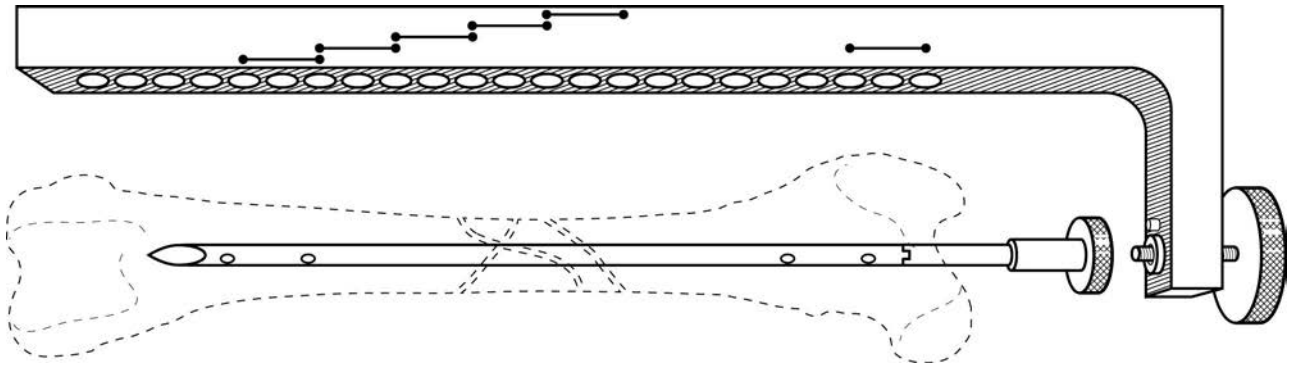


Figure 50-4. The drill aiming guide is attached to the end of the nail during surgery for accurate targeting of the drill holes into which are inserted the locking bolts.

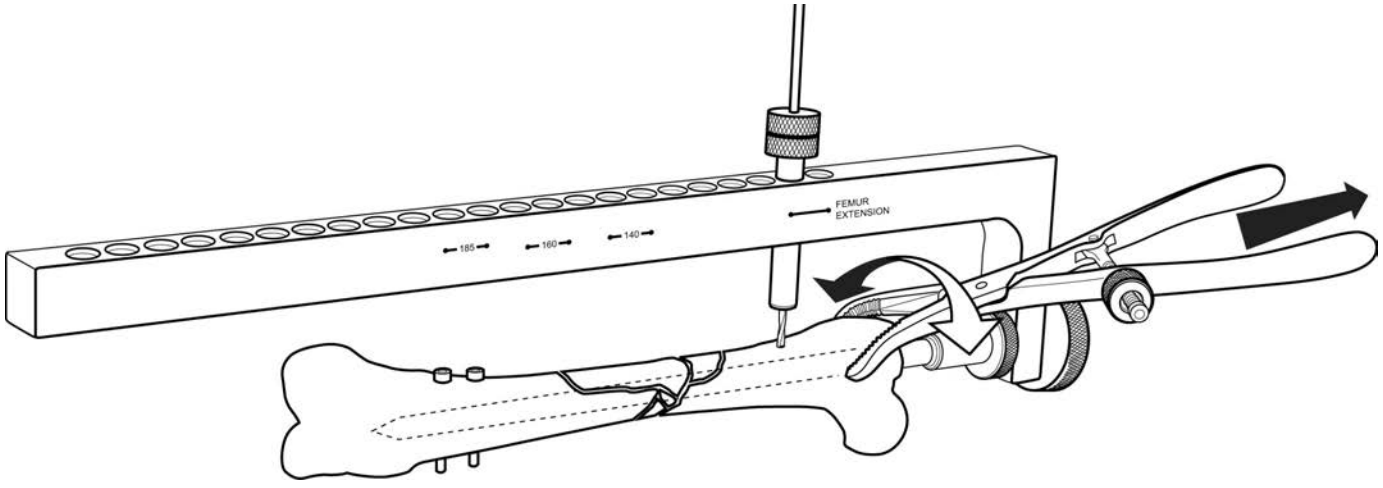


Figure 50-5. After the nail is locked into the distal fragment, alignment of the fracture is corrected for overall length and torsion, and then locked with the insertion of two proximal locking bolts.

Specific Fractures

Femur

Insertion of the nail by normograde technique in the trochanteric fossa allows it to be lateralized and thus avoid damage to the femoral head and coxo-femoral joint. The nail can be inserted by blind insertion through the gluteal muscles, or under direct visualization. The trochanteric fossa is exposed by transecting the tendon of the superficial gluteal muscle and retracting it proximally, and cranial retraction of the middle and deep gluteal muscles. Care is taken to avoid iatrogenic damage to the sciatic nerve that lies just caudal to the hip joint. Normally the femoral diaphysis of dogs has a cranio-caudal bend, or procurvatum. To overcome this curvature, two piece diaphyseal fractures may need to be axially aligned in slight recurvatum to allow the nail to be adequately seated in the distal metaphysis and condyles of the femur. In comminuted fractures in which anatomic reduction of the fragments is not the goal, this curvature is not an important factor in determining nail placement. In cats, the femoral diaphysis is generally quite straight, and can readily accommodate a small diameter nail without loss of normal bone alignment.

For more distal diaphyseal fractures, the nail can be introduced into the femur from the intercondylar notch and driven proximally. This allows the nail and locking bolts to engage more of the bone in the femoral condyles, and thus improve the stability of the fixation. Depending on the diameter of nail, and the amount of curvature in the femur, the nail may also be introduced through the articular cartilage surface at the very distal extent of the trochlear groove. However, it is important that the end of the nail is buried below the joint surface so it does not interfere with the patella. As an additional refinement to this technique, the buried end of the nail can be covered with a osteochondral plug that has been cut out of the trochlear groove with a bone trephine, prior to insertion of the nail.

Humerus

Fractures of the humeral diaphysis can be repaired via a limited lateral surgical approach to the diaphysis. It is not necessary to mobilize the brachialis muscle and radial nerve to the same extent needed for lateral bone plate fixation. For normograde insertion, the nail is started cranially on the ridge of the greater tuberosity, with the shoulder placed in slight flexion. It is not started on the most proximal point of the greater tuberosity because the inherent curvature of the humerus may prevent it from being adequately seated into the distal fragment. Alternatively the medullary canal can be reamed retrograde from the fracture site. Most humeral shaft fractures involve the distal one third of the diaphysis, and having adequate bone stock in the distal fragment and medial condyle for nail insertion will be a major consideration. In the majority of these types of fractures only single screw fixation distally is possible and thus a nail with one screw hole distally will be selected to avoid leaving an empty screw hole at the fracture site. In very large dogs the distal end of the nail can be directed medially and seated into the medial part of the humeral condyle. As with all intramedullary devices, implants should not impinge on the olecranon fossa. Distal interlocking screws are inserted with care, as they may be very close to the radial nerve.

Tibia

Closed nailing of tibial fractures may be possible, especially with the aid of fluoroscopic guidance, because the bone fragments are readily palpable. The entry point for the nail on the tibial plateau is located half way between the tibial tuberosity and the medial collateral ligament, and several mm inside the medial cortex. This point is centrally located with respect to the axis of the medullary cavity, and just cranial to the articular surface and insertion of the cranial cruciate ligament. To begin, a small diameter Steinmann pin is inserted normograde from this point and directed distally, ensuring it remains inside the medullary cavity. This hole is then enlarged with the reamer. If difficulty is encountered, retrograde reaming from the fracture site is then performed, to try to meet up with the proximal reaming tract. The tibial diaphysis is sigmoid in shape and narrowest distally, so nail diameter will tend to be smaller than that used in the femur.

A longer extension piece is used in tibial fracture so that the connection with the drill-aiming device does not impact upon the femoral condyle and patella. Due to the longer work distances, it should be recognized that there is an increased risk of deviation of the drill-aiming guide that may result in the drill missing the distal holes in the nail.

References

1. Browner B.D. The Science and Practice of Intramedullary Nailing, 2nd Ed. Baltimore: Williams and Wilkins, 1996.

2. Dueland RT, Johnson KA, Roe SC, Engen MH, Lesser AS. Interlocking nail treatment of diaphyseal long-bone fractures in dogs. J Am Vet Med Assoc 214:59-66, 1999.

3. Duhautois B. L'enclouage verrouille veterinaire: etude clinique retrospective sur 45 cas. Prat Med Chir Amin Comp 30:613-630, 1995.

4. Duhautois B. L'enclouage verrouille' en chirurgie veterinaire: de la conception aux premiers cas cliniques. Pract Med Chir Anim Comp 28:657-683, 1993.

5. Durall I, Diaz MC, Morales I. An experimental study of compression of femoral fractures of an interlocking intramedullary pin. Vet Comp OrthopTrauma 6:93-99, 1993.

6. Durall I, Diaz MC, Morales I. Interlocking nail stabilization of humeral fractures. Initial experience in seven clinical cases. Vet Comp Orthop Traumatol 7:3-8, 1994.

7. Durall I, Diaz MC. Early experience with the use of an interlocking nail for the repair of canine femoral shaft fractures. Vet Surg 25:397-406. 1996.

8. Horstman CL, Beale BS, Conzemius MG, Evans R. Biological osteosynthesis versus traditional anatomic reconstruction of 20 long-bone fractures using an interlocking nail: 1994-2001. Vet Surg 33:232-237, 2004.

9. Muir P, Parker RB, Goldsmid SE, Johnson KA. Interlocking intramedullary nail stabilization of a diaphyseal tibial fracture. J Small Anim Pract 25:397-406, 1993.

10. Durall I, Diaz-Bertrana MC, Puchol JL, Franch J. Radiographic findings related to interlocking nailing: windshied-wiper effect, and locking screw failure. Vet Comp Orthop Traumatol 16:217-222, 2003.

11. Suber JT, Basinger RR, Keller WG. Two unreported modes of interlocking nail failure: breakout and screw bending. Vet Comp Orthop Traumatol 15:228-232, 2002.

12. Muir P, Johnson KA, Markel MD. Area moment of inertia for comparison of implant cross-sectional geometry and bending stiffness. Vet Comp Orthop Traumatol 8:146-152, 1995.

13. Litsky AS, Johnson KA, Aper RL, Roe SC: A novel screw design for improving the fatigue life of interlocking nails. Proceedings Society for Biomaterials Annual Meeting, Sydney 2004.

14. Aper RL, Litsky AS, Roe SC, Johnson KA. Effect of bone diameter and eccentric loading on fatigue life of cortical screws used with interlocking nails. Am J Vet Res 64:569-573, 2003.

15. von Pfeil DJF, Dejardin LM, DeCamp CE, Meyer EG, Lansdowne JL, Weerts RJH, Haut RC. In vitro biomechanical comparison of a plate-rod combination-construct and an interlocking nail-construct for experimentally induced gap fractures in canine tibiae. Am J Vet Res 66:1535-1543, 2005.

16. Landsdowne JL, Sinnott MT, Ting D, Haut RC, Dejardin LM. Design and in vitro evaluation of the structural properties of a novel and current interlocking nail systems. Proceedings American College of Veterinary Surgeons annual meeting, October 5-7, 2006.

17. Dejardin LM, Lansdowne JL, Sinnott MT, Sidebotham CG, Haut RC. In vitro mechanical evaluation of torsional loading in simulated canine tibiae for a novel hourglass-shaped interlocking nail with a self-tapping tapered locking design. Am J Vet Res 67:678-685, 2006.

18. Mattoon JS. Digital radiography. Vet Comp Orthop Traumatol 19:123-132, 2006.

Chapter 51

Fixation with Screws and Bone Plates

Screw Fixation: Cortical, Cancellous, Lag, and Gliding

Brian Beale

Cortical and cancellous screws are commonly used for fracture repair in small animals. Cortical screws are fully threaded and are designed for use in cortical bone (Figure 51-1). Cancellous screws are fully or partially threaded and are used where cortical bone is thin and cancellous bone predominates (Figure 51-1). Cancellous screws have a steeper thread pitch, deeper threads, and a thinner core as compared with cortical screws.

Partially threaded cancellous screws are generally not used in cortical bone because removal of the screw is difficult as bone grows around the unthreaded shank. Both types of screws can be used for different purposes, including lag screws, positional screws, and plate fixation screws.

Lag screws are used for interfragmentary compression of fracture fragments (Figure 51-2). Compression occurs if the screw engages the far cortex and glides in the near cortex adjacent to the screw head. Cortical screws are selected for stabilization of cortical fragments in the diaphyseal region of the bone. The

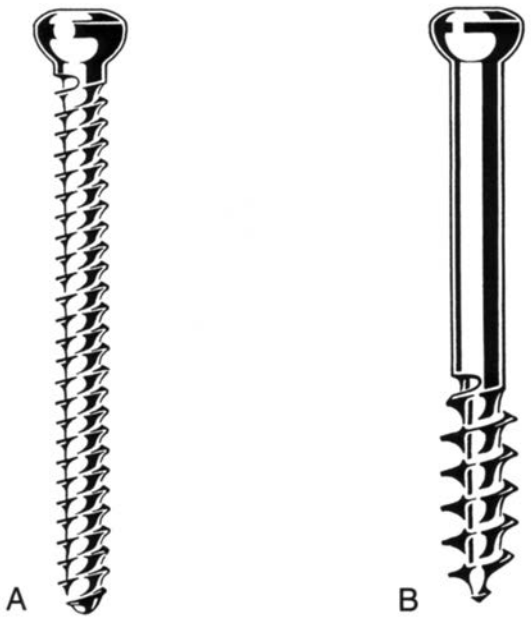


Figure 51-1. Cortical and cancellous screws. **A.** Cortical screws are fully threaded. The thread pitch is less steep as compared with cancellous screws to increase holding power in cortical bone. **B.** Cancellous screws can be fully or partially threaded and are used where cortical bone is thin and cancellous bone predominates. Cancellous screws have a steeper thread pitch and thinner core as compared with cortical screws.

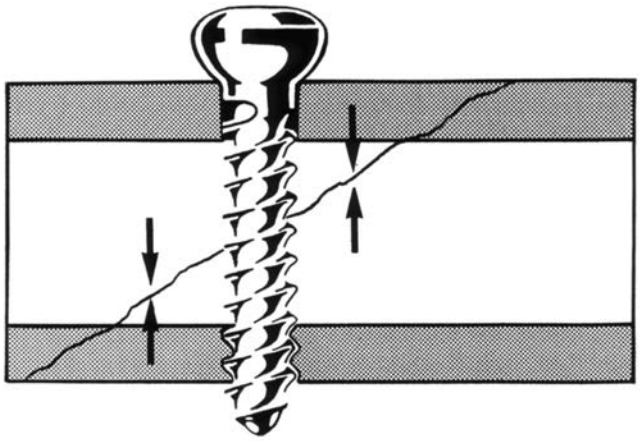


Figure 51-2. Screws can be used to provide interfragmentary compression. When using a fully threaded screw for this purpose, a glide hole must be drilled in the near cortex equal in size to the thread diameter of the screw.

fragments are reduced and are secured temporarily with an appropriate bone clamp. Predrilling of the guide hole or thread hole before reduction and temporary stabilization is sometimes advantageous because it allows accurate placement of the hole in narrow segments of the bone fragment. If predrilling is done, a pointed drill guide is used to align the predrilled hole with the opposite hole to be drilled. The use of cortical screws requires drilling of a glide hole in the near cortex, equal in size to the thread diameter of the screw, to prevent the screw from making purchase. Screw holes should be drilled in the center of the fragment to prevent shifting during tightening. The hole should be drilled in a direction that bisects the angle formed by perpendicular lines to the fracture line and the longitudinal axis of the bone in fragments having less than 40° inclination. If inclination of the fracture is greater than 40°, the hole should be drilled perpendicular to the fracture line. The holes should also be placed an adequate distance away from the edge and tip of the fragment to prevent fracture of the fragment at the screw hole. A countersink tool is optimally used in the near cortex to distribute loads transferred by the screw head to the bone more evenly, thus making fracture less likely. A drill sleeve (outer diameter equal in size to the glide hole, inner diameter equal in size to the thread hole) is inserted in the glide hole until it meets the opposite cortex. A thread hole equal in size to the core of the screw is drilled in the far cortex. A depth gauge is used to measure the length of screw needed. The selected screw should be 1 to 2 mm longer than the measured hole depth to ensure adequate thread purchase in the far cortex. The hole is carefully threaded with the appropriate tap. The surgeon must insert the tap at the same angle as the drill bit and must avoid excessive wobble during tapping to prevent stripping or microfracture of the screw hole. The appropriate screw is then inserted and tightened. Overtightening can lead to stripping of the screw threads or fracture of the bone fragment; appropriate tightness can usually be attained by grasping the screwdriver with the thumb and the first two fingers, instead of the entire hand, when tightening.

Cancellous screws are often used to stabilize fragments in the metaphyseal or epiphyseal regions (Figure 51-3). When using

cancellous screws in lag fashion, a glide hole is not needed if partially threaded screws are used. The smooth shaft should traverse the near fragment completely. Compression does not occur if screw threads engage the near fragment. The diameter of the hole in both cortices should be equal to the diameter of the core of the screw. Predrilling one fragment is often helpful for alignment of the hole in the center of the fragment. The fragments are reduced and temporarily are stabilized with a bone clamp. The hole is drilled, measured and tapped. Tapping of the hole is optional; it is often helpful to tap only the first few millimeters of the hole to assist with insertion of the screw. Pullout strength of these screws is enhanced if the entire length of the hole is not tapped. The screw is inserted and is tightened as described earlier for cortical screws.

Positional screws can be placed to hold fragments in alignment while a method of primary stabilization is applied. Small cortical fragments can be secured to the diaphysis with a screw that engages the cortices of both fragments. A glide hole is not used; therefore, compression of the fragment does not occur. This type of application is useful when compression of the fragment is likely to lead to its collapse into the medullary cavity or shifting of the fragment out of reduction.

Plate fixation screws are used to fasten a plate to bone. Glide holes are not used unless compression of fragments beneath the plate is desired. Both cortical and cancellous screws can be used, depending on the region of bone. The screws glide in the holes of the plate, thereby compressing the plate against the bone.

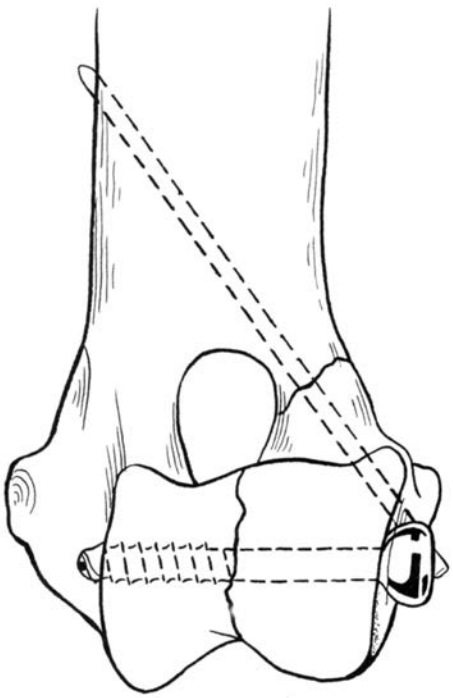


Figure 51-3. A cancellous screw and Kirschner wire are used for repair of a lateral condylar fracture of the distal humerus. When using cancellous screws in lag fashion, a glide hole is not needed if partially threaded screws are used. The smooth shaft must traverse the near fragment completely.

Application of Bone Plates in Compression, Neutralization, or Buttress Mode

Daniel A. Koch

This topic is written based on the available literature through 2010 and does not cover the most current literature on this topic.

Biology of Fracture Healing

Interfragmentary compression and internal fixation, leading to direct bone healing, have been the gold standard for treating long bone fractures in small animals for many years. Recent developments however, have led to the principle of biological fracture healing. It is characterized by minimal biological damage together with flexible fixation. The minimal biological damage is achieved by indirect reduction techniques and pure alignment of the fragments without the need for precise reduction. Maximal blood supply is preserved to avoid iatrogenic bone necrosis. Flexible fixation is achieved by wide bridging of the fracture zone using locked nails, bridge plating, internal or external fixators. Such fixation leads to indirect bone healing with callus formation.

Plate Function

If the surgeon is able to generate axial compression by the use of a tension device or with eccentric loaded screws, the plate functions as a compression plate. In most instances, this mode is only possible in simple transverse fractures. Whenever the internal fixation of a diaphyseal fracture consists of a lag screw or screws in combination with a plate (to protect the lag screw fixation), the plate functions in a neutralization mode. Such a

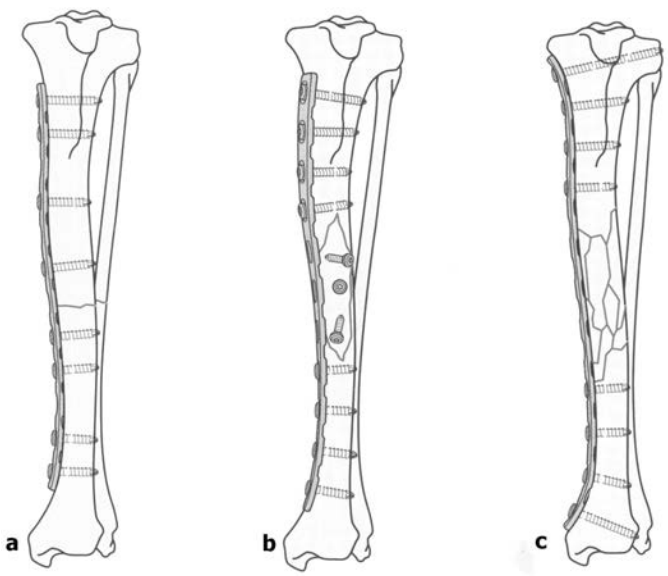


Figure 51-4. Plate function. **a.** transverse tibia fracture stabilized with a LC-DCP as a compression plate, **b.** long oblique fracture of the tibia reconstructed with lag screws and supported with a LC-DCP as a neutralization plate, **c.** comminuted non-reducible diaphyseal tibia fracture stabilized with a LC-DCP as a buttress plate. (Copyright c 2005 by AO Publishing, Switzerland. Originally published in "AO Principles of Fracture Management in the Dog and Cat". Thieme/AO Publishing, 2005)

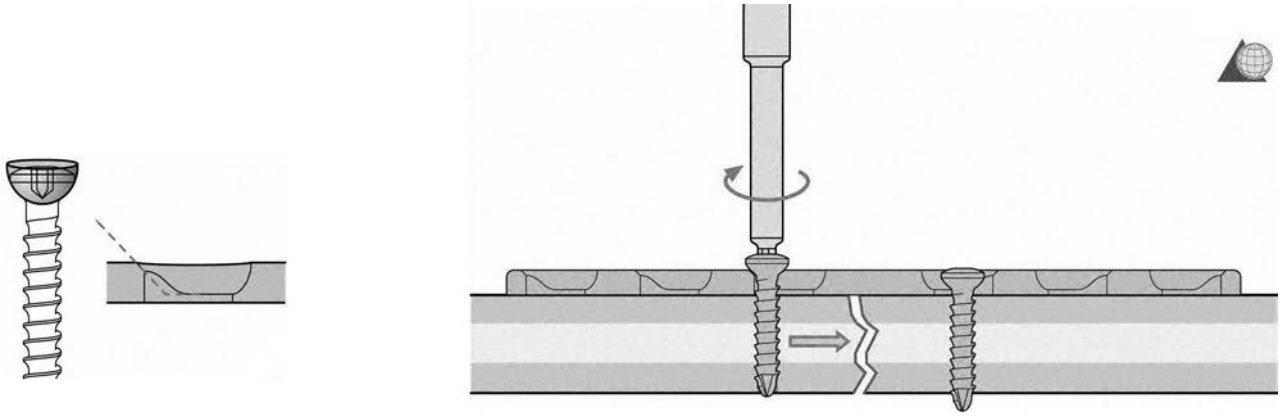


Figure 51-5. Dynamic compression principle. The horizontal movement of the screw head, as it impacts against the angled side of the hole, results in movement of the bone fragment relative to the plane, and leads to compression of the fracture. (Copyright c 2005 by AO Publishing, Switzerland. Originally published in "AO Principles of Fracture Management in the Dog and Cat". Thieme/AO Publishing, 2005)

plate protects the interfragmentary compression achieved with the lag screw or screws from all torsional, bending, and shearing forces. In comminuted fractures of the metaphysis or diaphysis, the application of axial compressive forces may lead to collapse and or angular deviation of the fractured bone. Lag screws can not overcome these forces. In order to prevent loss of bone length or proper alignment in comminuted fractures, it is necessary to supplement the fixation with a buttress plate. The function of the buttress (or bridging) plate is simply to prevent axial deformity as a result of shear or bending. This type of plate fixation is subjected to full loading. Therefore, every possible effort should be made to maintain all the soft tissue attachments and blood supply to the fragments, since healing will depend on the formation of a bridging callus rather than primary bone union. The proximal and distal ends of the plate ends must each be solidly fixed to the corresponding major bone segments by at least 3 screws. The addition of an intramedullary rod (plate-rod fixation) decreases the risk of plate fatigue by micromotion (Figure 51-4).

Dynamic Compression Plates

DCP

The dynamic compression plate (DCP; Synthes, Solothurn, Switzerland) was introduced in 1969. The veterinarian may chose from 4.5 mm (giant breed dogs), broad 3.5 mm (heavy and giant breed dogs), regular 3.5 mm (large dogs), 2.7 mm (medium and small dogs, cats) and 2.0 mm size (toy breed dogs, cats). The screw holes are best described as a portion of an inclined and angled cylinder. Tightening of a screw, which is inserted eccentrically at the inclined shoulder of the plate hole leads to movement of the bone fragment relative to the plate, and consequently, compression at the fracture site (Figure 51-5) The design of the screw holes allows for a displacement of up to 1.0 mm. Two eccentric screw insertions per fragment are possible. Depending on the application technique used, a DCP may function in compression mode, as a neutralization plate, or as a buttress plate.

LC-DCP

The limited contact dynamic compression plate (LC-DCP; Synthes, Solothurn, Switzerland) represents a further development of the DCP. Compared to the DCP, the area of the plate-bone contact (the plate "footprint") of the LC-DCP is greatly reduced. The capillary network of the periosteum is thereby less compromised, leading to a relative improvement of cortical perfusion, which reduces the osteoporotic changes underneath the plate. The geometry of the plate, with its structured undersurface, results in an even distribution of stiffness, making contouring easier, and minimizing the tendency to kink at the holes when bent. The plate holes are evenly distributed over the entire length of the plate, which adds to the versatility of application (Figure 51-6). The plate is available both in stainless steel and in pure titanium. Titanium exhibits outstanding tissue tolerance.

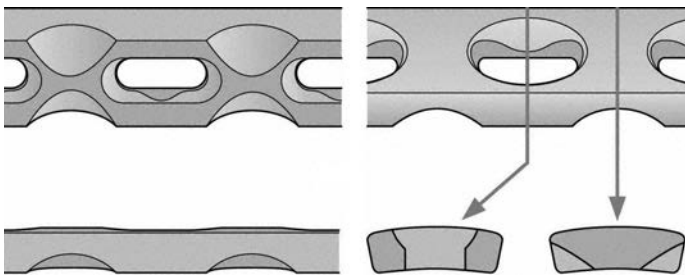


Figure 51-6. The LC-DCP with its scalloped undersurface for limited contact between plate and bone and even distribution of the holes throughout the plate. (Copyright© 2005 by AO Publishing, Switzerland. Originally published in "AO Principles of Fracture Management in the Dog and Cat". Thieme/AO Publishing, 2005)

Application Techniques

When using a 3.5 mm DCP or LC-DCP, the following steps are undertaken. The correct plate length and thickness is estimated from the radiograph. The plate is contoured with bending irons, bending pliers or a bending press. Special bending templates are available. Repeated bending is avoided, because this weakens the plate. The plate should be bent between the holes. The desired function of the screw must be determined (neutral or compression). The screw hole is drilled with the corresponding drill sleeve (standard or universal), which is slightly larger (2.5 mm) than the core of the screw (2.4 mm). The length is measured with the depth gauge. If the correct screw length is not available, the next longer screw is chosen. The hole is tapped (3.5 mm) and the screw is inserted with the screw driver (Figure 51-7).

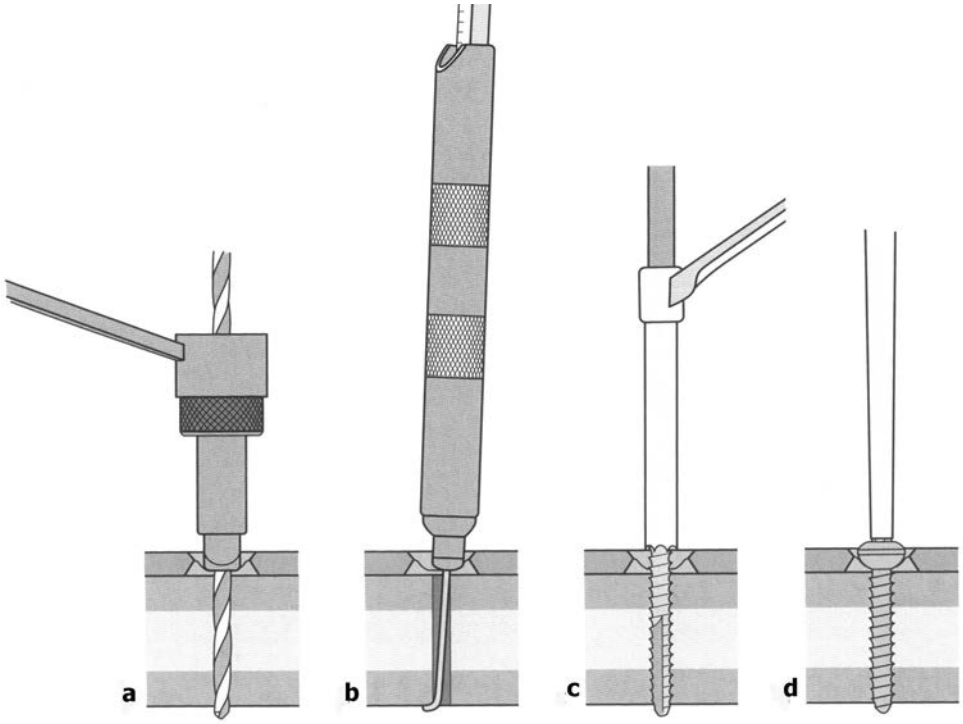


Figure 51-7. Application of a plate screw. **a.** Drilling of the hole in neutral position, **b.** measuring of the hole length, **c.** tapping, **d.** insertion of the screw. (Copyright c 2005 by AO Publishing, Switzerland. Originally published in "AO Principles of Fracture Management in the Dog and Cat". Thieme/AO Publishing, 2005)

As a rule of thumb, the following maximal forces on the screwdriver are recommended when inserting a plate screw: two fingers for a 2.0 mm screw, 3 fingers for a 2.7 mm screw and the whole hand for a 3.5 mm screw. For perfect force application, torque limiting screw drivers are available. Plate screws are applied first at the ends of the plate, then close to the fracture and finally, the remaining plate holes are filled. The screws are retightened until they are seated firmly.

Miniplates

The increasing demand for fracture treatment in cats and toy breed dogs and the ability of the veterinary surgeon, together with modern diagnostic aids, led to the development of small sized implants for stabilizing fractures in delicate areas such as the maxillofacial region.

The mini-fragment plates (Synthes, Solothurn, Switzerland) are designated for use with the 2.0 mm or 1.5 mm cortex screw. They are available as DCP, round hole plates, angled miniplate, T-miniplate or adaption plate. They are used in long bone fractures, mandibular fractures or pelvic fractures of toy breed dogs and cats (Figure 51-8).

The human Compact system (Synthes, Solothurn, Switzerland) was developed for hand and maxillofacial orthopedic surgery. The smaller sizes (1.0 mm, 1.3 mm and 1.5 mm) and varying plates are now available for veterinary use. The screws are self-tapping and are inserted with the stardrive screw driver. A similar system (Stryker, Kalamazoo MI, USA) is available with 1.3 mm, 1.7 mm and 2.3 mm plates and self-tapping screws, all made of titanium. It is especially helpful in feline orthopedics. The 2.3 mm system perfectly fits the demands, when long bones of cats or toy breed dogs are stabilized (Figure 51-9).

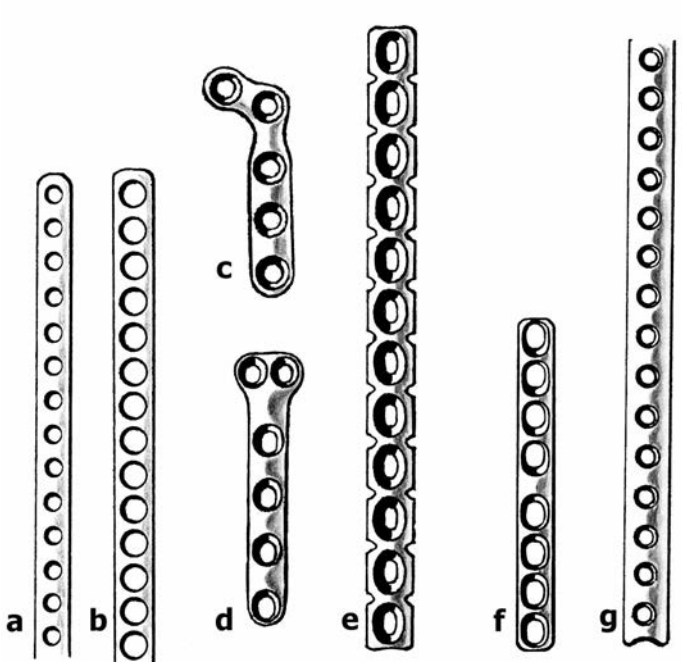


Figure 51-8. Miniplates and special plates. **a.** miniplate 1.5, **b.** miniplate 2.0, **c.** veterinary L-plate, **d.** veterinary T-plate, **e.** reconstruction plate. **f.** 2.0 DCP, **g.** tubular plate. (courtesy university Zurich)

Special Plates

Reconstruction plates are characterized by deep notches between the holes that allow accurate contouring. The plate is considered not to be as strong as the compression plates, and



Figure 51-9. Application of a 2.3 mm plate on a feline radius. (Copyright© 2005 by AO Publishing, Switzerland. Originally published in "AO Principles of Fracture Management in the Dog and Cat". Thieme/AO Publishing, 2005)

may be further weakened by heavy contouring. The holes are oval, to allow for dynamic compression. These plates are especially useful in fractures of bones with complex 3-D geometry, as encountered in the pelvis, especially the acetabulum (See Figure 51-8). Veterinary T- and L-plates are available in different sizes from 2.0 mm to 3.5 mm (See Figure 51-8). Double hook plates are used in proximal femur fractures as well as for intertrochanteric osteotomies. Right and left triple pelvic osteotomy plates with different torque are available in 2.7 mm and 3.5 mm sizes. Tubular plates are useful in areas with minimal soft tissue coverage, such as the olecranon, distal ulna or the malleoli. In scapula fractures, the tubular plate can be applied with its convex surface laid against the scapula spine (See Figure 51-8).

Internal fixators

Biomechanics of internal fixators

The introduction of locking bone plate/screw systems has generated certain advantages in fracture fixation over other plating methods. Locking plate/screw systems are appropriately classified as internal fixators. The stability is given by the locking mechanism between the screw and the plate. The plate does not need to have intimate contact with the underlying bone, making exact plate contouring less crucial. Diminished contact between the plate and the bone may also preserve the periosteal blood supply, thereby reducing the extent of bone resorption under the plate. Internal fixators are used in neutralization or buttress mode. Bone healing under internal fixators is by callus formation (indirect healing).

Experimental studies have shown, that internal fixators offer greater stability than standard reconstruction plates without locking screws. The screws must only be inserted in the cis-cortex. This increases the versatility of internal fixators, which become extremely helpful in acetabular fractures, carpal or tarsal fractures, or in situations where double plating is indicated.

LCP and UniLock

For veterinary use, the locking compression plate (LCP) und the UniLock are available (Synthes, Solothurn, Switzerland). They both have a locking system with threads. The LCP has a so called combination plate hole, which can accommodate either a conventional screw or the new locking head screw. All standard AO plates from 2.7 to 4.5 are available with the combination hole (Figure 51-10). The UniLock comes as 2.0 mm or 2.4 mm system, together with locking screws, non-locking screws and emergency screws. All screws are self-tapping. The locking screws are inserted perpendicular to the plate. A special drill guide, which is screwed into the hole and centers the drill precisely, facilitates the locking mechanism between screw and plate (Figure 51-11).

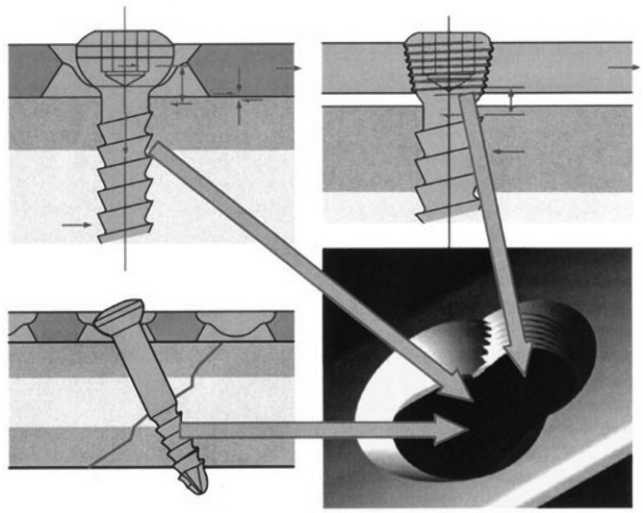


Figure 51-10. The LCP combination hole. One half has the design of the standard DCP for conventional screws, the other half is conical and threaded to accept the matching thread of the locking head screw providing angular stability and avoiding pressure between plate and bone. (Copyright c 2005 by AO Publishing, Switzerland. Originally published in "AO Principles of Fracture Management in the Dog and Cat". Thieme/AO Publishing, 2005)



Figure 51-11. UniLock 2.4 system. The 2.4 or 3.0 mm are locked on the matching plate holes by conical threads; 2.4 mm non locking screws can also be inserted. (Copyright© 2005 by AO Publishing, Switzerland. Originally published in "AO Principles of Fracture Management in the Dog and Cat". Thieme/AO Publishing, 2005)

Technical failures and their Prevention

Some common factors leading to technical failures and strategies to avoid them are listed below. Technical failures are usually due to incomplete assessment of the fracture patient, which in turn leads to suboptimal fixation.

Consider the following factors before performing osteosynthesis:

- Animals, which sustain injuries on more than one limb, need more stable fixations than those, which are able to protect a single limb injury by non-weight bearing.
- In case of an infected and unstable fracture, rigid fixation is mandatory.
- Whenever possible, the least invasive treatment is chosen.

Consider the following factors during osteosynthesis:

- Inadvertent stripping of the bone or detachment of muscles from fragments should be avoided. It is important to preserve as much blood supply as possible to enable optimal fracture healing.
- While using power equipment, cooling with isotonic solutions is mandatory to prevent heat necrosis on the bone and subsequent loss of fixation at the implant-bone interface.

Consider the following factors after osteosynthesis:

- Postoperative resorption at the fragment ends, which were anatomically reduced, are mostly due to the fact, that plate osteosynthesis was not rigid enough for direct or indirect bone healing. Due to the strain theory, the fracture gap must be widened and callus formation will start.
- Implant related stress protection of a healing bone can lead to bone resorption and osteoporosity. Therefore, implants should be removed, as soon as clinical fracture healing has been completed.

Suggested Readings

Gauthier E, Perren SM, Ganz R: Principles of internal fixation, Curr Orthop 6: 220, 1992.

Keller M, Voss K: UniLock: Applications in small animals. Dialogue 2: 20, 2002.

Koch DA: Screws and plates. In Johnson AL, Houlton JEF, Vannini R, eds: AO principles of fracture management in the dog and cat, Duebendorf: AO foundation, 2005, p 26.

Perren SM, Russenberger M, Steinemann S, et al.: A dynamic compression plate. Acta Orthop Scand Suppl 125: 31, 1969.

Perren SM, Klaue K, Pohler OEM, et al: The limited contact dynamic compression plate (LC-DCP) Arch Orthop Trauma Surg 109: 304, 1990.

Perren SM: Evolution of internal fixation of long bone fractures. J Bone Joint Surg (Br) 84B: 1093, 2002.

The SOP Locking Plate System

Karl H. Kraus and Malcolm G. Ness

Introduction

The SOP (String of Pearls) was designed to serve as a locking plate system for the veterinary and human orthopedic community. As with all locking plate systems, the SOP can be thought of mechanically as internal – external fixators. The SOP consists of a series of cylindrical sections ("internodes") and spherical components ("pearls"). There are three system sizes which accommodate 3.5 mm, 2.7 mm and 2.0 mm screws. The cylindrical component, or internode, has an area moment of inertia greater than the corresponding standard DCPs. Mechanical testing using ASTM standards has demonstrated that the 3.5 SOP is 50% stiffer, and has a bending strength (load at which the plate plastically bends) of 16 to 30% greater than the 3.5 mm LCP, DCP, or LC-DCP.

The SOP can be contoured in six degrees of freedom; medial to lateral bending, cranial to caudal bending, and torsion using specially designed bending irons (Figure 51-12). Properly performed, contouring results in bending or torsion at the internode, preserving the locking function of the pearl. Mechanical testing has demonstrated that although bending a SOP will reduce its stiffness and strength by approximately one third, a SOP bent through 40 degrees remains almost (96%) as stiff as an untouched 3.5 DCP. Similarly, a SOP twisted through 20 degrees remains significantly stiffer than the new and untouched 3.5 DCP.

The spherical component of the SOP accepts a standard cortical bone screw. There is a section of standard threads within the spherical component, and a section into which the head of a standard screw recedes. As the screw head recedes into the spherical component, it comes into contact with a ridge causing the screw to press fit into the pearl. This press fitting prevents loosening of the screw during the cyclic loading of weight bearing, and results in a very rigid screw/plate construct. This concept removes critical limitations of locking plate designs employing a hole with either single, double, or conical threads. The larger diameter part of the pearl receives a drill/tap guide

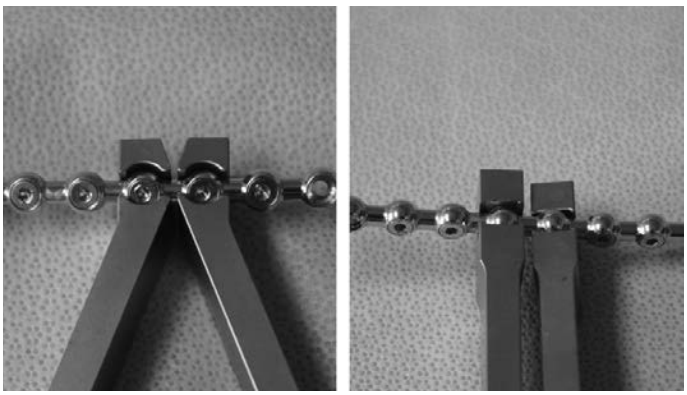


Figure 51-12. The SOP can be contured in six degrees of freedom; medial to lateral bending, cranial to caudal bending, and torsion using specially designed bending irons.

and allows drilling, measuring with a depth gauge, and tapping of the screw hole, with familiar ORIF instrumentation (Figure 51-13). The circular cross-section of the implant and the increased diameter of the pearls in comparison with the internodes gives the implant a relatively consistent stiffness profile – the screw holes are not notable "weak points". The larger size of the pearl protects it against deformation during contouring or load bearing. The use of inserts ("golf tees") placed into the pearls protects the pearl absolutely and preserves locking function completely during contouring.

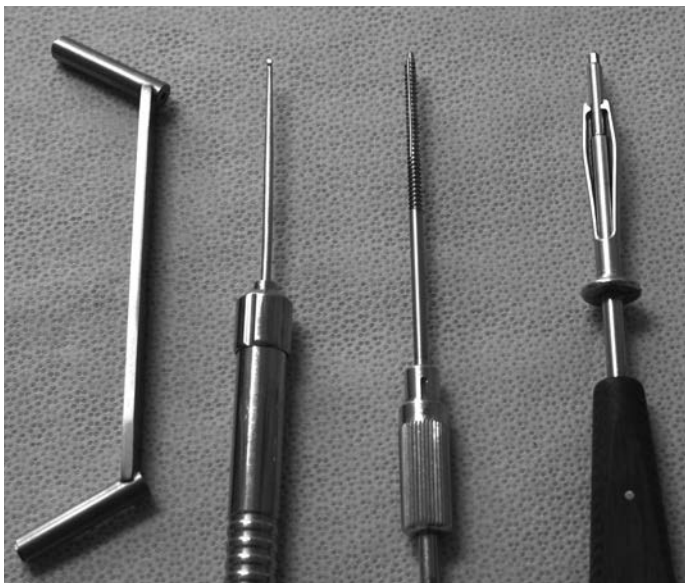


Figure 51-13. The larger diameter part of the spherical component of the SOP receives a drill/tap guide and allows drilling, measuring with a depth gauge, and tapping of the screw hole, with familiar ORIF instruments.

There is theoretical potential for the screw to cold weld, making it difficult to remove. However, this has not been seen in practice but should it happen, a section of the plate can be simply cut through an internode using a bolt cutter and the offending section removed.

Not all screws are alike. The SOP is designed to be used with high quality screws manufactured to standard tolerances for screw head and thread sizes. Self tapping screws must have triple flutes so that consecutive screws will tap without lifting the plate away from the bone. Inferior screws with unconventional design or loose manufacturing tolerances are becoming more common in veterinary orthopedic surgery as most orthopedic companies outsource screw production. Such screws may not have sufficient quality control to work in the SOP system. For this reason orthopedic screws from the supplier of the SOP should be used, or if using them from another supplier they should be tested in the SOP to assure compatibility.

Biomechanics

The biomechanics of interlocking plate systems differs fundamentally from conventional bone plates – extrapolation of experience gained using non-locking, DCP systems, is not always appropriate. Screws in conventional bone plates press the plate onto bone as the screw is tightened. The threads of the screw pull and slightly deform the bone that the threads engage. As bone is viscoelastic and remodels, the pull lessens over the first several minutes after installation due to bone relaxation, then over the next period of days and weeks due to remodeling. Oval holes allow dynamic compression and load sharing since the screw can move slightly along the long axis of the plate. The screw can pivot in the hole of the plate.

In contrast, locking systems, including the SOP, will function invariably as "buttress" systems – even when they are applied to an anatomically reconstructed fracture. The screws of interlocking plates act as transverse supporting members, subjected to cantilever bending. The primary loads on bone during weight bearing are axial, along the long axis of the bone. Axial loads of a bone encounter a screw and the load is transferred at the bone/screw interface to the screw, then to the plate, then back to the screw on the other side of the fracture, then to bone. Here, there is no pulling of the plate down to the bone so the resistance to pullout of a screw is less relevant. Importantly, the screw is integrally and always part of the transmission of forces across areas of fracture. Locking plate systems rarely utilize dynamic compression, and are acting as buttress devices. The result of die back of bone in the initial healing phase, and the reliance upon lag screws, wires or other mechanically inferior components within the reconstruction means that even where load sharing is achieved at surgery, locking systems invariably function in buttress mode.

With the difference in transmission of forces across the area of fracture, pullout strength of bone screws becomes far less important, making locking screw systems preferred choices in cancellous or osteoporotic bone. Conversely, the fatigue life of the screw/plate interface increases in importance. Clinically, this is of relatively less importance in engaging two cortexes with a bone screw, and much greater importance in increasing the number of bone screws, unicortical or bicortical, to enhance fatigue life. However, while adding a unicortical screw may be of limited benefit with conventional plates, unicortical screws within a locking system function effectively and are appropriate.

This highlights an important mechanical feature of all interlocking plate systems including the SOP. Specifically, there is a distinct stress riser at the screw/plate interface where forces are transferred from a less stiff element (the screw) to a much stiffer element (the plate or SOP). If excessive force is cyclically applied across the fracture, the shaft of the screw will cold work and become brittle. The yield point from elastic to plastic deformation will become less, and cracks will develop and propagate across the screw. This is fatigue failure and ultimately the screw will break. Theoretical considerations suggest that 4 screws in each major fragment is appropriate to protect the screws against fatigue failure. The cross sectional area of the SOP is pi r^2 or 20 mm^2. That of the shaft of a screw is about 5 mm^2. Therefore, by installing four screws on either side of the fracture the shear area of the screws will approximately equal that of the SOP. Again, the screws may be unicortical. This may be achieved by application of an additional SOP for example if the distal segment is short. A second SOP can be on the contralateral or orthogonal

side of the bone, or two SOPs can be nested side by side. The use of an intramedullary pin (SOP-rod technique) enhances the stiffness of a construct to an extent which is not appreciated by many surgeons. This increased stiffness substantially protects implants and protects against fatigue failure. The use of SOP in pairs (for example, in the spine) or in conjunction with a rod (for example, in long bone fractures) should be considered the norm.

Bone slicing is a potential problem associated with the use of locking systems in poor quality bone. With conventional plating systems applied to weak cancellous or osteoporotic bone, screw pullout is the critical factor. However, with locking screw systems screws cannot pullout, especially if there is some divergence or convergence with screws. Instead, failure will occur through slow creep of the screw through the weak bone, known as "bone slicing." Therefore, as locking plate systems are preferred in weak or osteoporotic bone, they may still exhibit this mode of failure if the bone / implant system used is not sufficiently robust. Bone slicing has not been identified in SOP cases so the importance of this phenomenon in veterinary patients is not yet known.

Application Techniques: Appendicular Skeleton

The primary utility of the SOP in the femur, humerus, tibia, radius, and ulna is in comminuted fractures. Although the SOP can be used in conventional "open approach" fracture surgery, it is especially valuable with biologic fixation methods and minimally invasive techniques. For example, techniques involving SOP and screws installed with stab incisions or mini approaches, or more open approaches where the area of comminution is preserved. The comminuted, diaphyseal femoral fracture will be used as an example of standard SOP methods (Figure 51-14).



Figure 51-14. An example of standard SOP methods for repair of a comminuited, diaphyseal femoral fracture.

Comminuted diaphyseal femoral fractures are best repaired using the SOP in combination with under sized intramedullary pins, also known as a Rod and Beam fixation. A standard surgical approach appropriate to the specifics of the fracture is made. An intramedullary pin of 1/3rd to 1/2 the diameter of the medullary cavity is placed normograde from the intra-trochanteric fossa, threading the area of comminution, into the distal femoral segment. The limb is aligned with reference to adjacent anatomical landmarks. In the femur the coxofemoral joint should be in slight anteversion while the stifle is flexed. An elevator is passed along the lateral aspect of the femur, under the biceps and vastus. Inserts should be placed into the SOP holes before contouring to prevent distortion of the holes. An SOP of appropriate length is contoured: it is helpful to have radiographic images of the opposite, un-fractured femur to guide the contour. The contour does not have to be perfect, as the SOP does not need to lie directly on bone. The distal aspect of the SOP can be contoured to follow the femoral condyles caudally and the proximal SOP can be twisted directing the screws antegrade to the femoral neck. The SOP is placed in the soft tissue tunnel, and contour is reviewed. Four screws should be engaged on each side of the fracture. Unicortical screws are appropriate and "empty" screw holes – even over the fracture – are acceptable. The IM pin will prevent bending of the SOP, so there may be a long area without screws in the center of the femur.

The drill guide is placed into a screw hole on one end of the bone and the remaining screw holes observed to make sure the SOP is positioned properly. Remember that the screw will always be directed perpendicular to the spherical component of the SOP. Though you can twist the SOP to change screw direction, this is done prior to installation of screws. The drill and tap guide will direct the drill and tap in the proper direction. The insert is removed from the SOP at the first screw location, either proximal or distal. The drill hole is made using the drill guide, then the depth is measured. A screw is placed. Standard or self tapping screws can be used according to surgeon preference. It is possible for the tap/self-tapping screw to not engage the bone hole immediately. This results in the SOP being pulled too far away from the bone. This can be prevented by applying gentle axial pressure during early placement of the tap/self-tapping screw. Note also that when using a bone tap, care must be taken subsequently when placing the screw to ensure that the screw threads engage in the bone as desired, and not 360° later. The screw should be tightened so that the screw head seats firmly into the spherical component of the SOP. If a unicortical screw is placed, the depth gage measures the minimal length the screw needs to be by the standard method of hooking the near cortex. Then the depth gage is advanced to the trans cortex or, in some cases, the intramedullary pin. A screw 0 to 2 mm longer than the measured minimum distance is chosen. Measuring the distance to the transcortex or intramedullary pin will assure that an oversized screw will not interfere with any structure. The same procedure is repeated for all screws.

Applying a SOP is similar to standard ORIF principles and procedures with these notable exceptions. First, the SOP does not need to lie directly on the outer cortical surface. It should be placed close to the bone to keep its profile as low as possible, but might

contact the bone in a few locations or not at all. This preserves the periosteal blood supply of the bone and healing callus. The screw will tighten into the plate, this does not assure that the screw is in solid bone. However, locking screws are better for soft or osteoporotic bone as screw thread holding power is not the method of transmission of forces. Some divergence of screws is desirable. The SOP can be contoured in six degrees of freedom. It is possible, and sometimes desirable, to contour the SOP in non-standard shapes, to follow the fracture configuration or tension surface of a bone. The SOP can be contoured into a spiral for example.

Technical Guidelines

Note that these are guidelines and not rules. They are provided to experienced, knowledgeable and sensible surgeons with the assumption that such experience, knowledge and common sense will be brought to bear on each individual case.

Femur

SOP-rod:
IM pin 20%-40% diameter of medullary canal,
  Normograde or retrograde
  Open or closed placement
4 screws in distal and 4 screws in proximal fragments
Single 2.7 SOP (plus rod) in patients up to 10 kg (lateral aspect)
Single 3.5 SOP (plus rod) in patients up to 35 kg (lateral aspect)
Double 3.5 SOP (plus rod) in patients over 35 kg (lateral aspect)

Humerus – diaphysis

SOP-rod:
IM pin 20%-40% diameter of medullary canal,
  Normograde or retrograde
  Open or closed placement
  Bed into medial epicondyle
  Consider reverse placement through medial epicondyle in very distal fractures
4 screws in distal and 4 screws in proximal fragments
Single 2.7 SOP (plus rod) in patients up to 10 kg (medial aspect, lateral aspect or "spiral")
Single 3.5 SOP (plus rod) in patients up to 35 kg (medial aspect, lateral aspect or "spiral")
Double 3,5 SOP (plus rod) in patients over 35 kg. (medial aspect, lateral aspect or "spiral")

Humerus – elbow "Y" or "T"

Combined medial and lateral approaches or transulnar approach (Figure 51-15)
Anatomic reconstruction with lag screws, K wires etc
Two SOPs, one medial and one lateral
Total of 4 SOP screws in reconstructed condylar fragment (not necessary to have all 4 screws in the same SOP)
Total of 4 screws in proximal major fragment (not necessary to have all 4 screws in the same SOP)
Two x 2.7 SOPs in patients up to 20 kg
Two x 3.5 SOPs in patients over 35 kg

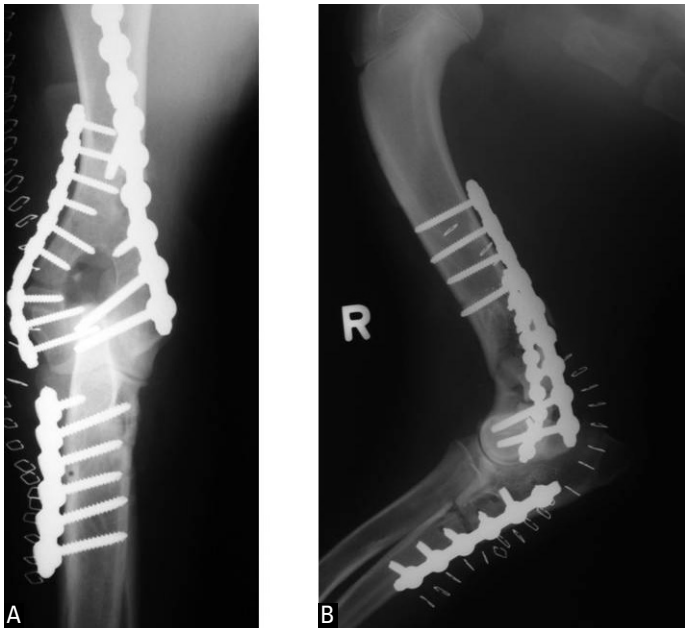


Figure 51-15. Combined medial and lateral approaches **A.** or transulnar approach **B**.

Tibia – diaphysis

IM pin 20% to 40% diameter of medullary canal,
  Normograde
4 screws in distal and 4 screws in proximal fragments
Single 2.7 SOP (plus rod) in patients up to 10 kg (medial aspect)
Single 3.5 SOP (plus rod) in patients up to 35 kg (medial aspect)
Double 3.5 SOP (plus rod) in patients over 35 kg.(medial aspect)

Ulna – Radius

Small IM pin in ulna
  Normograde or retrograde
SOP on radius
4 screws in proximal and 4 screws in distal fragment
SOP on medial or dorsal aspect distally
SOP on cranial aspect proximally
Avoid overlong screws transfixing radius and ulna
2.7 SOP in patients up to 10 kg
3.5 SOP in patients over 10 kg

Spine – Fractures or Distraction-fusion

The SOP serves well as a locking spinal fixation system, much like a pedicle screw system or locking cervical fusion devise (Figure 51-16). It does not lag onto bone which accommodates irregularities of the vertebral column. The SOP is applied to the dorsal lateral aspect of the spine, directing the screws at 30 to 40 degrees from the mid saggital plane into the vertebral bodies. Two SOP plates are applied to the left and right sides of the spine. With vertebral luxations, two three hole SOPs are applied with four screws engaging the vertebral bodies on either side of the luxation. With vertebral fractures and instabilities, longer plates are applied and may engage two vertebrae on either side of the instability. As the SOP is not lagged onto bone, the irregularities do not pose a problem as seen in applying standard orthopedic plates. The cylindrical shape lies on the pedicle and avoids compression of nerve roots exiting the intervertebral foramen.



Figure 51-16. The SOP serves well as a locking spinal fixation system, much like a pedicle screw system or locking cervical fusion device.

As the angle of screw placement is greater in the thoracolumbar area compared to the lower lumbar area, the SOP can be twisted to vary the screw angles.

The SOP can be used for cervical fracture repair, or cervical fusion in cases of instability. Two SOPs are applied to 4 adjacent vertebrae. In this way a minimum of 4 screws are on either side of the fracture or instability. The screws are directed slightly laterally. The screws need not penetrate the vertebral canal. It is important to direct the screws without damaging the spinal cord, nerve roots, venous sinus, or vertebral artery.

Always use SOPs in pairs

Cervical – ventral aspect of vertebrae

Thoracic, T-L, Lumbar - SOPs bilaterally on lateral aspects with screws directed ventro – medially

Lumbo-sacral – bilateral SOPs with screws directed ventro-medially into lumbar vertebral bodies. Caudally the SOP can be twisted and contoured to engage the iliac shaft.

Minimum of 3 scews in each vertebral body (not necessary to have all screws in the same SOP)

Use longest possible screws to engage maximum amount of vertebral bone

Penetration of far cortex is not essential but should be performed when possible

Stand SOP off spine to avoid damage to emerging nerve roots

2.7 SOP in patients up to 10 kg

2.7 and 3.5 SOPs can be used in combination

Pelvis

SOP can be used successfully in most pelvic fractures. The reconstructed pelvis is inherently fairly stable by virtue of its shape and extensive musculature. Potentially disruptive forces tend to be very much smaller than those encountered in long bone fractures. Consequently, pelvic implants can be relatively smaller than those needed for long bones and, similarly, pelvic fracture fragments can often be effectively stabilized with relatively few screws.

Ilium

Gluteal roll-up approach – can be extended caudally by trochanteric osteotomy

SOP applied to lateral aspect of pelvis

Minimum 2 screws cranial and 2 screws caudal

Twist SOP cranially to optimise stability in thin bone

2.7 SOP in patients up to 20 kg

3.5 SOP in patients over 15 kg

Two SOP plates nested whenever possible (Figure 51-17)

Acetabulum

Open reduction and temporary fixation with K wires, bone forceps etc.

SOP applied to dorsal aspect of acetabulum (Figure 51-18).

Minimum 2 screws cranial to fracture and 2 screws caudal to fracture

Single locked screw in stable butterfly fragment is acceptable

2.7 SOP in patients up to 35 kg

3.5 SOP in patients over 35 kg

Miscellaneous Applications

SOP has been used successfully in a variety of other situations including shoulder arthrodesis, pan-tarsal arthrodesis, augmentation of TPLO and TPO procedures and in the revision/salvage of failed fracture and arthrodesis surgeries. The information provided in these guidelines and the recommendations given for "standard" cases will provide the surgeon with a starting point for implant selection and surgical planning in non-routine applications.

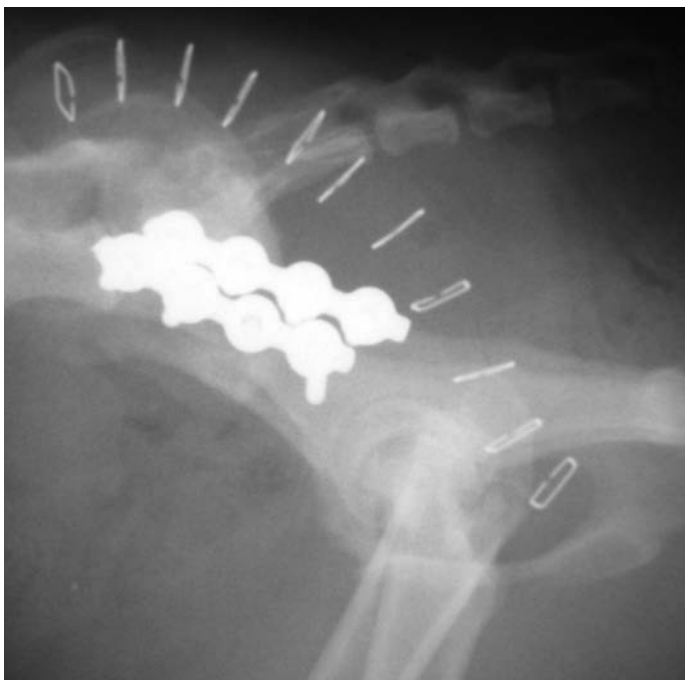


Figure 51-17. Pelvis. Two SOP plates nested.



Figure 51-18. SOP applied to dorsal aspect of the acetabulum.

Suggested Readings

DeTora MD, Kraus KH. Mechanical testing of locking and non-locking 3.5mm bone plates. Vet Comp Orthop Trauma 21: xx-xx, 2008.

Egol KA, Kubiak EN, Fulkerson E, Kummer F, Koval KJ. Biomechanics of locked plates and screws. J Orthop Trauma 18(8): 488-93, 2003.

Schutz M, Sudkamp NP. Revolution in plate osteosynthesis: new internal fixator systems. J Orthop Sci 8: 252–258, 2003.

Gardner MJ, Brophy RH, Campbell D et al. The mechanical behavior of locking compression plates compared with dynamic compression plates in a cadaver radius model. J Orthop Trauma 9: 597-603, 2005.

Sommer C, Gautier E, Muller M et al. First clinical results of the Locking Compression Plate (LCP) Injury; 34 (Suppl 2): B43-B54, 2003.

Chapter 52

Plate-Rod Fixation

Application of Plate-Rod Constructs for Fixation of Complex Shaft Fractures

Donald A. Hulse

Introduction

Bone healing occurs by direct or indirect union. Direct bone union is characterized by remodeling of existing haversian systems through simultaneous bone resorption and bone deposition. Indirect bone union occurs through the sequential deposition of tissues with increasing mechanical strength: immature connective tissue - fibrocartilage - woven bone. Another method of indirect bone union, and possibly the mechanism associated with indirect fracture reduction techniques, is by omitting the stage of fibrocartilage deposition proceeding directly to the formation of woven bone. For either direct or indirect bone union to occur, certain biologic and mechanical events must be satisfied. Biologically, adequate vascular supply and appropriate histochemicals (BMP, growth factors) are needed to support existing bone cells and provide stimulus to differentiate pluripotential cells. Mechanically, the fixation must be strong and stiff enough to prevent excessive micromotion (strain) at the fracture interface but allow sufficient micromotion to stimulate bone formation. To satisfy mechanical conditions, surgeons often choose to apply a neutralization plate or a compression plate to provide interfragmentary compression. Coupled with atraumatic technique conditions are met to achieve direct bone union and an early return to clinical function. However, if in the application of the bone plate small fracture gaps are present on the transcortical surface, high local strain will occur (small fracture gaps concentrate strain). Additionally, with highly comminuted fractures, the vascular envelope is often damaged during reduction of fracture fragments delaying the appearance of the biological elements needed for bone union. High local strain and vascular compromise act synergistically in delaying the healing response. The delay in healing is coupled with the fact that the without the integrity of the bone column stress is carried by the plate and may lead to cyclic failure of the plate. The concept of indirect reduction is one which strives to preserve the biologic envelope of the fracture area. This is chiefly applied to comminuted fractures where reduction of fracture fragments is likely to destroy vascular attachments. Experience suggests that it is preferable not to disturb bone fragments or the fracture hematoma thereby preserving the biologic milieu. The surgeon should regain spatial alignment of the limb and then bridge the fractured zone with a buttress plate being careful to limit manipulation of the soft tissues to a minimum.

From a mechanical perspective, the plate must limit the strain at the fracture site to a level that is compatible for direct or indirect bone union. Comminuted fractures distribute strain over a large

surface area which lowers interfragmentary strain to a level compatible with direct or indirect bone union. However, if the bony column is not reconstructed, the bone plate is placed under considerable stress since it must carry all the imposed physiologic load until callus (bio-buttress) is formed (Figure 52-1). If a standard plate is used, empty plate holes will be present overlying the area of comminution. In that an empty plate hole serves as a stress concentrator, plate failure can occur in this area. One method to reduce plate strain is to combine the use of an IM pin with that of the bone plate – i.e. a plate-rod construct (Figure 52-2).

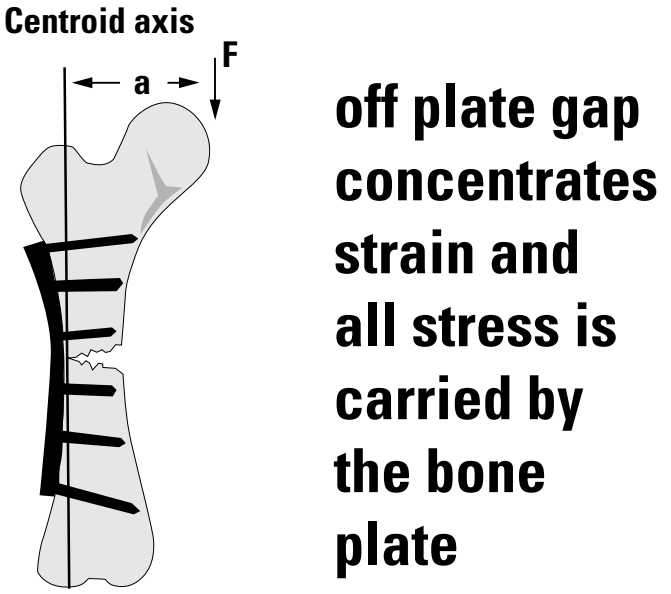


Figure 52-1.

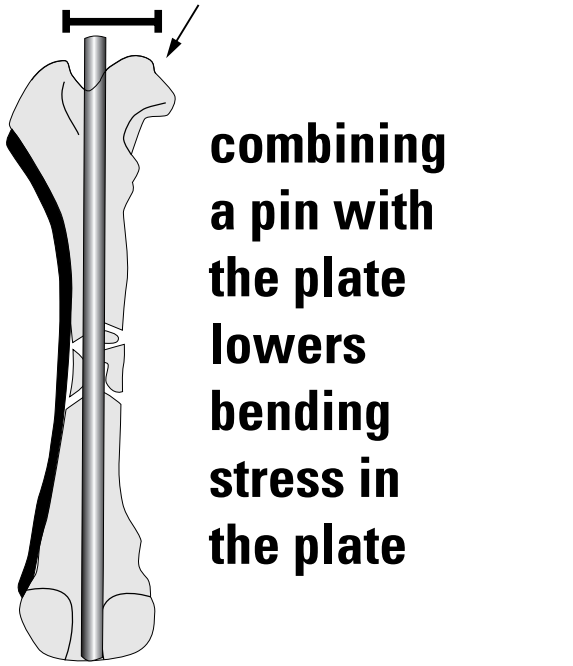


Figure 52-2.

Clinical Indications

Indications for application of plate-rod constructs are fractures where biological assessment indicates prolonged healing, mechanical assessment indicates the implants must sustain maximum stress, and clinical assessment indicates a comfortable, low maintenance system is needed. An example of a patient which fulfills these requirements would be a middle aged or older large or giant breed dog, having sustained multiple limb injuries with one injury being a multifragmented fracture with severe disruption of the soft tissue envelope. The plate/rod technique is mostly applied in the femur and humerus but may be applied to the tibia and radius as well.

Technique

Fractures of the Femur

Use a minimally invasive exposure or one employing the concept of OBDNT (Open But Do Not Touch). Insert (retrograde or normograde) an IM pin which occupies 40% the diameter of the marrow cavity. An IM pin of this approximate size reduces the stress on the plate by 50% or more. More importantly, the fatigue life of the plate is extended at least 10 fold. However, an IM pin which only occupies 25% of the marrow cavity reduces the stress in the plate by a factor of 10%. Therefore, the appropriate pin size is critical. Inserting the intra-medullary pin establishes varus-valgus alignment and assists in regaining appropriate length. Apply a buttress plate to the tension surface of the bone and contour it to the anatomic shape of the bone. Use a radiograph of the intact bone of the opposite leg as a template to help contour the plate if the bone of the affected leg is severely comminuted. Apply a plate of appropriate length to the tension surface of the bone. When applying minimally invasive technique, the plate must span the length of the bone from proximal metaphysis to distal metaphysis. Insert the most proximal and distal plate screws so that they avoid the IM pin and engage both near and far cortices. At this point examine for proper rotational alignment: As a general guide, the internal and external rotation of the hip should be equal when starting at a neutral position. Once rotational alignment is established, insert additional screws; place an additional screw proximally and an additional screw distally for a total of two screws in the end plate holes proximally and two screws in the most distal plate holes (Figure 52-3).

If it is necessary to place screws in more central plate holes, insert the plate screws so that they engage only the near cortex – i.e.monocortical screws (Figure 52-4). If large fragments are identified without disruption of the soft tissue envelope, they can be gently "lassoed" with absorbable suture and pulled into alignment. A cancellous bone graft should be harvested from the ipsilateral humerus or ilium and packed into the area of comminution.

Fractures of the Humerus

Use a minimally invasive exposure or one employing the concept of OBDNT (Open But Do Not Touch); the lateral approach is commonly used. The intra-meduallary pin should approximate 40% the diameter of the marrow cavity. An IM pin of this approximate size reduces the stress on the

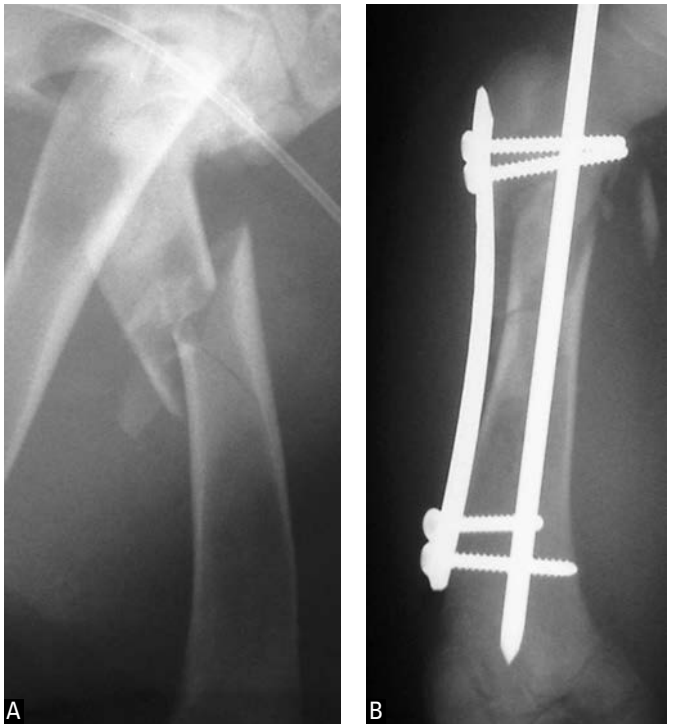


Figure 52-3. A. and **B.**



Figure 52-4. A. and **B.**

plate by 50% or more. More importantly, the fatigue life of the plate is extended at least 10 fold. The pin may be retrograded or normograded. Apply a plate of appropriate length to the tension surface of the bone. When applying minimally invasive technique, the plate must span the length of the bone from proximal metaphysis to distal metaphysis. Insert the most proximal and distal plate screws so that they avoid the IM pin and engage both near and far cortices. At this point examine for proper rotational alignment: As a general guide, the internal and external rotation of the shoulder should be equal when starting at a neutral position. Once rotational alignment is established, insert additional screws; place an additional screw proximally and an additional screw distally for a total of two screws in the end plate holes proximally and two screws in the most distal plate holes. If central screws are inserted, they should be monocortical screws (Figure 52-5).

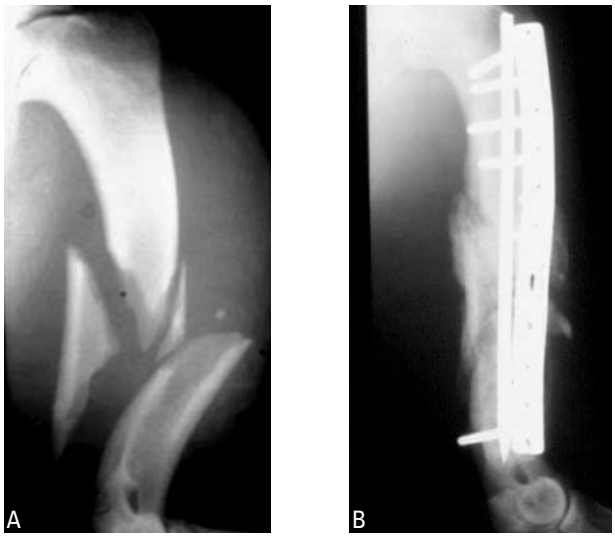


Figure 52-5 A. and **B.**

Fractures of the Tibia

Use a minimally invasive exposure or one employing the concept of OBDNT (Open But Do Not Touch); the anteromedial approach is commonly used. The intra-meduallary pin should approximate 40% the diameter of the marrow cavity. An IM pin of this approximate size reduces the stress on the plate by 50% or more. More importantly, the fatigue life of the plate is extended at least 10 fold. The pin must be normograded; the pin will assist in re-establishing appropriate varus-valgus alignment and length. Rotation alignment is judged by aligning the fabella of the femur with the medial and lateral malleoli of the distal tibia. Apply a plate of appropriate length to the medial surface of the bone. When applying minimally invasive technique, the plate must span the length of the bone from proximal metaphysis to distal metaphysis. Insert the most proximal and distal plate screws so that they avoid the IM pin and engage both near and far cortices. Place an additional screw proximally and an additional screw distally for a total of two screws in the end plate holes proximally and two screws in the most distal plate holes. If central screws are inserted, they should be monocortical screws (Figure 52-6).

Fractures of the Radius/Ulna

Use a minimally invasive exposure or one employing the concept of OBDNT (Open But Do Not Touch); the anteromedial approach is commonly used for the radial exposure, whereas a posterolateral approach is used for the ulna. The intra-meduallary pin is placed in the ulna for this construct. The size of the pin approximates the diameter of the marrow cavity of the ulna. The pin can be normograded or retrograded and should be placed prior to applying the plate on the radius. The pin will assist in re-estab-

lishing appropriate varus-valgus alignment, rotational alignment and length. Next apply the bone plate to the cranial surface of the radius. When applying minimally invasive technique, the plate must span the length of the bone from proximal metaphysis to distal metaphysis. All the plate screws are inserted as bicortical screws (Figure 52-7).



Figure 52-6. A. and **B.**



Figure 52-7. A. and **B.**

Suggested Readings

Hulse D, Ferry K, Fawcett A, et. al. Effect of intramedullary pin size on reducing bone plate strain. Vet Comp Orthop Traumatol 2000;13:185-190.

Chapter 53

External Skeletal Fixation

Basic Principles of External Skeletal Fixation

James P. Toombs

Introduction

The external skeletal fixation (ESF) system integrates the use of transfixation pins, an external frame, and sometimes an intramedullary pin connected to the frame for definitive fixation. Clinical use of the ESF system may include supplemental interfragmentary fixation techniques such as lag screws, K-wires, and cerclage wires when appropriate. Bone plate and screw fixation and the interlocking nail are examples of other fixation systems. All three of these major fixation systems are used for similar indications including fracture management, arthrodesis, and corrective osteotomy repair. Each fixation system has its unique advantages and disadvantages, and no single fixation system is preferred in all instances. They all provide suitably rigid fixation of fractures. The two internal fixation systems provide the advantage of more straight forward postoperative care compared to the ESF system. ESF, however, provides better opportunity to maximize the biologic potential for healing within the fracture zone. Specific advantages and disadvantages of the ESF system are summarized in Table 53-1.

Table 53-1. Attributes of the ESF System

Unique Advantages
• Closed or minimally-invasive application techniques are possible
• Fracture alignment can be easily adjusted during and after surgery
• Fixation rigidity can be changed to suit the physiologic needs of the tissues throughout the fracture healing process
• ESF devices are relatively inexpensive and many of the components are reusable
Disadvantages which must be Overcome
• Fixation pins penetrate soft tissues between the skin and bone and may impair the function of neurovascular bundles and musculotendinous units
• Pin tracts represent an avenue of entry for contaminating bacteria
• External fixation frames must be placed distant to the central axis of the bone and thus are at a mechanical disadvantage when confronted with disruptive forces acting at the fracture site – the fixation frame must be designed to overcome this disadvantage
• Postoperative care is more demanding and must address such issues as pin tract hygiene and the potential for the externally placed elements to injure the patient or owner

This section will cover terminology and basic principles of external skeletal fixation applicable to all of the different ESF devices commonly used in North America. Subsequent sections will cover specific application techniques for the acrylic and pin external fixator (APEF), Securos external fixator, IMEX-SK external fixator, circular external fixator, and hybrid external fixator. All of these devices provide stronger, more reliable fixation that is easier to apply compared to earlier experience with the Kirschner-Ehmer (KE) external fixator. For these reasons, the second generation veterinary external fixation devices mentioned above have for the most part replaced the KE splint in current clinical usage.

Nomenclature of ESF

An external fixator has two fundamental elements regardless of the device being used. These are the fixation pins and the connecting column (fixation frame). Fixation pins are percutaneous devices that engage both the near cortex and far cortex of major bone segments for attachment of the fixator to the bone. Originally, fixation pins were smooth Steinmann pins with trocar points that were passed at convergent or divergent angles relative to the long axis of the bone. Angling of this type of fixation pin was necessary to limit pin migration attributable to poor security of the pin-bone interface with smooth implants. One of the most important improvements in veterinary ESF was the development of affordable, properly-sized, threaded fixation pins with a raised thread profile (positive profile thread). These modern fixation pins have significantly reduced the morbidity formerly experienced with ESF due to the fact that they provide reliable, long-term pin-bone interface security. The most recent development in veterinary fixation pin technology is an intelligently designed negative profile threaded pin with a taper run out junction to alleviate the stress concentration point normally found at the junction between the threads and the shaft of the pin (Duraface pins – IMEX Veterinary Inc.). Owing to a larger pin shaft diameter, Duraface pins have been shown to be mechanically superior to positive profile pins of the same thread diameter.

Fixation pins are classified as either half-pins or full-pins. Half-pins penetrate the near side soft tissues to transfix the bone with the end-threaded portion of the pin, and they are attached to a single connecting column (Figure 53-1). Full-pins go through the near side soft tissues to transfix the bone with centrally

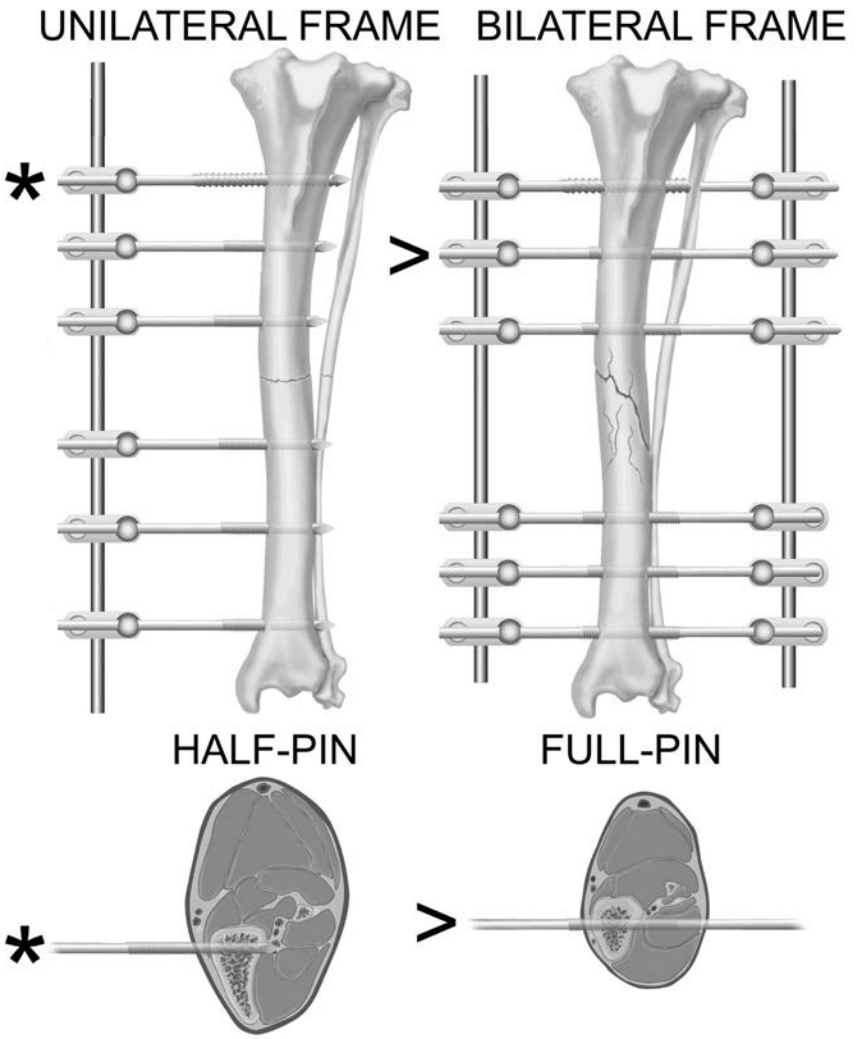


Figure 53-1. Cranial views of a unilateral frame and a bilateral frame applied to the tibia and corresponding cross-sectional views at the level of an end-threaded half-pin *(*)* and a centrally-threaded full-pin *(>)*. Note that the half-pins attach to a single medially placed connecting column (unilateral frame), whereas the full-pins attach to two connecting columns, one medially and one laterally.

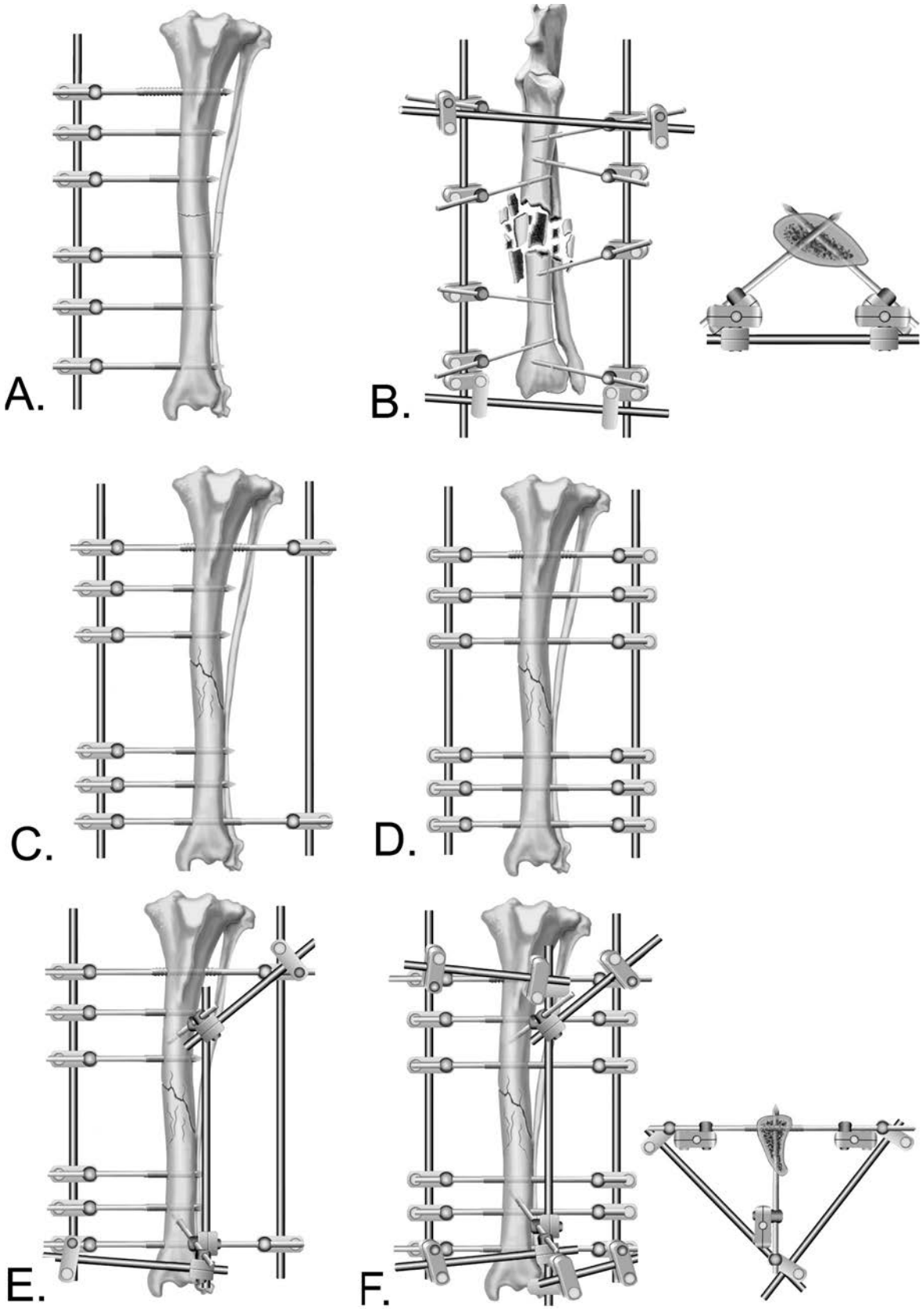


Figure 53-2. Different frame configurations. **A.** Type I-a (unilateral uniplanar) frame applied to the medial aspect of the tibia. **B.** Type I-b (unilateral biplanar) frame applied to the cranial aspect of the radius. The corresponding cross-sectional view shows the craniomedial and cranilateral pin planes that were used to build this construct. **C.** Minimal Type II (bilateral uniplanar) frame applied to the tibia. One full-pin has been applied both proximally and distally and the remaining positions are completed with half-pins placed from the medial side of the bone. **D.** Maximal Type II (bilateral uniplanar) frame applied to the tibia. Full-pins have been applied at all positions to build this construct. **E.** Minimal Type III (bilateral biplanar) frame applied to the tibia. **F.** Maximal Type III (bilateral biplanar) frame applied to the tibia. The corresponding cross-sectional view shows the medio-lateral and cranial pin planes that were used to build this construct.

placed threads, proceed through the far side soft tissues, and are attached to two different connecting columns, one on the lateral side of the limb and one on the medial side (Figure 53-1).

Connecting Columns are fastened to and interconnect the fixation pins, thus providing support for the fixation pins and the fractured bone. It is in the design of the connecting columns that the different ESF devices find their uniqueness. Similar to the KE splint, the Securos fixator and the IMEX-SK fixator use clamps and rods to form the connecting column or fixation frame. However, both of the newer devices are superior to the KE splint in terms of strength and versatility. The APEF uses acrylic cement to both grip and interconnect the fixation pins. Low cost and greater freedom in terms of the shape of the frame are the inherent advantages of the APEF frame. The clamp and rod devices offer the advantages of reusable components and greater ability to easily make adjustments of the frame in terms of fracture alignment and fixation rigidity. Once the acrylic frame has cured into a rigid solid, frame adjustments are laborious and messy.

Classification of different external fixator frame configurations is useful in that it evokes a mental picture of what a given construct looks like, and furthermore, the classification predicts the mechanical performance of one construct versus others. The most commonly used classification system initially considers whether a fixator is unilateral (connecting column on one side of the limb) or bilateral (connecting columns on both sides of the limb), and then further considers whether it is uniplanar (all fixation pins placed in more or less a single plane) or biplanar (fixation pins placed in two distinctly different planes). This consideration results in four different classification types (Figure 53-2). In order of weakest to strongest they are: Type I-a (a one column construct that is unilateral and uniplanar); Type I-b (a two column construct that is unilateral and biplanar); Type II (a two column construct that is bilateral and uniplanar); and Type III (a three column construct that is bilateral and biplanar). At each step forward in this progression, construct rigidity increases (i.e Type I-a is the weakest and Type III is the strongest).

Type I-a configurations (Figure 53-2A) may be appropriate for straight forward fractures in patients that are likely to heal quickly (i.e not comminuted fractures in patients that are elderly or have other medical problems that will delay bone healing). Type I-a frames are generally applied to the medial aspect of the tibia, the lateral aspect of the femur and humerus, and the craniomedial aspect of the radius. They may be supplemented with a small intramedullary pin (one that fills approximately 40% of the medullary cavity) and there are mechanical advantages to attaching this pin to the external fixation frame. This is called an intramedullary (IM) pin tie-in configuration (Figure 53-3). This strategy is most often employed with external fixators applied to the femur or humerus. The increased distance of the frame from the central axis of these bones (because of thick overlying soft tissue) makes the external fixator extremely vulnerable to disruptive bending forces without the additional strength provided by the centrally placed IM pin. The IM pin tie-in strategy is seldom used for the tibia, and is contraindicated for the radius. An acceptable alternative for the bones of the antebrachium involves placing a small IM pin in the ulna and applying an external fixator to the radius.

A Type I-b configuration (Figure 53-2B) is basically the combination of two Type I-a frames placed on different aspects of the bone. Mechanical performance is optimized when the second frame is placed in an orthogonal position relative to the first (i.e. the plane of the fixation pins of one frame is 90° different from the plane of the fixation pins of the second frame). On the tibia this would translate as a medial frame and a cranial frame. The two pin planes on the radius are usually craniomedial and craniolateral (coming in on either side of the extensor muscles) and the degree of separation between the pin planes is often less than 90°.

Anatomical restrictions necessitate the construction of modified Type I-b frames for the femur and humerus (Figure 53-4). The major safe corridor for pin placement is found laterally, although a reasonably safe craniolateral corridor may also be used in the proximal 25 to 30% of these bones. Two different modifications are shown: a two-frame construct supplemented with an IM pin tie-in (Figure 53-4A); and a three-frame construct (Figure 53-4B). The major frame has been placed laterally in both cases. Fixation pins placed in a craniolateral plane enable the construction of a second craniolateral frame. If a full-pin is placed through the distal metaphysis, the medial aspect of this pin provides the opportunity for construction of a third (craniomedial) frame. The three-frame construct can also be supplemented with an IM pin tie-in (not shown in Figure 53-4B). Modified Type I-b frames are sometimes used on other bones as well (Figure 53-5).

In order for a fixation frame to qualify for Type II status, it must have a minimum of two full pins, one in the proximal segment

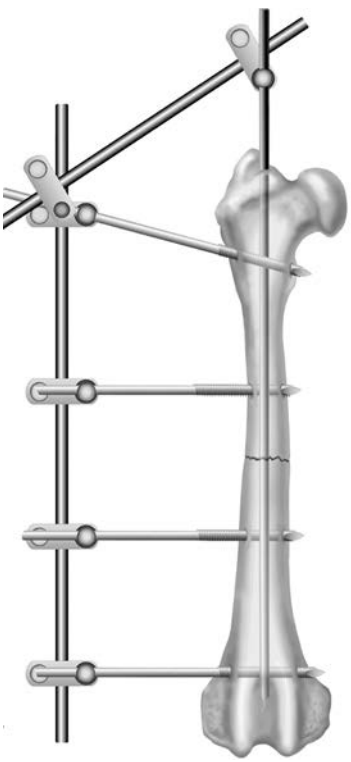


Figure 53-3. Type I-a frame applied to the lateral aspect of the femur. Note that a small intramedullary pin supplements the external fixator and is connected to the fixation frame. This is referred to as an IM pin tie-in construct.

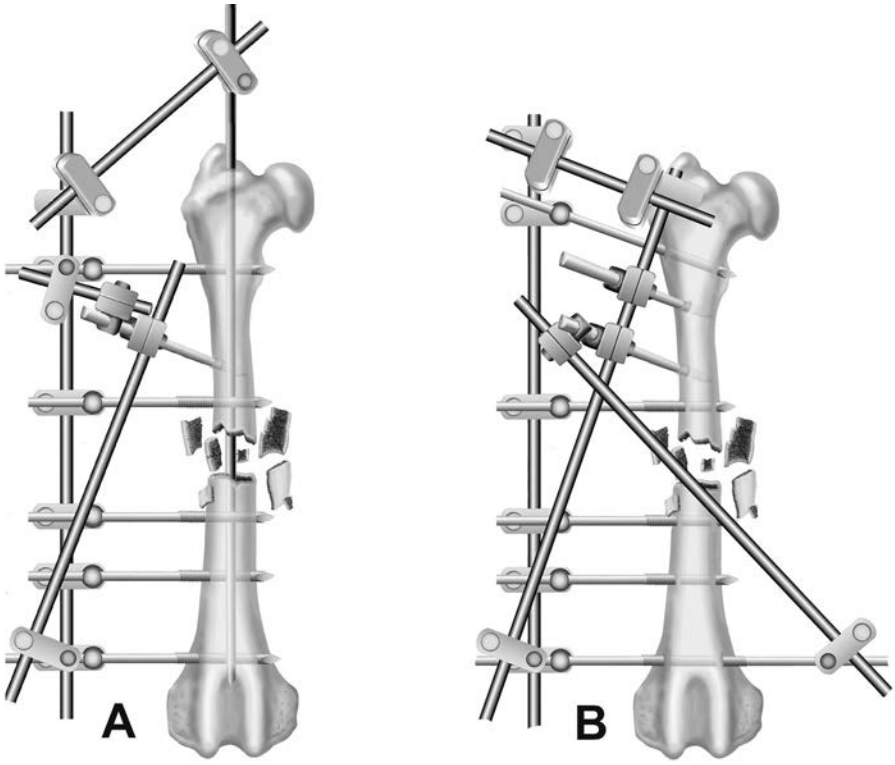


Figure 53-4. Cranial views of modified Type I-b frames applied to the femur. **A.** Two-frame Type I-b construct with an IM pin tie-in. The major frame has been applied laterally and the secondary frame is constructed off of a craniolaterally placed half-pin in the proximal segment of the bone. **B.** Three-frame Type I-b construct. The major frame has been applied laterally. The secondary frame is constructed off of several craniolaterally placed half-pins in the proximal segment. The tertiary frame is applied to the medial aspect of a distally placed full-pin and connected to one of the craniolaterally placed half-pins.

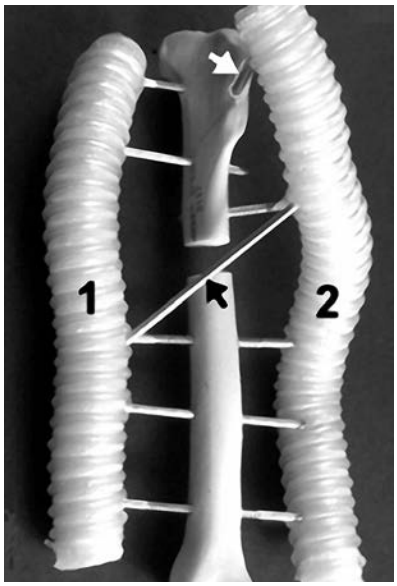


Figure 53-5. Craniomedial view of a Type I-b acrylic frame fixator (APEF) applied to the tibia. The major frame *(1)* has been applied medially. The secondary frame *(2)* was placed laterally along the distal aspect and contoured to grip half-pins placed craniolaterally and cranially in the proximal segment. This cannot be called a Type II frame because no full-pins have been place in the proximal segment of the bone.

and one in the distal segment. In a minimal Type II frame, all of the rest of the fixation pins in the construct are half-pins (Figure 53-2C). If full-pins are used at all positions within the construct, this constitutes a maximal Type II frame (Figure 53-2D). The creative APEF construct shown in Figure 53-5 falls just short of being a Type II configuration due to lack of a proximal full-pin. Although it has two connecting columns and multiple full-pins, all of the fixation pins applied to the proximal segment are half-pins. This is another example of a modified Type I-b construct. It has two connecting columns (medial and craniomedial) but it is not bilateral proximally, and it has groups of fixation pins placed in distinctly different planes (i.e. a two column configuration that is unilateral and biplanar).

General Strategies for External Fixator Application

The following general principles are important for the proper application of an external fixator regardless of the specific device being used. A complete work-up including good quality, properly positioned radiographs (two orthogonal projections including the injured bone and the joint above and below it), thoughtful pre-operative planning, and aseptic surgical technique are required similar to other orthopedic procedures.

The Hanging Limb Technique

The hanging limb technique (Figure 53-6) and four-corner patient draping are performed so that the surgeon has access to the

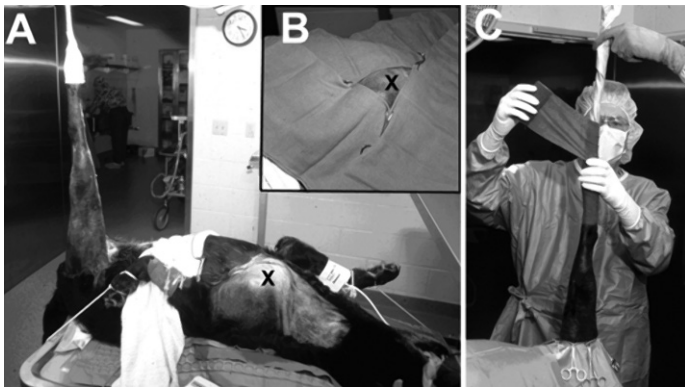


Figure 53-6. The hanging limb position and surgical draping in a dog with a comminuted midshaft fracture of the left tibia. **A.** The dog is placed in dorsal recumbency on the surgical table and the injured limb is suspended via an adhesive tape stirrup to a hook in the ceiling. The left proximal humerus *(x)* has been clipped and prepared to enable harvesting of a cancellous bone graft. Note that the limb has been secured caudally to facilitate easy access to the greater tubercular region of the humerus. **B.** Sterile towels were applied to isolate the cancellous bone donor site *(x)*. This site is covered with paper drapes during four-corner draping of the patient. When cancellous bone graft is harvested, the towel clamps are palpated through the paper drape and a window is cut through to for access to the donor site. **C.** Four-corner draping of the patient has been completed and a sterile covering is being placed over the tape stirrup used to suspend the leg.

entire circumference of the limb. If a cancellous bone graft is needed, the patient must be clipped, prepped, and draped to accommodate this as well.

Important aspects of the hanging limb technique are as follows. The equipment needed to hang the limb is a sturdy hook positioned in the ceiling directly over the surgery table and a surgical table that can be raised and lowered. Adhesive tape is secured to the paw of the injured limb leaving very long ends to form a stirrup. The tape should be placed on the paw securely so that it will not fall off with tension, but should not be so tight that it will constrict blood supply to the foot. Elevation of the surgical table should position the injured segment of the limb at a convenient working height for the surgeon when the limb is suspended from the hook with the tape stirrup. The surgical table is then lowered until the injured hindquarter or forequater is suspended about 1cm above the surface of the table. The hook, tape stirrup, and limb should form a straight vertical line when viewed cranially or caudally and laterally. The paw and the proximal limb should be palpated through the drapes to ensure that there is no rotational malalignment.

Suspension of the injured leg is often maintained throughout surgery when an external fixator is being applied to either the radius or the tibia. This provides a linear traction force that provides approximate alignment of the fracture and proper positioning of the overlying soft tissues. The distal portion of the leg and a portion of the tape used to suspend it are covered with sterile drape material to prevent contamination of the surgery site. If the surgeon needs to move the joints above and below the fractured bone during surgery to check for proper rotational alignment, the surgery table can be temporarily raised thus relieving traction on the limb. After proper alignment is verified, the table is lowered to restore traction on the limb. This provides a much more stable working environment greatly facilitating external fixator application.

Keeping the limb suspended throughout surgery is not recommended for application of an external fixator to the femur or humerus. The larger muscle mass surrounding these bones effectively resists the ability of traction to restore proper alignment of the fractured bone. Additionally, a small IM pin is often used to supplement the external fixator, and placement of this pin is extremely difficult with the limb suspended. For fractrures of the femur or humerus, the hanging limb technique is used to prepare the leg for surgery, but after the limb is draped, the paw is grasped with a piece of sterile drape material and the tape suspending the limb is cut. The distal portion of the limb is then covered by wrapping it with the sterile piece of drape material.

Open Versus Closed Repair Techniques

The choice of various open versus closed repair techniques should be based upon the specific bone involved, the type of fracture, and what can be accomplished in terms of restoring meaningful load-sharing.

Invasive open technique involves a panoramic surgical approach to the fractured bone and no restrictions in terms of handling intermediate fragments within the fracture zone. This method results in a variable degree of disruption of blood supply to the injured tissues. The goal of invasive open technique is anatomic reconstruction of fracture segments and fragments to restore a load-sharing bony column. Invasive open technique should not be used unless achievement of this goal is relatively certain.

Open but do not touch technique (OBDNT) is a relatively atrumatic method with a goal of restoring normal alignment of the major proximal and distal fracture segments. No attempt is made to reduce intermediate fracture fragments. A panoramic approach is made to the fractured bone to facilitate proper alignment of the fracture. The major proximal and distal segments can be grasped at a safe distance away from the fracture zone and manipulated to restore axial alignment, normal length of the injured limb segment, and proper rotational alignment. The surgeon accepts a "hands off" (do not touch) philosophy with regard to the fracture zone and the intermediate fragments and fracture hematoma that are found within it. Intermediate fracture fragments are left in situ to act as a living bone graft. Liberal application of cancellous bone graft over the fracture region is usually done as well. The OBDNT technique is extremely useful for treatment of comminuted shaft fractures, especially those involving the femur or humerus where thick overlying soft tissues often complicate the process of restoring normal fracture alignment.

Miniexposure technique is more invasive than OBDNT but less invasive than the open repair technique. This method involves making a small incision over the fracture region to enable manipulation of the proximal and distal segments with the goal of improving alignment or achieving anatomic reduction. A two-piece oblique midshaft fracture of the tibia is a clinical example of where the

miniexposure technique would be helpful. In this case a limited incision would be made over the medial aspect of the bone. The incision should be of sufficient length to allow for reduction of the fracture and application of several lag screws to maintain it. The bone would then be spanned with an external skeletal fixator for definitive stabilization. Similar to other open repair techniques, application of a cancellous bone graft should be considered to offset the negative biologic effects of the surgical approach when the miniexposure technique is used.

Closed Technique preserves the biological environment of the hard and soft tissues in that no surgical approach is made to the fracture region. Functional alignment of the fractured bone rather than anatomic reduction is the goal of this technique. Closed repair technique is most applicable to comminuted shaft fractures of the tibia and radius/ulna. It is seldom a useful technique for dealing with similar fractures of the femur or humerus due to the large muscle mass surrounding these bones. Approximate alignment of the fracture is obtained by use of the hanging limb technique. Fixation pins of the external fixator are placed through separate 1cm long access incisions over the bone. Alignment of the fracture is adjusted, if necessary, as a spanning external fixator is placed to stabilize the fractured bone.

Principles of Fixation Pin Selection

Threaded pins with a raised (positive) thread profile and Duraface negative profile threaded pins provide for optimal pin-bone interface security and longevity. Other negative profile threaded pins and smooth (nonthreaded) fixation pins are notorious for loosening prematurely and should be avoided. There are two basic types of positive profile threaded pins: end-threaded half-pins; and centrally-threaded full-pins. Further details about the fixation pins available from different manufacturers can be found in the later sections of this chapter on specific ESF devices (APEF, Securos Fixator, and IMEX-SK Fixator).

Fixation pins must be appropriate in size relative to the bone in which they are placed. The threaded diameter of the fixation pin selected should be approximately 25% of the bone diameter. The ability of a pin to tolerate disruptive forces increases exponentially with increasing diameter, but using too large a pin weakens the bone and increases the risk of secondary fracture through the pin-bone interface when it is confronted with postoperative weight-bearing loads.

Use of fixation pins with deeper and broader threads (cancellous thread) in areas of soft metaphyseal bone will prolong the pin-bone interface at these locations. In hard diaphyseal bone, fixation pins with a standard (cortical) thread pattern should be used. The difference between cancellous thread and cortical thread is shown in Figure 53-7. Hardness of the bone can be gauged during pre-drilling, but when in doubt the surgeon should select fixation pins with cortical thread. Placement of cancellous thread pins in hard cortical bone results in microfractures that compromise pin-bone interface security. The most appropriate locations for the use of cancellous thread fixation pins are the proximal metaphysis of the humerus and tibia, and the distal metaphysis of the femur.



Figure 53-7. End-threaded half-pins with cortical thread **A.** and cancellous thread **B**.

Principles of Fixation Pin Insertion

Optimal pin-bone interface security depends upon fixation pins being placed in mechanically intact bone. This requires pin application a safe distance away from fracture lines and fissure lines. The safe distance has been stated to be 1 cm away from the fracture zone. A more useful guideline suggests that the safe distance is equal to one bone diameter. This guideline adjusts up and down according to patient size which is entirely appropriate, as 1 cm can be a dauntingly long distance in the bone of a tiny kitten, yet a negligible distance in the bone of a Great Dane.

Pin-bone interface security also depends upon fixation pins being properly centered within the bone. When there is maximal distance between where the pin penetrates the near cortex and the far cortex, the pin is optimally centered within the bone (Figure 53-8A). Pre-drilling of the bone should precede fixation pin insertion. The surgeon must pay careful attention while pre-drilling to make sure that the hole is correctly centered in the bone. With a properly centered hole, there is initial resistance as the bit cuts through the near cortex, followed by no resistance as the bit falls some distance across the medullary cavity. A second point of resistance is encountered as the bit cuts through the far cortex. If these separate resistance points are not felt during pre-drilling, the hole is probably through the side of the bone (Figure 53-8B). When this problem is encountered, the surgeon should abandon that hole and drill another one that is properly centered a safe distance away from the poorly positioned hole.

When a bone is approximately round in cross-section, what feels like the center when walking the drill sleeve across it is the proper location for the pre-drilled hole. The proximal tibia is

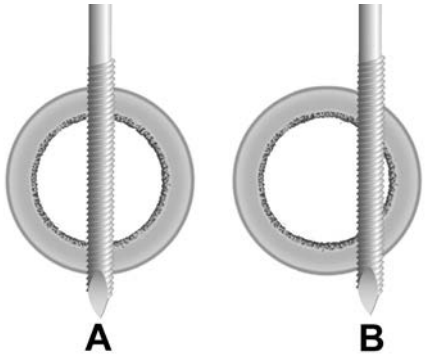


Figure 53-8. Fixation pin centering as seen in cross-sectional images of the bone. **A.** Optimal centering of the fixation pin maximizes the distance between where the pin engages the near and far cortex of the bone. **B.** This distance in reduced with poor pin centering which predisposes secondary fracture through the pin hole.

triangular in cross-section. At this location a properly centered hole should be placed slightly caudal to what feels like the center of the bone in order to increase the distance between the points of near cortical and far cortical engagement.

Fixation pins are typically placed through separate release incisions at least 1 cm in length that are made over the center of the bone. With minimally invasive technique, the surgeon is frequently unable to see the bone. To determine the location of the bone, the surgeon can probe through the overlying soft tissues with sterile hypodermic needles and mark the edges with strategically placed needles. An incision centered over the bone is then made through the skin and subcutaneous tissues with a scalpel blade. The release incision through deeper tissues is made by blunt dissection down to the bone using a mosquito hemostat or Metzenbaum scissors. Muscle tissue should be divided parallel to the direction of its fibers (usually parallel to the long axis of the bone). Exposure can be maintained by placement of mini Gelpi retractors in the release incision.

A drill sleeve is passed through the incision down to the level of the bone and walked along its surface to locate the edges. Once the drill sleeve is centered over the bone, a drill bit is inserted through it and a hole is pre-drilled in the bone. The diameter of the drill bit should be equal to or slightly smaller than the diameter of the smooth shaft of the pin to be applied. The drill must be spinning in a clockwise direction for the drill bit to cut through the bone. Operation of the drill at high speed during pre-drilling is safe because the flutes of the bit allow an escape channel for debris, thus avoiding thermal necrosis of the bone. In contrast, the drill must be spinning clockwise at a much slower speed when the threaded fixation pin is applied to the bone. This is due to the lack of an escape channel for debris as the threads of the pin cut corresponding threads into the bone. If the pin is allowed to spin too quickly, thermal necrosis of bone immediately surrounding the pin will occur, thus jeopardizing the security of the pin-bone interface.

Once the threads of a positive profile pin cut the initial threads in the near cortex of the bone, the slow clockwise rotation of the pin will advance it through the bone by gear effect. Any attempt of the surgeon to speed this up (e.g. applying greater pressure on the drill or using it a higher speed) is detrimental to the pin-bone interface and should be avoided. The full threaded diameter of the pin should engage the far side of the far cortex in order to obtain a mechanically optimal pin-bone interface. This means that the trocar tip of the pin will extend into the soft tissues on the far side of the bone when a half-pin is applied. The surgeon can usually palpate the tip of the pin exiting the far cortex through the overlying soft tissues in order to judge proper length. Ideally, only the trocar tip of the pin exits the far side. If a longer portion of the pin protrudes and there are no vital anatomic structures near it, it is better to leave the pin "too long" instead of switching the drill to reverse (counterclockwise spin) and backing it up. Two-way insertion of a fixation pin (going in too far and then partially backing out) has been shown to weaken the pin-bone interface.

The greater the amount of soft tissue that a fixation pin must traverse before reaching the bone, the greater the likelihood that it will cause postoperative morbidity. Cross-sectional anatomy of the limb at various levels proximal to distal on the injured bone should be carefully considered in order to select the safest soft tissue corridors to be used for fixation pin placement sites. It is important to avoid large muscle bellies, tendons, blood vessels, and nerves. If penetration of a muscle belly cannot be avoided, an ample release incision to prevent soft tissue tension on the fixation pin is necessary in order to keep morbidity low. Preferred pin placement corridors in different bones are summarized in Table 53-2. The importance of ample release incisions at every pin placement site cannot be overemphasized. When placement of the external fixator is complete, the surgeon should release traction on the leg and move the joints above and below the

Table 53-2. Preferred Pin Placement Corridors for Different Bones

Bone	Optimal Pin Placement Zones	Secondary Acceptable Zones
Tibia	Medial aspect due to minimal soft tissue coverage	Cranial aspect of the distal 75% of the bone; avoid tibial tuberosity region
		Lateral aspect of the distal 75% of the bone is useful for Type II frames
Radius	Craniomedial aspect has minimal soft tissue coverage	Craniolateral aspect for 2nd frame of Type I-b constructs
		Medio-lateral plane for Type II frames
Femur	Lateral aspect of the diaphyseal region	Craniolateral aspect in the proximal 25% of the bone for 2nd plane of Type I-b constructs
		Lateral and medial aspects of the distal metaphysis and center portion of the condyles laterally and medially
Humerus	Lateral aspect of the diaphysis but be careful distally to avoid the radial nerve	Craniolateral aspect in the proximal 35 % of the bone
	Lateral and medial aspects of the central portion of the condyle	Lateral and medial aspects of the distal metaphysis as long as pin position does not interfere with elbow function

NOTE: Fixation pins should be placed at a safe distance away from the proximal and distal joint surfaces of the bone (i.e. at least 1 bone diameter away).

injured bone through full ranges of motion. If there is soft tissue tension detected at a pin placement site during movement of the joints, the release incision should be enlarged to relieve it.

Principles of Frame Construction

Significant mechanical gains occur with the application of additional fixation pins in a fracture segment up to and including the 4th pin. As a general rule, the surgeon should strive to place a minimum of three fixation pins proximal to the fracture region and three fixation pins distal to it. Fixation pins in different planes can be summed to achieve this goal (i.e. a Type I-b fixator with two medially placed pins and one cranially placed pin in the proximal fracture segment would provide the recommended minimum of three fixation pins per segment).

The working lengths of the fixation pins and the fixation frame (Figure 53-9) should be kept as short as possible to optimize the mechanical performance of the external fixator. The concept of working length can be appreciated by taking a 1/8" (3.2 mm) Steinmann pin and applying a controlled amount of bending force to it. When the pin is grasped with both hands, one at each end of the pin (long working length) and force is applied, the pin feels quite flexible. When the pin is grasped more toward the middle portion (i.e. short working length) and the same amount of force is applied, it feels more rigid. Fixation pin working length is the distance between where the pin attaches to the frame (where it exits the bolt of the pin-gripping clamp) and where it enters the near cortex of the bone. Soft tissue thickness over the bone basically dictates the fixation pin working length. Some degree of postoperative swelling should be anticipated and the fixation frame should be positioned far enough away from the skin to accommodate this. It is recommended that the nearest portion of the fixation frame (usually the inner aspect of the fixation clamps) should be positioned about 1cm away from the skin. This keeps fixation pin working length relatively short, but allows a small amount of space for postoperative swelling. Fixation frame working length is the distance between the fixation pins placed immediately proximal to and immediately distal to the fracture zone. These implants should be placed as close to the fracture as possible while respecting the guideline of safe distance, which is one bone diameter away from the fracture region. Frame working length is mainly determined by the length of the fracture zone.

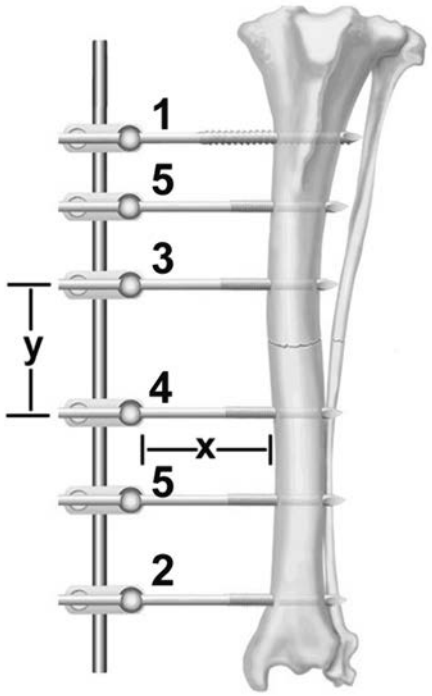


Figure 53-9. Fixation pin and frame working lengths and the order of pin placement. Fixation pin working length *(x)* is the distance between the near cortex of the bone and the inside of the pin-gripping clamp. Frame working length *(y)* is the distance between the fixation pins that are closest to the fracture. Fixation pins are generally placed in the following order in relation to the fracture: the pins farthest away are placed first *(pins 1 and 2)*; the pins closest to the fracture are placed next *(pins 3 and 4)*; and finally pins are applied between the far and near pins in each segment *(pins 5 and 6)*.

Clamps should be positioned on the connecting rod such that fixation pin working length is kept as short as possible. When the clamp is positioned such that the pin-gripping bolt is between the connecting rod and the skin surface (Figure 53-10A), this is referred to as the "clamp-in" position. This is the preferred position because it shortens fixation pin working length. When the clamp is positioned such that the pin-gripping bolt is toward the outer aspect of the connecting rod (Figure 53-10B), this is referred to as the "clamp-out" position". This unnecessarily increases fixation pin working length. The clamp-out position should only be used when it provides a unique angle required to place the pin in a safe region of the bone that cannot be obtained with the clamp-in position.

Fixation pins should be placed in a specific order during construction of the frame (Figure 53-9). Pins are initially placed at the proximal and distal ends of the bone. A connecting rod is attached to the proximal and distal pins with clamps. The surgeon should check at this point to make sure that acceptable alignment of the bone has been achieved before proceeding. The proximal and distal clamps can be loosened to permit adjustment of fracture alignment if needed. Adjustments are easy to make at this early phase of frame construction, but become increasingly difficult as additional fixation pins are added to each segment of the bone. The fixation pins closest to the fracture zone are

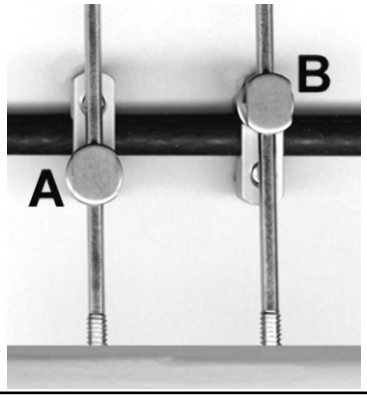


Figure 53-10. Clamp-in position **A.** positions the pin-gripping bolt of the clamp closer to the bone compared to the clamp-out position **B.** Note that fixation pin working length is shorter when the preferred clamp-in position is used.

applied next. Empty clamps are placed on the connecting rod and pre-drilling is done via a drill sleeve passed through the pin bolts of these clamps. This far-far-near-near strategy of pin placement relative to the fracture zone provides for optimal mechanical performance of the fixation frame. Additional fixation pins are placed in the middle portion of each fracture segment until sufficient stability is obtained.

The simplest frame configuration that will provide adequate stability for a given fracture should be used. For relatively straight forward two-piece midshaft fractures, a Type I-a frame is often sufficient on the tibia or the radius. With this type of fracture in the femur or the humerus, use of a Type I-a frame with an IM pin tie-in is recommended. If intraoperative evaluation by palpation of the fracture reveals that a Type I-a frame is allowing too much deflection of the fracture, it is easy to add a second frame in another plane thus converting it to a stronger Type I-b construct. This strategy is applicable to all four bones mentioned. For challenging comminuted shaft fractures or the tibia or radius, the surgeon should plan for a stronger frame and start with either a Type I-b or a Type II construct. Challenging fractures of the femur and humerus can often be more reliably managed with internal fixation techniques such as interlocking nail (see Chapter 50), bone plate and screw fixation (see Chapter 51), or plate-rod fixation (see Chapter 52).

When application of the external fixator is complete, do not trim the fixation pins short until acceptable fracture alignment has been verified with postoperative radiographs. The ability to make adjustments is often compromised once the fixation pins have been cut short. Once acceptable alignment has been obtained, all fixation pins should be trimmed such that the cut edge of the pin does not extend beyond the outer edge of the clamp. Even shorter than this is preferable, when possible (the size and style of the pin cutter often determines the degree to which pins can be trimmed).

Postoperative Care

Effective postoperative management of an external fixator is defined by the following goals: 1) a healthy patient that walks comfortably on the limb throughout the healing period; 2) clinical union of the fracture and removal of the fixator as quickly as possible; and 3) avoidance of fixator induced injuries to the patient, owner, and veterinarian. Achieving these goals depends upon a carefully structured program of controlled physical activity, soft tissue care, pin tract hygiene, bandaging of the fixator, and appropriately timed staged disassembly of multiplanar frames. Because the fixator is external to the limb and has many edges (some of which are sharp), it can potentially injure the patient or owner if it is not properly bandaged. Worse yet, if the fixator becomes entangled in elements of the animal's environment (i.e. chain-link fence, etc.) and the animal struggles to free itself, the repair may be torn apart. Careful bandaging of the fixator allows it to bounce off of environmental objects rather than being caught up in them and protects the owner and the patient from being injured by the sharp edges of the fixator. Postoperative care of the soft tissues surrounding the fixation pins is equally critical to patient comfort during the early stages of healing. Excessive pin tract inflammation will increase patient morbidity and decrease use of the limb. This inflammatory response is attributed to the presence of a contaminated foreign object (the fixation pin), inadequate drainage, and too much soft tissue motion around the fixation pins.

Careful attention to wound management during the first five to seven days after ESF application is critical in order to control of pin tract contamination and soft tissue inflammation. The pin tracts are vulnerable to infection until the proliferative stage of healing (fibroblasts and neocapillaries) leads to development of a bacteriostatic lining of granulation tissue. The more contaminated the early pin tract wound becomes, the longer it remains in the debridement stage of wound healing (polymorphonuclear leukocytes and macrophages). The longer the pin tract remains in the debridement stage the greater the likelihood of infection. This is because the microorganism load will begin to overwhelm regional defense mechanisms. Infection will further prolong the debridement stage, creating even more inflammation. This negative cycle of events leads to high patient morbidity, eventual disruption of the pin-bone interface, and finally to loosening of the fixator. To avoid this vicious cycle, the microorganism load of the pin tracts must be kept as low as possible to enable a brief debridement stage, rapid onset of the proliferative stage, and development of healthy granulation tissue around the fixation pins.

Reduction of soft tissue motion can be attained by packing the area around the pins and between the skin surface and the fixator frame with a bulky wad of gauze as part of the standard postoperative bandaging regime. It makes little difference to the pin tract microflora whether the fixation pin is moving in the soft tissues or the soft tissue is sliding along the pin. The effect is the same, that being increased pin tract inflammation, and pain. All pins will cause some degree of inflammation and drainage. This drainage will inevitably contain bacteria. When the fluid can drain freely, secondary infection is rare unless the pin is loose in the bone or the soft tissues are moving excessively on the pin. If this drainage is blocked, secondary infection of the pin tract is likely.

Adequate release incisions facilitate drainage and regularly changed gauze packing acts like a wick to pull it out from the wound. Clinical signs distinguish normal drainage (usually serous) from that associated with pin tract sepsis. Signs suggestive of an infected pin include excessive drainage (usually thick and foul-smelling), pain, lameness, induration or erythema of the soft tissues, and pin laxity. Failure to keep the pin tract clean and freely draining and failure to relieve soft tissue tension on the pin can promote infection, increase patient morbidity, and lead to pin loosening.

Early Postoperative Management

Systemic antibiotics are given throughout surgery and during recovery from general anesthesia and are usually discontinued thereafter. Immediate post-op pain management is generally achieved with morphine. The day after surgery, a 1 week course of carprofen (2.2 mg/kg per os BID) is started.

Pin tract wounds should be covered with a sterile dressing for the first five to seven days (or until healthy granulation tissue develops). Pin-skin junctions are cleaned with dilute hydrogen peroxide solution to remove blood clots, serum crusts, etc. A thin film of triple antibiotic ointment (polymyxin, neomycin, bacitracin) is applied to the skin around each pin placement site. Wads of "fluffed-up" gauze sponge are packed around the pins and between the skin surface and the fixator frame to immobilize the soft tissues, to keep the pin tracts clean, and to wick drainage away from the wounds. Gauze packing is held in place with an overwrap of Kling bandaging gauze. This sterile dressing is covered with a modified Robert Jones bandage for at least the first 36 to 48 hours to prevent swelling in the distal portion of the limb. The fixator dressing is changed at 36 to 48 hours and every other day thereafter until healthy granulation tissue develops. Application of a Robert Jones bandage over the dressing should be continued during the first week after surgery.

After about 1 week, the Robert Jones bandage is usually abandoned in favor of a simpler "bumper" bandage. This is intended to pad and cover the edges of the frame to reduce the likelihood of it causing injury or entanglement. At each bandage change the same methods of skin hygiene and gauze packing described above are used. Physical activity is limited to short walks outside on a leash for urination and defecation.

Care at Home

After granulation tissue develops the owner is instructed to change the bandage and packing on an as needed basis, usually every 3 to 5 days. If the bandage becomes wet or dirty, if wound drainage increases, if odor is detected, or if the animal is licking or biting the wrap, more frequent bandage changes may be necessary. Physical activity is restricted to leash walks. Running, jumping, and playing with other animals or children should be discouraged. Walking up and down stairs should be kept to a minimum. Good functional usage of the limb is expected throughout the healing period. If this suddenly declines the animal should be re-examined as soon as possible. If the owner is willing, rechecking these patients every other week even if they are doing well is recommended. Radiographic examination at about 6 weeks after surgery should be done to assess healing and to enable staged disassembly of the fixator.

Staged Disassembly of the External Fixator

It is biologically advantageous to reduce the stiffness of the fixator (via staged disassembly) during the later stages of fracture healing. This involves the sequential removal of fixation elements to allow the healing bone to be stimulated by carefully controlled increases in axial stress. During the early stages of bone healing, rigid fixation benefits revascularization of the fracture region, maintains tissue strain at a low enough level to enable the formation of bridging callus, and allows the patient to walk comfortably on the limb. During the later stages of bone healing, strategic reduction of fixation rigidity transfers a greater percentage of axial weight bearing forces to the injured bone while continuing to protect against disruptive bending and rotational forces, and stimulates bony remodeling according to Wolff's Law.

Research has shown that there is an "optimum time window" for initiating staged disassembly. In mature patients this interval is generally felt to be at 6 to 8 weeks after surgery. In young growing patients, this window probably occurs several weeks earlier. The decision to begin staged disassembly is based upon radiographic appearance and palpation of the fracture. When there is scant evidence of bridging callus and palpable instability of the fracture, staged disassembly is delayed.

When disassembly is determined to be appropriate, the following guidelines are applied: 1) The external fixator is examined for any fixation pins that are showing signs such as excess drainage or inflammation. If there are "problem pins", the disassembly strategy should include their removal. 2) Consider removing any pins that have the potential to cause morbidity. Examples would include a pin in the soft bone of the distal femur, or one that goes through the thick lateral soft tissues of the proximal tibia. 3) When possible, it is best to remove frames rather than just individual pins. 4) When a Type II or Type III configuration is present, conversion to a Type I-a or Type I-b to encourage axial loading of the bone is recommended. When a Type I-b is present, down-staging to a Type I-a is appropraite. 5) When an IM pin "tie-in" configuration is present, the IM pin is usually removed last in an attempt to encourage axial loading while protecting against bending stress. It is advisable to retain one proximal fixator pin to enable maintenance of the "tie-in" in order to prevent IM pin migration. However, if the IM pin is a significant source of morbidity, it may be the first element of the fixation to be removed. 6) Staged disassembly is different and individualistic for each and every case depending upon the progression of healing. With some cases, disassembly may be a one or two step process and for others more steps may be required. 7) Once the frame has been simplified to a Type I-a construct, removal of central pins will increase the working length of the frame and reduce fixation stiffness.

External Fixator Removal

Radiographic exams are scheduled based upon the expected healing time for a particular fracture and patient. When radiographic evidence of healing is sufficient, the frame is loosened and the limb segment is palpated to verify clinical union. If the bone has united, the remaining portion of the fixator is removed. Exercise restriction should continue for about 4 to 6 weeks after fixator removal while the empty holes in the bone begin to heal. These empty holes can act as stress raisers predisposing to fracture of the healed bone through a bony pin tract.

Suggested Readings

Aron DN, Palmer RH, Johnson AL: Biologic strategies and a balanced concept for repair of highly comminuted long bone fractures. Comp Contin Educ Pract Vet 17:35, 1995.

Johnson AL, Egger EL, Eurell JAC, Losonsky JM: Biomechanics and biology of fracture healing with external skeletal fixation. Comp Contin Educ Pract Vet 20:487, 1998.

Kraus KH, Toombs JP, Ness MG: External Fixation in Small Animal Practice. Oxford: Blackwell Publishing, 2003.

Griffin H, Toombs JP, Bronson DG, et al: Mechanical evaluation of a tapered thread-run-out half-pin designed for external skeletal fixation in small animals. Vet Comp Orthop Traumatol 24:257, 2011.

Application of the Acrylic and Pin External Fixator (APEF)

James P. Toombs and Erick L. Egger

Introduction

Acrylic frame fixators are devices in which the pin-gripping clamps and connecting rods are replaced with acrylic columns (methyl methacrylate) to form the external fixation frame. A powder component (polymer) is added to a liquid component (monomer) to form a liquid or dough that can be poured or molded. The mixture undergoes an exothermic reaction and forms a rigid solid about 8 to 12 minutes after mixing. The resulting acrylic column grips and interconnects the fixation pins thus forming the fixation frame. Different sizes of fixation pins can easily be used in the same construct and frames can be built to any shape that the surgeon desires (i.e. fixation pins do not have to line up to connect with a linear rod as they do with the clamp and rod ESF devices). The use of curved acrylic columns, when needed, does not compromise the stiffness of the frame.

Acrylic frame fixators can be applied to most bones but they are particularly useful for mandibular fractures and transarticular applications because the acrylic connecting columns are easily contoured to the shape of the body and joint angles. The acrylic used is radiolucent, which does not interfere with radiographic assessment of initial reduction or fracture healing. The first reports of acrylic frame fixators involved the use of Steinmann pins or very long orthopedic screws as fixation pins. The screws were inserted in the bones leaving the heads extended externally where they were connected with a column of dental acrylic. Homemade acrylic-pin splints are similarly constructed using methyl methacrylate that is available as hoof repair or dental molding acrylic. "Plumber's Epoxy" has also been described for similar applications. The APEF System[a] utilizes acrylic and positive profile threaded fixation pins and provides all of the basic components required to facilitate the construction of an acrylic frame fixator.

Components of the APEF System

The acrylic frame is constructed with acrylic bi-packs, plastic sidebar tubes for molding liquid acrylic, and end caps to plug the molding tubes. A temporary frame alignment device is useful for maintaining fracture reduction/alignment while the applied acrylic frame is setting.

Acrylic Bi-Packs (Figure 53-11) offer pre-measured volumes of polymer and monomer packaged in separate compartments of a mixing bag. When the ends of the bag are pulled, a plastic divider strip pops off and the mixing bag becomes a single compartment. Acrylic is mixed for 2 to 3 minutes until a smooth consistency is achieved and then the corner of the bag is cut off. The acrylic is poured into plastic sidebar tubes that have been pushed onto the ends of the fixation pins thus providing an injection mold for the acrylic. The effect of acrylic column diameter has been studied. In general, bending strength increases proportionally with the diameter of the column until about 2.5 cm, at which point



Figure 53-11. Acrylic bi-pack *(1)* with liquid monomer in the top compartment and powdered polymer in the bottom compartment. Sidebar tubes are available in three sizes: 21 mm standard tube *(2)*, 15 mm small tube *(3)*, and 10 mm mini tube *(4)*. End caps for each size are shown below the tubes.

increasing diameter may result in heat-generated "vaporization" of the acrylic monomer creating voids in the column and strength loss. While an objective rule for optimal acrylic column diameter for every fracture is not possible, a convenient guideline is that the acrylic diameter should be the same size or larger than the outer diameter of the bone being stabilized. For more complex, unstable, or slower healing fractures, this relationship may be augmented by increasing the diameter of a single column or by using multiple columns. This bi-pack preparation and application technique minimizes the mess and odor associated with mixing acrylic (compared to Caulk Dental Acrylic and Technovit Hoof Acrylic used in "homemade" versions of the acrylic frame fixator), but the surgeon does pay an increased price for this convenience. Acrylic Bi-Packs are available in five different volumes: a triple pack contains 150 ml of mixed acrylic and will fill approximately 18 inches of the 21 mm tubing (enough to apply a Type III frame to a large dog); a double pack contains 100 ml of mixed acrylic and will fill 12 inches of 21 mm tubing (sufficient for a Type I-b frame or a Type II frame in a large dog); a single pack contains 50 ml of mixed acrylic and will fill 6 inches of 21 mm sidebar tube or 12 inches of 15 mm tubing (enough for a Type I-a frame in a large dog, or either a Type I-b or Type II frame in a small dog or a cat); a half pack contains 25 ml of mixed acrylic and will fill one small tube (sufficient for a Type I-a frame in a small dog or a cat); and a quarter pack contains 12.5 ml of mixed acrylic that is generally used with the 10 mm diameter sidebar tube (sufficient for an acrylic frame in a small bird or other small exotic pet).

[a]Innovative Animal Products LLC, 5812 Highway 52 North, Rochester, MN 5590

Sidebar Tubes (Figure 53-11) are pushed onto fixation pins to provide a mold for liquid acrylic to form a cylindrically-shaped mass that acts as both a linkage device and a connector. The result is a neat, professional-looking frame (unlike some of the acrylic frames made by hand-molding dough stage acrylic onto fixation pins). Sidebar tubes are less prone to leak liquid acrylic than other types of tubes used for improvised versions of the acrylic frame external fixator. Stock sidebar tubing is sold as 48 or 60 inch long segments that are easily cut with scissors to the desired length. Sidebar tubes are available in three different diameters: standard sidebar tubes are 21 mm (appropriate for patients 8 to 10 kg or larger); small sidebar tubes are 15 mm (appropriate for small dogs, cats, and some avian patients); and mini sidebar tubes are 10 mm in diameter (appropriate for very small puppies and kittens, small birds, and other small exotic pets).

End caps are available in three sizes (21, 15, and 10 mm diameter) to plug the dependent ends of sidebar tubes. This prevents leakage when liquid acrylic is poured into the sidebar tube to form the frame.

Frame Alignment Device (Figure 53-12.) This is used to as a temporary mechanical splint to maintain fracture alignment or reduction until the primary splint (the acrylic frame) becomes rigid. This is referred to as a bi-phase technique. The frame alignment device consists of four universal clamps (that can be tightened without a wrench) and stainless steel connecting rods. The clamps can be applied close to the skin, just inside the sidebar tubes, and can be easily removed after the acrylic frame has become rigid. With bi-phase technique utilizing K-E components for the temporary splint, the clamps must be placed external to the sidebar tubes to enable their later removal. Because of their closer proximity to the bone, the frame alignment clamps have a mechanical advantage over traditional mechanical clamps in maintaining fracture alignment. Additionally, the position of the frame alignment clamp inside of the sidebar tube ensures that the frame will be at least 1 cm away from the skin. Maintaining this distance is important to avoid thermal injury to soft and bony tissue that can occur during the exothermic phase of the acrylic setting period.

Technique for APEF Application

The APEF system is usually applied using bi-phase technique (application of a temporary mechanical splint to maintain alignment while a definitive acrylic frame is applied and sets up). Key steps for application to a fracture involving the radius and ulna are illustrated in Figure 53-13. The injured limb is prepared for surgery and suspended using the hanging limb technique. Aseptic technique must be maintained throughout the pin placement and wound closure phases of the procedure.

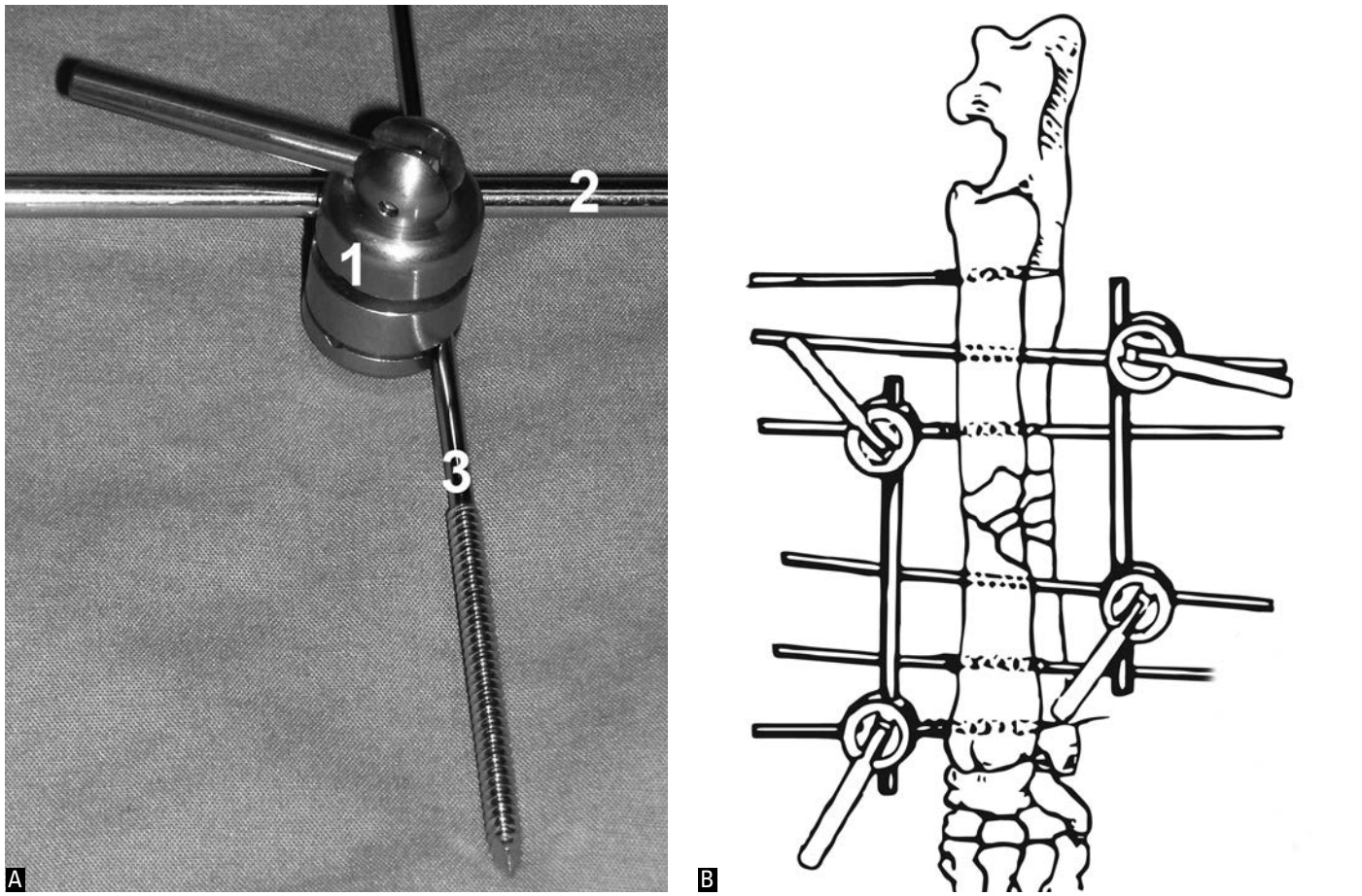


Figure 53-12. A. The frame alignment device uses a special clamp *(1)* that temporarily grips a connecting rod *(2)* and a fixation pin *(3)* to provide for fracture alignment. A wrench is not required to tighten the special clamp which includes a tightening arm at the top of the clamp **B.** Clamps and rods have been applied above and below the fracture and the frame alignment device has been tightened to temporarily maintain fracture alignment so that the acrylic frame can be applied. After the acrylic sets, the frame alignment clamps and rods are removed.

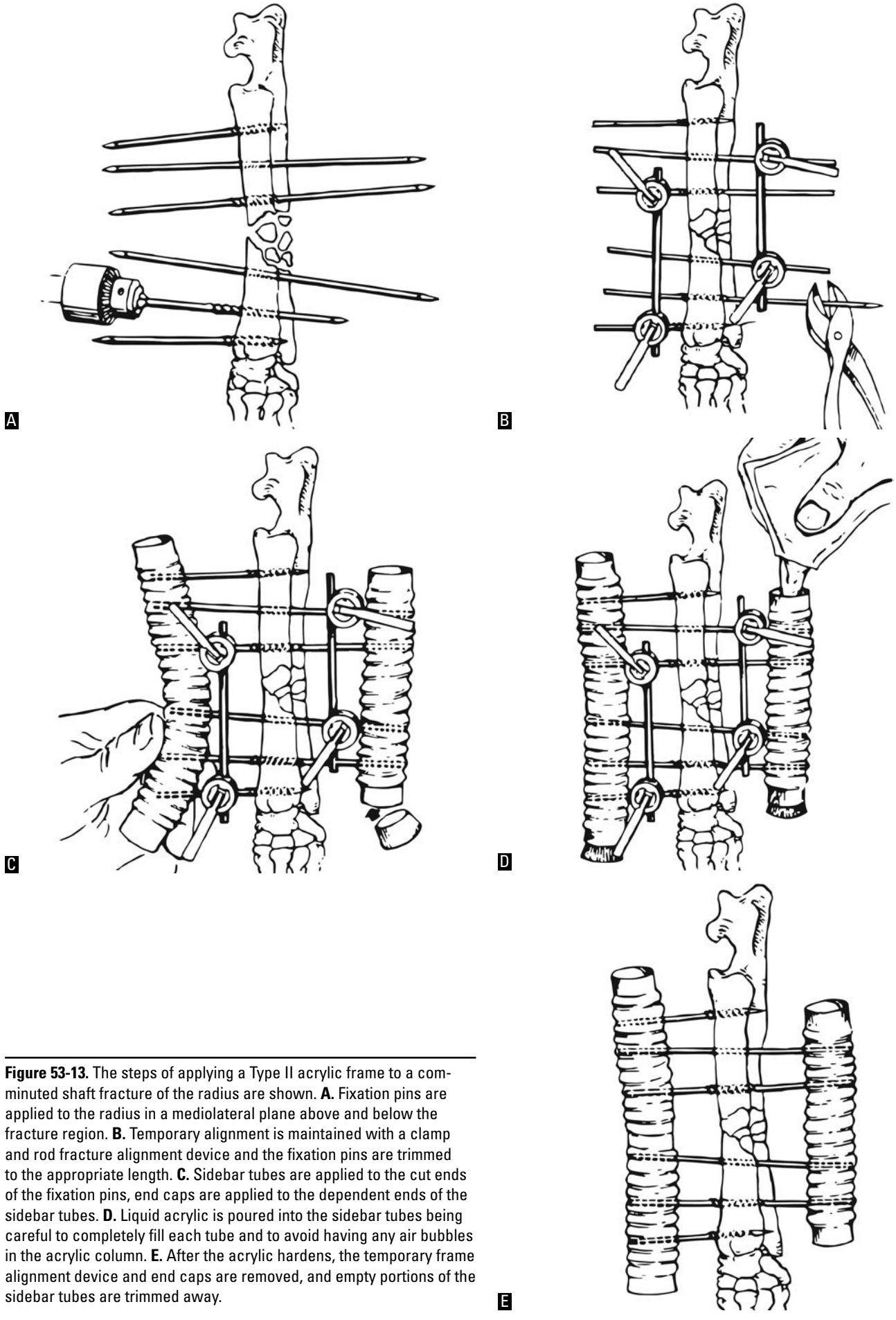


Figure 53-13. The steps of applying a Type II acrylic frame to a comminuted shaft fracture of the radius are shown. **A.** Fixation pins are applied to the radius in a mediolateral plane above and below the fracture region. **B.** Temporary alignment is maintained with a clamp and rod fracture alignment device and the fixation pins are trimmed to the appropriate length. **C.** Sidebar tubes are applied to the cut ends of the fixation pins, end caps are applied to the dependent ends of the sidebar tubes. **D.** Liquid acrylic is poured into the sidebar tubes being careful to completely fill each tube and to avoid having any air bubbles in the acrylic column. **E.** After the acrylic hardens, the temporary frame alignment device and end caps are removed, and empty portions of the sidebar tubes are trimmed away.

Fixation pins are placed using appropriate insertion techniques (pre-drilling of the bone, proper centering of the pin, and slow-speed power insertion). Pin orientation and order of pin insertion are not restricted by frame or clamp design. Typically, at least 3 pins are applied proximal to the fracture region, and 3 more are applied distal to it (Figure 53-13A). Phase 1 reduction is obtained by applying a temporary clamp and rod device (alignment frame). The alignment frame is attached to pins, the fracture reduced, and the clamps tightened to maintain reduction (Figure 53-13B). Open reduction incisions are sutured, and pins are cut off one tube diameter away from the clamps. From this point on, aseptic technique is not required as some of the components used to build the frame are supplied from the manufacturer clean, but not sterile. Our current research is finding that either using knurled pins or placing at least five notches in the portion of the pin that will reside within the acrylic column will increase the strength of the pin-connecting column interface to approximately that of the pin-bone interface when positive profile threaded pins are used. Sidebar tubing is pushed onto the cut ends of the fixation pins such that the pins penetrate the inner wall of the tube and stop short of penetrating the outer wall. The dependent ends of tubes are plugged with end caps (Figure 53-13C). Acrylic is mixed for 2 to 3 minutes after removing the bi- pack divider. The corner of the acrylic bi-pack bag is cut off and acrylic is poured or injected into the open ends of the sidebar tubes (Figure 53-13D). Any acrylic that leaks out from the tube (at points of pin penetration) can be caught in a paper cup and poured back into the top of the tube. Studies of significantly curving the acrylic column (as usually occurs in a transarticular application) reveal a decreased resistance to axial compressive forces. Consequently, we often add a 1/8 to 3/16" diameter Steinmann pin link from one end of the curve to the other to restore overall construct strength. Similar linkages are also commonly placed to connect different columns in biplanar frames (Type I-b and Type III constructs).

After the acrylic hardens (approximately 10-12 minutes), the alignment frame and end caps are removed, and any excess tube length, if present, is cut away (Figure 53-13E).

Readjustment of a Completed Acrylic Frame

If unacceptable fracture alignment is evident in postoperative radiographs, adjustment of the fixation frame is more difficult than would be the case with clamp and rod ESF devices. Splint adjustment requires removing a short segment of the acrylic column with a saw or cast cutter. The plastic molding tube is peeled back from each end and several holes are drilled in the cut ends of the acrylic to provide a base for the patch. A small amount of new acrylic is mixed and hand molded to fill the gap and overlap the existing column ends. The fracture is then manipulated into correct alignment and is held in this position while the acrylic cures. More fixation pins can be added to either replace existing pins or increase overall frame stability. The plastic molding tubing is removed from the existing acrylic column and several 1/8" diameter holes are drilled in the acrylic adjacent to the proposed pin insertion site. After aseptically preparing the skin and acrylic column surface, the new fixation pin is inserted using appropriate technique. The free end of the pin is bent to contact or cross the column. A mini pack of APEF acrylic or other acrylic is mixed to dough consistency and molded around the new pin and existing column to incorporate it.

Staged Disassembly of an Acrylic Frame

Progressive staged disassembly of an acrylic frame is done by cutting fixation pins to disengage them from the frame and/or by removal of portions of acrylic column (Figure 53-14). Acrylic frames can be cut with a cast saw, Gigli wire, OB wire, or a hacksaw blade. Different options available for staged disassembly of a Type II acrylic frame are shown in Figure 53-14. These include: 1) Removal of central segment of the lateral connecting column converts the construct to a Type I-a configuration (i.e. the lateral portion of the frame is now irrelevant mechanically). This strategy simplifies protective bandaging of the fixator compared to the next option; 2) Conversion to a Type I-a frame can also be accomplished by cutting all of the fixation pins as they exit laterally. This strategy may increase morbidity and make safe bandaging of the fixator more complicated; and 3) Cutting the central fixation pins on the medial aspect of the limb can be done as a later staged disassembly. This increases working length of the medial frame which, in turn, decreases frame stiffness.

Acrylic Frame Removal

Frame removal is achieved by cutting each fixation pin between the skin and acrylic column. Each pin is then removed using a hand chuck or pliers. Alternatively, the acrylic connecting bar can be cut between pins and each pin removed using the small block of acrylic as a handle.

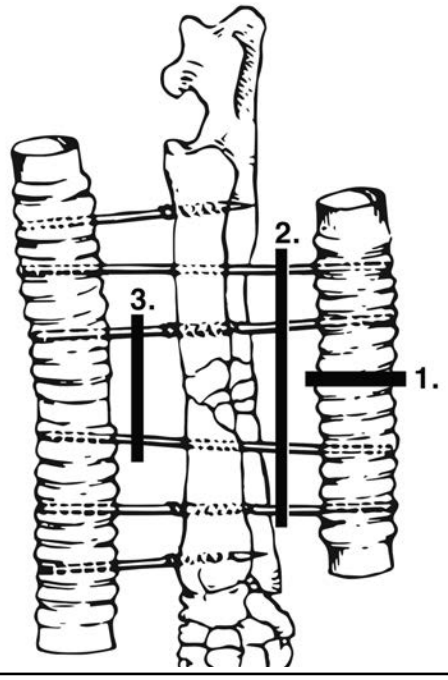


Figure 53-14. Different options for staged disassembly of a Type II frame. *1.* Removal of an acrylic segment from the central portion of the lateral column effectively converts the frame to a Type I-a construct. *2.* Cutting the fixation pins on the lateral aspect of the leg enables removal of the lateral column, another method of downstaging to a Type I-a frame. *3.* Cutting the central two pins on the medial side of the leg increases the frame working length of the remaining medially placed column, which reduces its stiffness.

Suggested Readings

Martinez SA, Arnoczky SP, Flo GL, Brinker WO. Dissipation of heat during polymerization of acrylics used for external skeletal fixator connecting bars. Vet Surg 26:290, 1997.

Ness MG. The acrylic and pin external fixator system. In Kraus KH, Toombs JP, and Ness MG: External Fixation in Small Animal Practice. Oxford: Blackwell Science Ltd, a Blackwell Publishing Company, 2003, p. 60.

Okrasinski EB, Pardo AD, Graehler RA. Biomechanical evaluation of acrylic external skeletal fixation in dogs and cats. J Am Vet Med Assoc 199:1590, 1991.

Shahar R. Evaluation of stiffness and stress of external fixators with curved acrylic connecting bars. Vet Comp Orthop Traumatol 13:65, 2000.

Staumbaugh JE, Nunmaker DM: External skeletal fixation of comminuted maxillary fractures in dogs. Vet Surg 2:72,1982.

Tomlinson JL, Constantinescu GM: Acrylic external skeletal fixation of fractures. Comp Cont Educ 13:235,1991.

Willer RL, Egger EL, Histand MB: A comparison of stainless steel versus acrylic for the connecting bar of external skeletal fixators. J Am Anim Hosp Assoc 27:541-548,1991.

Herndon GD, Egger EL: The effect of contouring the connecting bar in an acrylic-pin external fixator. Vet Comp Orthop Traumatol 14:190, 2001.

Roe SC, Keo T: Epoxy putty for free-form external skeletal fixators. Vet Surg 26:472, 1997.

Amsellem PM, Egger EL, Wilson DL: Bending Characteristics of PMMA columns, connecting bars of carbon fiber, titanium, and stainless steel used in external skeletal fixation and an acrylic interface. Vet Surg 39: 631-637, 2010.

Case JB, Egger EL: Evaluation of Strength at the Acrylic-Pin Interface for Variably Treated Exteranl Skeletal Fixator Pins. Vet Surg 40:211-215, 2011.

Application of the Securos External Fixator

Karl H. Kraus

Introduction

The Securos external fixation system was designed to be a simple and economical orthopedic device, which clinically enables state-of-the-art techniques to optimize mechanical and biologic requirements for bone healing with external fixators. These techniques include adding and subtracting fixator clamps transversely, stronger connecting frames, guide for pre-drilling pilot holes and placing full pins, radially preloaded positive profile fixation pins, and axial dynamization. The Securos and SK systems have supplanted the Kirschner-Ehmer fixator system in veterinary surgery.

Fixation Pins and Connecting Rods

Fixation pins are available in four sizes: 1.6 mm (1/16th inch), 2.4 mm (3/32nd inch), 3.2 mm (1/8th inch), and 4 mm (5/32nd inch) shaft diameters. Both end threaded and center threaded pins are available in each size. The pins are made of 316L stainless steel that has been hardened to 210,000 psi, far greater than the stiffness of Steinman pins, and act much like locking orthopedic screws. The thread profile is like an orthopedic screw called a buttress thread and is self-tapping (Figure 53-15). This thread profile results in less bone being removed during insertion therefore less damage to the bone. The diameter of the core of the pin in the area of threads is 2% larger than the pilot hole and shaft diameter of the pin. As the pin is inserted, the slightly larger diameter in the area of the threads that engages bone expands on the hole slightly. This effect, called radial preload, enhances the pin-bone interface. The connecting rods are 9.5 mm for large, 4.8 mm for medium and 3.2 mm for small fixators. The small and medium connecting rods are 308 stainless steel, which is stiffer and stronger than 316 stainless steel. The connecting rods for the large fixator are either carbon fiber, or titanium which are both stronger and lighter than 316 stainless steel.

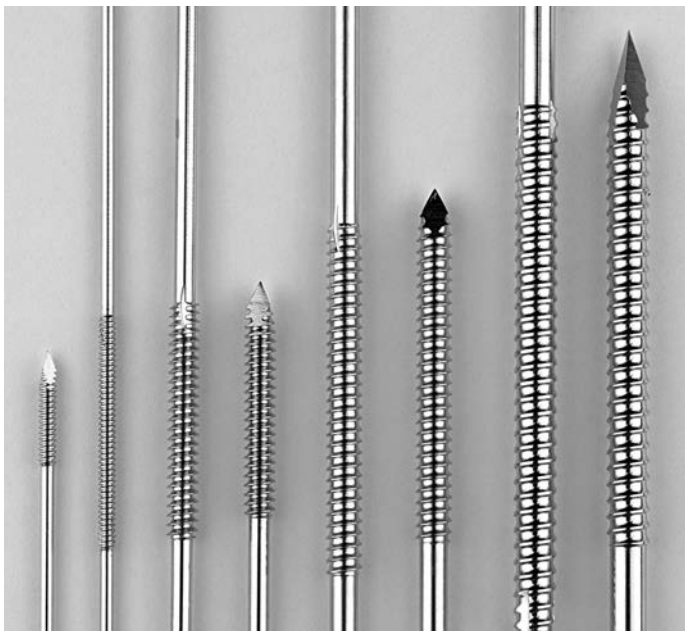


Figure 53-15. Fixation pins End threaded and center threaded fixation pins. The thread profile is a buttress thread that decreases the amount of bone removed. They are made of spring hardened 316L stainless steel making them much stiffer than a standard Steinman pin.

Clamps

There are three sizes of clamps. Small and medium sized clamps are composed of three components, a U-shaped body, a pin-gripping head, and a bolt (Figure 53-16). Similar components comprise the large clamp except that the clamp body has two parts (Figure 53-16). The large clamp accommodates 3.2 mm and 4mm fixation pins, the medium clamp accommodates 3.2 mm and 2.4 mm inch fixation pins, and the smaller clamp accommodates 2.4 mm and 1.6 mm fixation pins. The U-Shaped part and the head can be placed together then slid over a fixation pin and snapped transversely on a connecting rod (Figure 53-17). A bolt screws into the head component. As the head part is drawn into the U-shaped part a bevel on the head part contacts the connecting rod. At this contact area there is a small deformation of the stainless steel that rigidly unites the clamp, pin, and connecting rod, much like a spot weld. The U-shaped component only bends elastically. Thereby during use it is acting like a lock washer preventing loosening. The clamps do not plastically deform with proper usage and therefore can easily be reused. Double connecting clamps are made by using two U–shaped components, a head

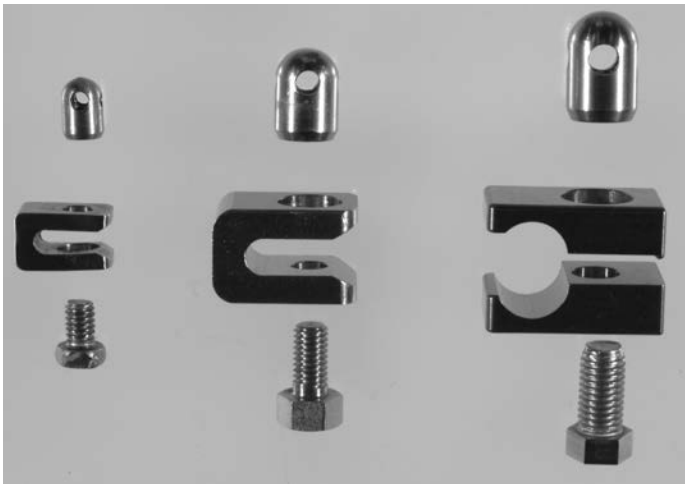


Figure 53-16. Clamps. The small and medium Securos clamp consists of three components, a U-shaped clamp body, a pin-gripping head, and a bolt. The large clamp consists of four components. The clamps are applied transversely onto a connecting rod.

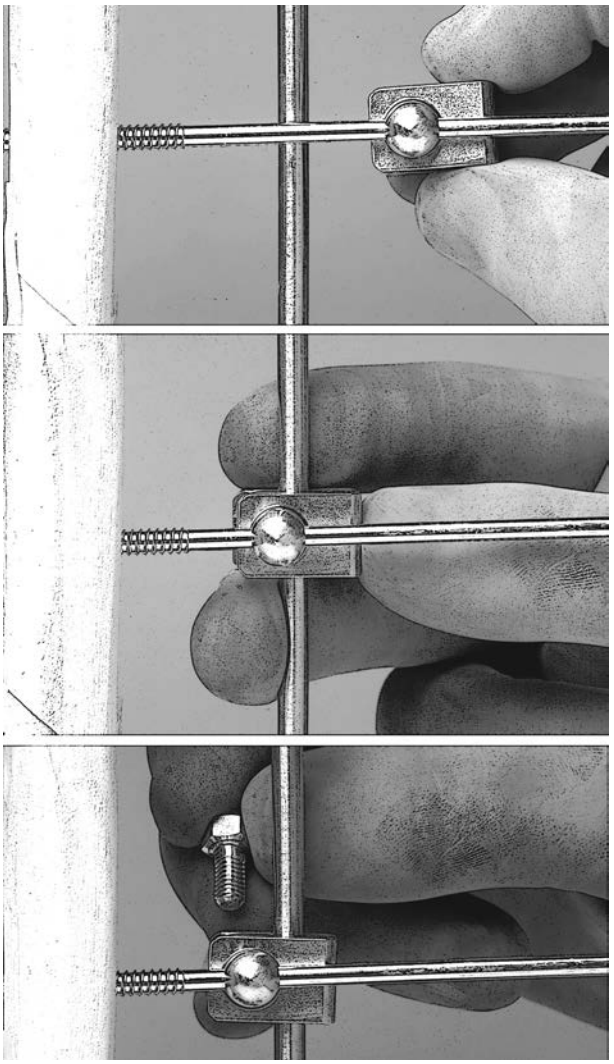


Figure 53-17. Transversely adding clamps. Small and medium clamps are transversely added by placing the U-shaped component and head component together and sliding them down a fixation pin (top panel). The clamp is snapped onto the connecting rod (middle panel), then a bolt is applied (bottom panel). The large clamps are assembled on the connecting rod.

component, a longer bolt, and small sleeve (Figure 53-18). Two new or used U-shaped components and one new or used head component can be used with the longer bolt and sleeve, obviating the need for separate complete double clamps.

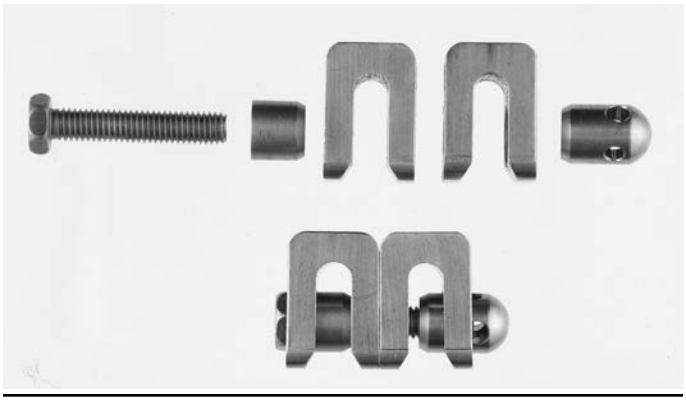


Figure 53-18. Double clamps. Double clamps are composed of two U-shaped components, a head component, and a sleeve and longer bolt. Double clamps use components of regular fixation clamps.

Aiming Instrument

An aiming instrument is available for all three sizes and allows simple pre-drilling of pilot holes, and accurate placement of half-pins or full-pins (Figure 53-19). The handle contains a drill sleeve for drilling pilot holes for fixation pins. Once two pins are placed and connecting rods are installed, the handle connects to the connecting rod. The drill guide places a fixation pinhole in exact relationship to the connecting rod for application of a clamp. The pin can be angled proximally and distally up to 30 degrees, and can also be angled either cranially or caudally. With the drill sleeve removed, the handle directs the fixation pin to the pilot hole. If a full-pin is being installed, an arm on the aiming instrument is used to direct the fixation pin to the exact



Figure 53-19. Aiming instrument. An aiming instrument is used to pre-drill pinholes, guide fixation pins into the pilot hole, and place full pins accurately to the opposite connecting rod.

position on the opposite connecting rod to install a clamp. The pilot hole and fixation pin can be directed to either side of the opposite connecting rod and angled proximally and distally as much as 30 degrees.

A unique feature of the Securos system is a method of simply changing the fixation frame to allow weight bearing forces to go through the long axis of the bone (axial dynamization) without removing fixation pins. In bilateral fixators, the clamp bolt can be replaced with one that is slightly longer. This bolt has a square head instead of a hexagonal head for easy identification. This allows the clamps to slide along the connecting rod, but the pin is fixed to the clamp (Figure 53-20). Therefore weight bearing will cause pure axial loads to be exerted on a healing fracture while the bone is supported in torsion, translation and bending.

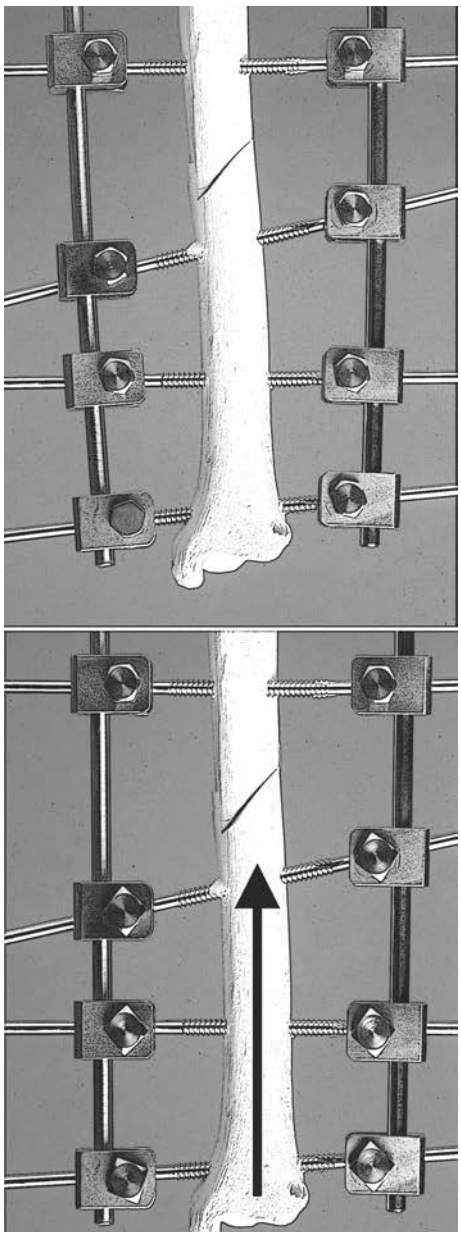


Figure 53-20. Dynamization bolts. Axial dynamization is achieved in bilateral fixators by replacing the bolt of the fixation clamp with a slightly longer bolt with a square head (for identification) either proximal or distal to the fracture. This allows the fracture to carry axial loads (arrow) while being supported in torsion, translation, and bending.

Application Technique

The fracture is reduced and a proximal fixation pin and distal fixation pin are placed near the ends of the long bone. Connecting rods are secured to the fixation pins with clamps and the clamps are tightened. Clamps are not pre-placed on the connecting rods. The aiming instrument is used to place additional fixation pins. In placing half-pins, only the handle of the aiming tool is used (Figure 53-21). It is placed on the connecting rod and a drill sleeve is inserted. An intramedullary pin is advanced to the desired

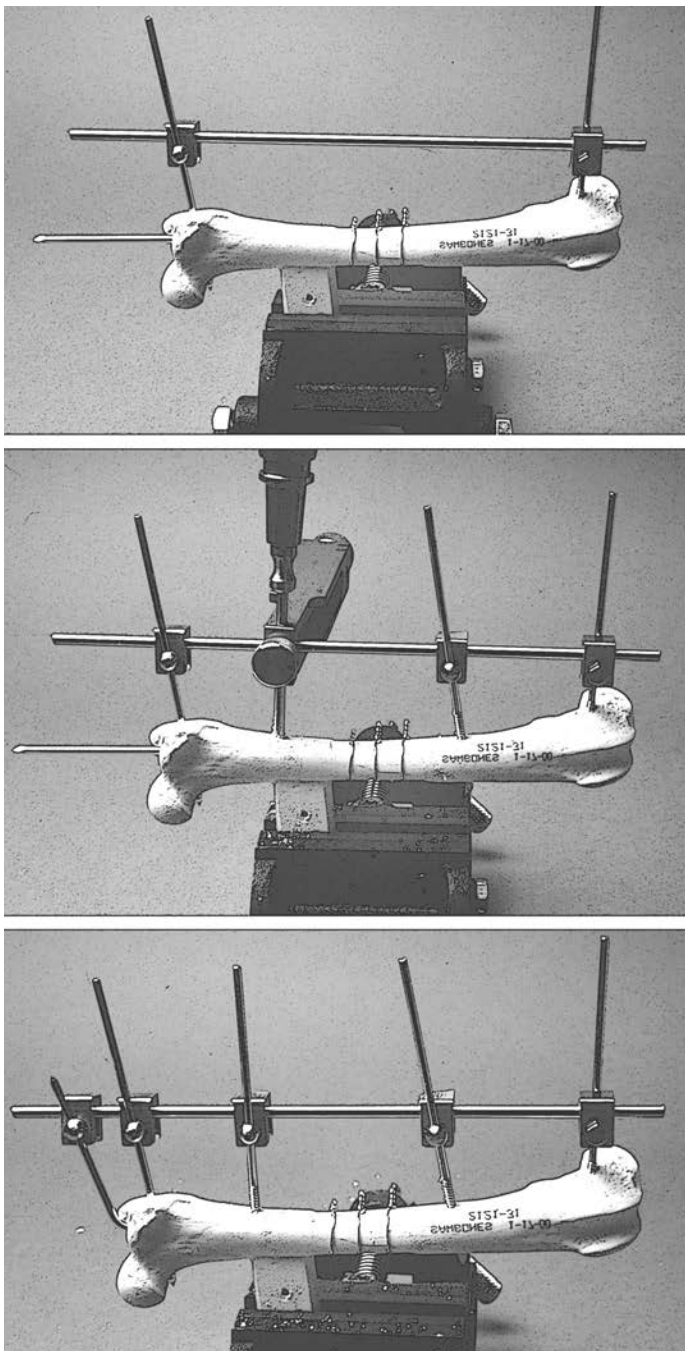


Figure 53-21. Application of unilateral fixator frames. Unilateral fixators are applied placing the first two pins and connecting rod in standard fashion. Consecutive fixation pins are added using the aiming instrument by drilling a pilot hole, inserting a fixation pin through the device, removing the device and snapping on a clamp. An intramedullary pin can be easily tied in.

location and used as a trochar to locate proper placement in bone. The aiming instrument is tightened to maintain its position on the connecting rod. A releasing incision is made and the drill sleeve is advanced to bone. The Steinmann pin is removed then a pilot hole is drilled with a twist drill bit. A pilot hole the same diameter of the shaft of the fixation pin is used (1.6 mm, 2.4 mm, 3.2 mm, 4 mm). There is a separate drill sleeve for each drill bit size.

After the pilot hole is drilled, the drill sleeve is removed and the fixation pin is inserted. The aiming instrument will guide the fixation pin to the pilot hole. The pin should be placed with a power drill capable of spinning a low speed while still providing high torque. The fixation pin is placed so that it penetrates both corticies such that only the trocar point can be felt protruding from the far cortex. The aiming instrument is then removed. A clamp is then applied by placing the U-shaped body component with the head shaped component and sliding it over the fixation pins. Together, they are snapped on the connecting rod. The bolt is then inserted and tightened. The larger clamp is placed somewhat differently in that the two body components are placed on the connecting rod, then the head component, then the bolt.

Full-pins in bilateral fixators are placed in similar manner, but the arm on the aiming instrument is used. The most proximal and distal fixation pins are placed with connecting rods on both medial and lateral aspects of the limb. The aiming instrument is placed on either connecting rod with the arm in place (Figure 53-22). There are two grooves on the far end of the arm. The arm is slid so that the opposite connecting rod rests in either one of these two grooves. A Steinman pin is inserted into the drill sleeve and through skin to see whether it will contact bone. A Steinman pin is also inserted

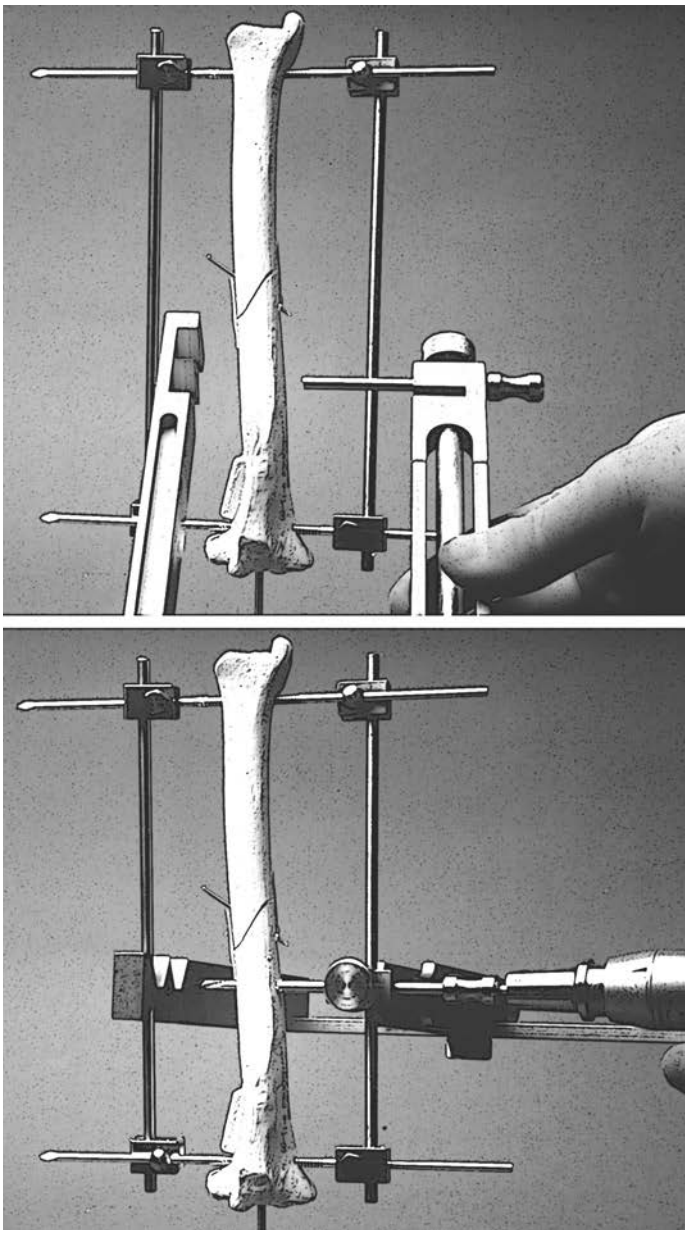


Figure 53-22. Application of bilateral fixator frames. Bilateral fixators are constructed by applying the first two pins and connecting rods in standard fashion. Additional fixation pins are applied by used the aiming instrument with its arm for full pins. Full-pins need not be placed in one plane and can be placed in front or back of either connecting rod allowing four pin orientations to the connecting rods. Pilot holes are drilled, then the fixation pins placed in accurate orientation to both connecting rods.

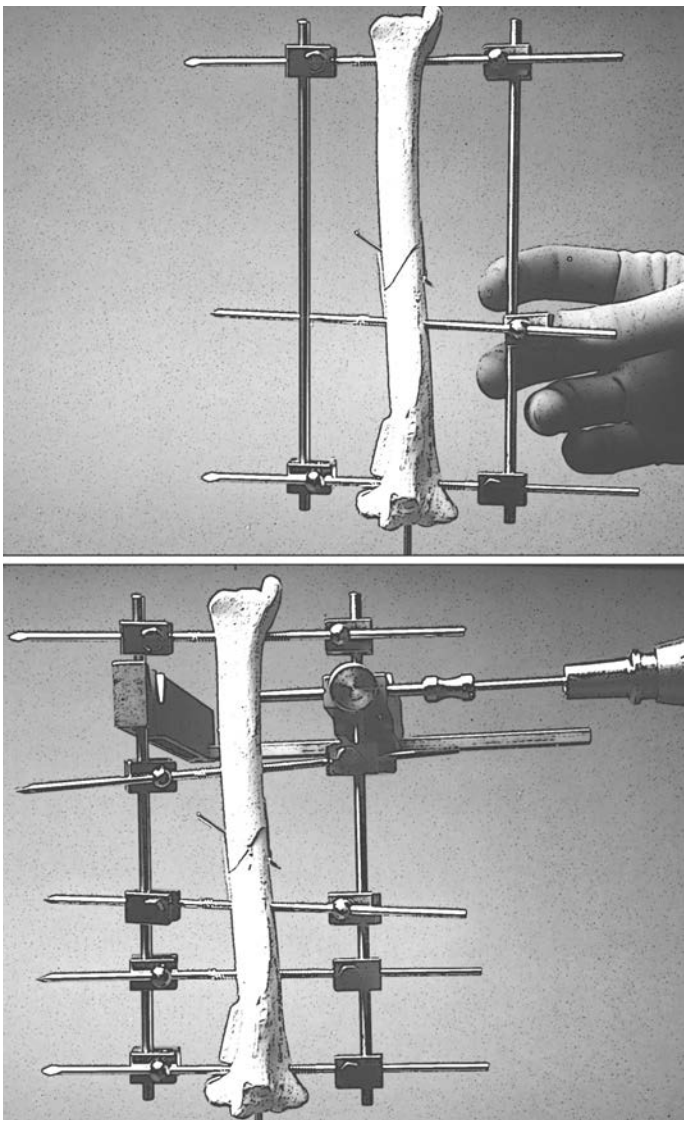


Figure 53-23. Application of multiple full pins. Once the fixation pin is in place, clamps are applied which connect the fixation pin with connecting rods. Additional full-pins or half-pins can be applied at the discretion of the surgeon.

in a hole between the two grooves on the arm and through skin, again to see whether it will contact bone. This assures that in this position a full-pin will have sufficient bone purchase. If in the first position there is not sufficient pin purchase, then the other groove in the arm of the aiming tool is used. If these two positions do not result in adequate pin purchase, the handle of the aiming instrument is flipped over so that the fixation pins starts from the opposite side of the connecting rod. This allows four possible positions to accomplish secure full-pin fixation. If none of these positions result in being able to place a properly-centered full-pin, then a half-pin is placed instead. Pilot holes for full-pins are drilled in similar manner to that described for half-pins, the drill sleeve is removed, then the full fixation pin is placed. It will advance through the hole on the arm of the aiming instrument. The instrument is then removed and clamps slid on the fixation pins then snapped on the connecting rod and tightened (Figure 53-23).

Suggested Readings

Kraus KH, Toombs JP, Ness MG. External Fixation in Small Animal Practice. Oxford: Blackwel Publishing, 2003, 43.

Kraus KH, Wotton HM: Effect of clamp type on four-pin type II external fixator stiffness. Vet Comp Orthop and Traumatology, 12:178, 1999.

Kraus KH, Wotton HM, Rand WM: Mechanical Comparison of Two External Fixator Clamp Designs. Vet Surg 27:224, 1998.

Kraus KH, Wotton HM, Schwartz LA, et. al. Type-II external fixation using new clamps and positive-profile threaded pins, for treatment of fractures of the radius and tibia in dogs. J Am Vet Med Assoc 212:1267, 1998.

Application of the IMEX-SK External Fixator

James P. Toombs

Introduction

In order to improve the performance of external fixators in small animal patients, newer devices have addressed the following problems characteristic of the Kirschner-Ehmer (KE) splint: 1) weak frame components often necessitate the use of complex full-pin frames; 2) single clamps do not easily accommodate positive profile fixation pins; 3) fixation pin size is dictated by clamp size and the use of different pin diameters within a single construct is difficult; 4) clamps are susceptible to permanent deformation and loosening; and 5) clamps cannot be easily added to or subtracted from the middle portion of a construct. The IMEX™ SK™ external fixator was designed to overcome all of these problems.

Application of axial compression to a unilateral K-E splint in a fracture gap model reveals the connecting rod to be the weak link in the construct. With the K-E splint, this weakness is compensated for by using an aggressive Type II or Type III frame when dealing with an unstable comminuted fracture. Although use of multiple full-pins improves mechanical performance of the external fixator, it often does so at the expense of increased patient morbidity attributable to full-pins traversing a thick layer of soft tissue on one side of the limb.

Design of the SK fixator is based upon the use of larger connecting rods made of strong, light-weight material (carbon fiber composite or titanium). Increased connecting rod strength enables the use simpler, half-pin, Type I-a or Type I-b frames to successfully manage unstable comminuted fractures with the SK™ device. This in turn reduces the amount of soft tissue that will be penetrated by the fixation pins, thus reducing patient morbidity.

Components of the SK External Fixator

Clamps

Both single clamps and double clamps are available (Figure 53-24). Single clamps are used for attaching fixation pins to a connecting rod and double clamps are used for making rod-to-rod connections between fixation frames that have been applied in different planes. SK clamps are available in 3 different sizes: mini, small and large (Figure 53-25).

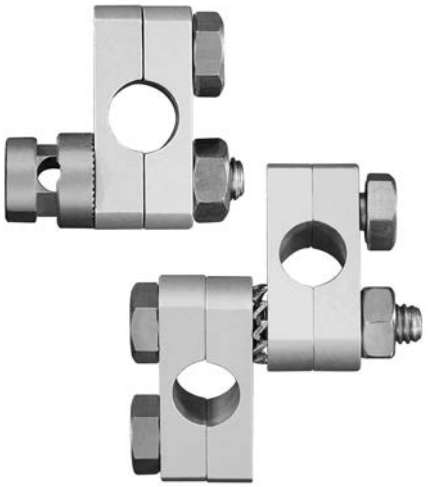


Figure 53-24. SK single clamp (top) used for securing a fixation pin to the connecting rod, and SK double clamp (bottom) used for making rod-to-rod connections between frames (also see Figure 53-34).

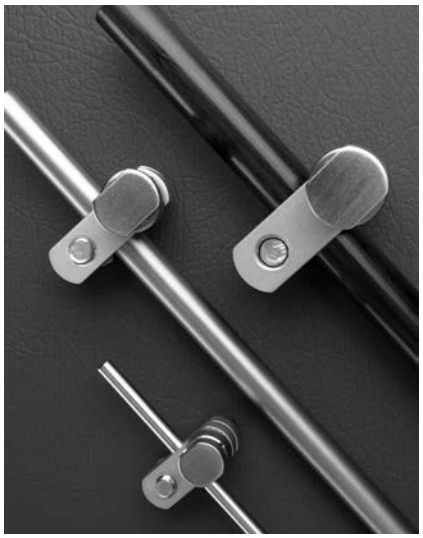


Figure 53-25. The 3 different sizes of SK clamps: large clamp with 9.5 mm carbon fiber connecting rod (top); small clamp with 6.3 mm titanium connecting rod (middle); and mini clamp with 3.2 mm stainless steel connecting rod (bottom).

The SK single clamp is comprised of B-1 and B-2 aluminum body parts, and stainless steel components including a primary pin-gripping bolt with a slotted washer, a nut to tighten the primary bolt, and a secondary bolt. Correct assembly of the clamp is shown in (Figure 53-26). The clamp is symmetrically tightened by a secondary bolt on one side of the clamp and by a primary bolt and a nut at the opposite end of the clamp. The slotted washer on the primary pin-gripping bolt enables the clamp to securely grip a wide variety of different fixation pin diameters. Fixation pin sizes, connecting rod materials and diameters, and the appropriate wrench size specific to each clamp size are summarized in Table 53-3.

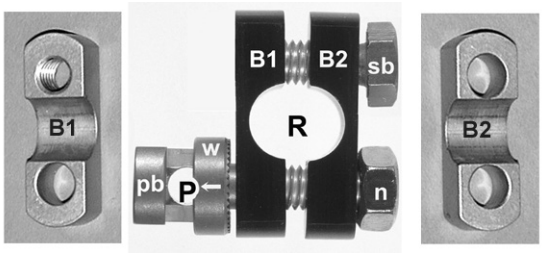


Figure 53-26. Anatomy of the SK single clamp. The modular aluminum clamp body has been manufactured with either a silver or black finish and has two slightly different components. The *B1* body part has a threaded hole that enables the secondary bolt *(sb)* to tighten the top of the clamp by lag effect, whereas the *B2* body part has a smooth gliding hole in this location. The rod-gripping channel *(R)* is in the center of the clamp. The pin-gripping bolt *(pb)* has a sliding washer *(w)* with a slot or meniscus *(arrow)*, enabling a wide range of different pin diameters to be securely grasped in the pin-gripping channel *(P)* of the bolt. The bottom half of the clamp is tightened by a nut *(n)* applied to the end of the pin-gripping bolt.

Table 53-3. Pin, Rod, Wrench and Bolt Sizes for Different Sizes of the SK Fixator

Clamp Size	Fixation Pin Shaft Diameter	Connecting Rod Diameter	Wrench/ Bolt/Nut Size
MINI	0.035" to 3/32" (0.9 mm to 2.5 mm)	3.2 mm[a.]	7 mm
SMALL	5/64" to 5/32" (2.0 mm to 4.0 mm)	6.3 mm[b.]	8 mm
LARGE	~7/64" to 3/16" (3.0 mm to 4.8 mm)	9.5 mm[c.]	10 mm

Superscript letters indicate types of rods available: [a.]stainless steel; [b.]carbon fiber composite and titanium; [c.]carbon fiber composite and aluminum.

Connecting Rods

Mini SK connecting rods are 3.2 mm in diameter, available in lengths ranging from 50 mm to 150 mm, and are made of stainless steel. Small SK connecting rods are 6.3 mm in diameter, available in lengths ranging from 50 mm to 250 mm, and are made from either carbon fiber composite or titanium. Small carbon fiber composite rods have similar bending stiffness to the 4.8 mm stainless steel connecting rods utilized by the size medium K-E splint, whereas small titanium connecting rods are twice as stiff. Large SK connecting rods are 9.5 mm in diameter, available in lengths ranging from 50 mm to 350 mm, and are made from either aluminum or carbon fiber composite. Large SK rods offer a four-fold increase in bending stiffness compared to small titanium connecting rods.

Fixation Pins

During the 1980s, small animal surgeons began to use positive profile threaded fixation pins in external fixator constructs. Early experience was gained with some of the smaller diameter implants designed for human patients such as the centrally-threaded skeletal traction pin (Synthes) and the end–threaded Turner hip pin (Zimmer). Although improved results were seen with these implants compared to the use of smooth fixation pins, many of the pins specifically designed for ESF in humans were too large to enable safe use in dogs and cats. The negative profile end-threaded fixation pins designed for small animal patients (Ellis™ pin from Kirschner and SCAT™ pin from IMEX) offered only modest improvement compared to results obtained with smooth pins. In the early 1990s positive profile threaded pins were developed specifically for use in small animal patients. These implants have greatly improved the success rate of ESF in challenging fracture cases.

Positive profile end-threaded half-pins (INTERFACE™ pins) and centrally- threaded full-pins (CENTERFACE™ pins) made for the SK fixator are summarized in Tables 53-4 and 53-5. These fixation pins are available with a standard or cortical thread profile for use in diaphyseal bone, and a cancellous thread profile for use in soft metaphyseal bone (Figure 53-27). Cancellous thread versions feature a greater thread diameter, deeper threads and a larger pitch than compared to pins with cortical thread. Use of cancellous pins should be confined to the proximal metaphysis of the tibia, the distal metaphysis of the femur, and the proximal metaphysis of the humerus. Their use in hard diaphyseal bone is contraindicated. Fixation pins with extended thread length are available and are occasionally required in order to fully purchase the increased diameter of the bone in some metaphyseal locations.The majority of pin sizes are available with either

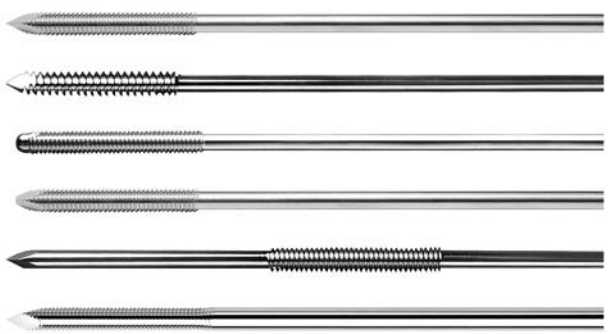


Figure 53-27. Different types of fixation pins (from top to bottom): INTERFACE half-pin with cortical (standard) thread; INTERFACE half-pin with cancellous thread; first version of INTERFACE NP half-pin with cortical thread and atraumatic rounded tip; revised version of INTERFACE NP half-pin with blunt trocar tip; CENTERFACE full-pin with centrally placed cortical thread; and DURAFACE half-pin with taper run-out junction and cortical thread.

a trocar point or with an atraumatic NP (no point) tip (see Figure 53-27). Since NP pins to not have a cutting trocar point, the surgeon is forced to use proper pre-drilling technique to apply them. Compared to pins with a trocar point, NP pins require slightly greater insertional force until the initial threads engage and cut threads in the near cortex of the bone. After that, the gear effect of pin threads moving on bone threads allows the fixation pin to smoothly advance across the bone. The first version of the NP pin had a rounded tip, and its ability to accurately center itself in the pre-drilled hole was slightly less than that of a pin with a trocar tip. The tip of the NP pin was later revised to a blunted trocar tip to improve the ability of the pin to properly center within the pre-drilled bone hole.

The most recent development in fixation pin technology is the DURAFACE pin (Figure 53-27). It is a pin with a larger diameter smooth shaft and a taper run-out junction leading to a negative profile thread at the end of the pin. Unlike other negative profile

Table 53-4. Positive Profile Threaded Fixation Pins for IMEX-SK Fixators

PIN DESCRIPTION Name – SD / TD	Recommended drill bit diameter	Thread Length	Pin Length
Miniature INTERFACE half-pins			
.035" - 0.9 mm / 1.1 mm	–	12 mm	75 mm
.045" - 1.2 mm / 1.4 mm	1.1 mm	12 mm	75 mm
.062" - 1.6 mm / 1.8 mm	1.5 mm	12 mm	75 mm
.078" - 2.0 mm / 2.3 mm	1.5 mm	15 mm	75 mm
.094" - 2.4 mm / 2.9 mm	2.0 mm	17 mm	75 mm
Miniature CENTERFACE full-pins			
.035" - 0.9 mm / 1.1 mm	–	11mm	75 mm
.045" -1.2 mm / 1.4 mm	1.1 mm	12 mm	75 mm
.062" -1.6 mm / 1.8 mm	1.5 mm	12 mm	75 mm
INTERFACE half-pins			
2.0 mm[c] - 2.0 mm / 2.5 mm	2.0 mm	20 mm	95 mm
small[a,b,c] - 2.4 mm / 3.2 mm	2.3 mm	25 mm	100 mm
small-plus[a,c]- 2.8 mm / 3.5 mm	2.7 mm	28 mm	110 mm
3.0 mm - 3.0 mm / 3.5 mm	3.0 mm	30 mm	110 mm
medium[a,b,c] - 3.2 mm / 4 mm	3.1 mm	31 mm	115 mm
medium-plus[a,c]- 3.5 mm / 4.3 mm	3.5 mm	35 mm	130 mm
large[a,b,c] - 4 mm / 4.8 mm)	3.9 mm	38 mm	150 mm
CENTERFACE full-pins			
2.0 mm[c] - 2.0 mm /2.5 mm	2.0 mm	15 mm	95 mm
small[a,b,c] - 2.4 mm / 3.2 mm	2.3 mm	19 mm	100 mm
small-plus[a,c] - 2.8 mm / 3.5 mm	2.7 mm	25 mm	115 mm
3.0 mm - 3.0 mm / 3.5 mm	3.0 mm	28 mm	120 mm
medium[a,b,c] - 3.2 mm / 4 mm	3.1 mm	30 mm	125 mm
medium-plus[a,c] - 3.5 mm / 4.3 mm	3.5 mm	35 mm	140 mm
large[a,b,c] - 4 mm / 4.8 mm)	3.9 mm	38 mm	150 mm

SD = shaft diameter

TD = thread diameter

[a] **extended thread length version available**

[b] **cancellous thread version available**

[c] **NP (no point) version available**

Table 53-5. Negative Profile Threaded Fixation Pins for IMEX-SK Fixators

PIN DESCRIPTION Name – SD / TD	Recommended drill bit diameter	Thread Length	Pin Length
DURAFACE half-pins			
2.5 mm[c] - 2.5 mm / 2.5 mm	2.0 mm	20 mm	95 mm
small[a,c] - 3.2 mm / 3.2 mm	2.3 mm	25 mm	100 mm
small-plus[a,c] - 3.5 mm / 3.5 mm	2.7 mm	28 mm	110 mm
medium[a,c] - 4.0 mm /4.0 mm	3.1 mm	31 mm	115 mm
medium-plus[a,c] - 4.3 mm / 4.3 mm	3.5 mm	35 mm	130 mm
large[a,c] - 4.8 mm / 4.8 mm)	3.9 mm	38 mm	150 mm
DURAFACE Short No-Point half-pins			
2.5 mm - 2.5 mm / 2.5 mm	2.0 mm	10 mm	80 mm
small - 3.2 mm / 3.2 mm	2.3 mm	15 mm	90 mm
small-plus - 3.5 mm / 3.5 mm	2.7 mm	18 mm	95 mm
medium - 4.0 mm / 4.0 mm	3.1 mm	21 mm	100 mm
medium-plus - 4.3 mm / 4.3 mm	3.5 mm	24 mm	20 mm
large - 4.8 mm / 4.8 mm)	3.9 mm	27 mm	140 mm

SD = shaft diameter

TD = thread diameter

[a] **extended thread length version available**

[c] **NP (no point) version available**

pins, this implant has improved mechanical performance compared to other pins with the same thread diameter, but does not have a stress concentration point at the smooth-threaded junction that could predispose bending or breakage of the implant. DURAFACE pin options are summarized in Table 53-5.

Application Techniques

The slotted washer on the primary pin-gripping bolt enables the use of a wide range of different pin sizes for each SK clamp size (Tables 53-3 and 53-6). The curvature of the meniscus in the washer corresponds to the smallest pin shaft diameter that can be gripped by the primary bolt. The hole in the primary bolt is large enough to accommodate sleeved pre-drilling and application of a positive profile pin directly through the bolt. The diameter of the pin-gripping channel in the primary bolt determines the maximum diameter of a positive profile threaded pin that can be passed through it. When a larger threaded pin is desired, sleeved pre-drilling of the bone is done through the clamp, the clamp is temporarily removed, the pin is applied to the bone, the pin-gripping bolt is applied to the smooth shaft of the pin, and the clamp is re-assembled to attach the pin to the rod. This technique is applicable when a size medium cancellous INTERFACE half-pin is used with a small SK clamp at positions other than the most proximal and most distal ones within a construct. The shaft and thread diameters of this pin are 3.2 mm and 4.8 mm respectively, and the diameter of the pin-gripping channel in the primary bolt of a small clamp is 4.0 mm. Although the threaded diameter won't pass through the clamp, the primary bolt is able to grip the shaft diameter of the pin.

The slotted washer of the primary bolt has a multi-toothed surface that engages the outer surface of the clamp body when the clamp bolt is tightened (Figure 53-28). This provides positive retention between the washer and the clamp body thus eliminating pin-bolt slippage in relation to the connecting rod. The circular shape of the serrated area on the washer makes its positive retention capability function at any desired angle using either half-pins or full-pins.

The split body design of the SK clamp allows for easy addition or subtraction of a clamp from a construct without taking the frame apart (as would be necessary with a KE splint). Primary and secondary bolts enable symmetrical tightening of the clamp to securely grip both the fixation pin and the rod. This is accomplished without deforming the clamp body.

In the early phase applying a linear fixator, disruptive torque forces produced by the tightening of the first several clamps may cause loss of fracture reduction or alignment. SK clamps have a feature that makes it easy to counter these forces. The flat surfaces on the end of the primary pin-gripping bolt and the flat surfaces on the assembled clamp body (Figure 53-29) are the same dimension as the wrench used to tighten the clamp. A second wrench can be applied to either of these surfaces to counter disruptive torque forces during clamp tightening.

While the secondary bolt allows for symmetrical tightening of the SK clamp, it also enables an empty clamp to serve as a targeting device. For example, when the surgeon wants to place a pin in

Table 53-6. Pin Size versus SK Clamp Size

IF = INTERFACE half-pin
CF = CENTERFACE full-pin
DF = DURAFACE half-pin

Sizes of pins that can be used to build	
Mini SK constructs	.035" Miniature IF and CF
	.045" Miniature IF and CF
	.062" Miniature IF and CF
Small SK constructs	.072" Miniature IF
	2.0 mm IF and CF & 2.5 mm DF
	.094"Miniature IF
	Small IF and DF & 3.2 mm DF
	Small Plus IF and CF & 3.5 mm DF
Large SK constructs	3.0 mm IF and CF
	Medium IF and CF & 4.0 mm DF
	Medium Plus IF and CF & 4.3 mm DF
	Large IF and CF & 4.8 mm DF

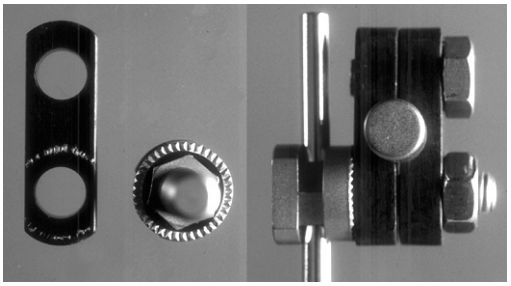


Figure 53-28. Small SK single clamp tightened to grip a medium INTERFACE pin and a 6.3 mm titanium connecting rod (right image). Note that the teeth of the washer engage the clamp body. Portions of the disassembled clamp (left image) show that the teeth of the washer have made indentations in the B1 body part which improves the mechanical performance of the clamp.

the same plane as the pin adjacent to it, this is accomplished a follows. A drill sleeve is inserted through the pin-gripping channel of the primary bolt (Figure 53-30) of a loose clamp placed on the connecting rod. The clamp is rotated until the long axis of the drill sleeve is a plane identical to that of the fixation pin adjacent to it. The secondary bolt is tightened to maintain this orientation and the nut on the primary bolt is partially tightened to secure the drill sleeve (NOTE – over-tightening of the nut will crimp the wall of the drill sleeve which is to be avoided). The bone is pre-drilled through the sleeve, the primary bolt is loosened to remove the sleeve, and the threaded fixation pin is inserted through the clamp and into the bone. Regardless of the desired plane of pin insertion, the secondary bolt can be used to stabilize the position of the clamp/drill sleeve unit to facilitate accurate pre-drilling.

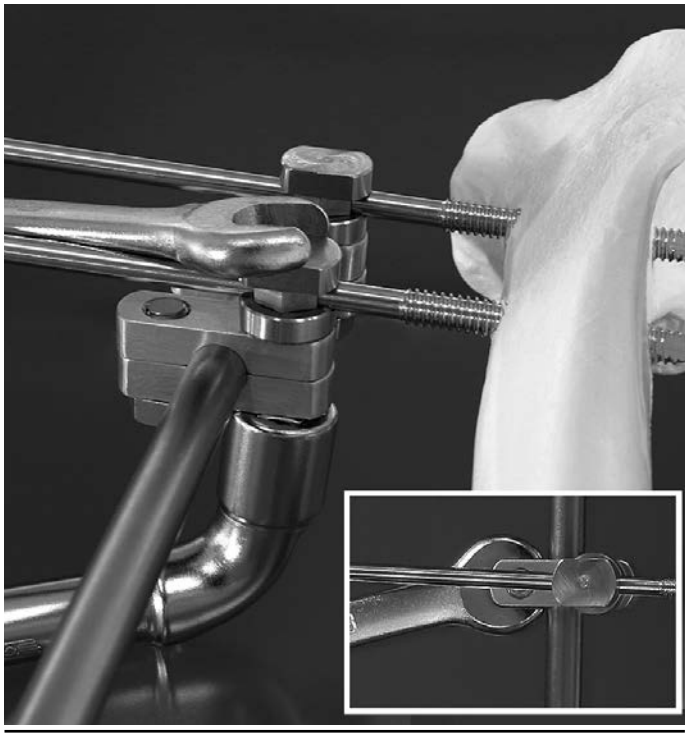


Figure 53-29. Two wrench technique for tightening of the clamp. An open end wrench is applied to the flat surfaces of the head of the pin-gripping bolt (large picture) or to the proximal and distal surfaces of the clamp body (inset picture) to neutralize torque forces that could disrupt fracture alignment during the process of tightening the clamp with the L-shaped combination wrench.

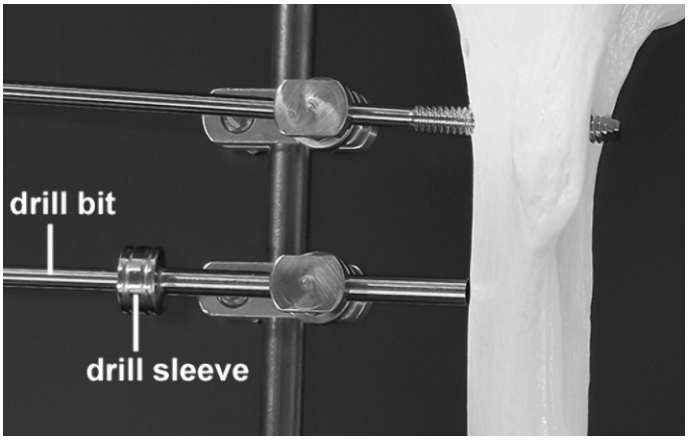


Figure 53-30. Use of a drill sleeve placed through a clamp to assist with proper targeting of the fixation pin. If desired, the surgeon can position the drill sleeve in the same plane as a previously placed pin (proximal-most pin in this picture). This orientation is maintained by tightening the secondary clamp bolt to secure the position of the clamp on the rod, and light tightening of the nut on the primary clamp bolt to secure the position of the drill sleeve. This same strategy can be used to insure that multiple full-pins are placed in the same plane for Type II fixators.

Application of a Type I-a Construct

The fracture is reduced (hanging limb technique is useful for accomplishing this in fractures of the radius / ulna or tibia) and a proximal fixation pin and a distal fixation pin are placed near the ends of the bone. The example shown in Figures 53-31 and 53-32 involves fixator application to the tibia, in which the fixation pins are passed in a mediolateral plane through the medial aspect of the bone (preferred anatomic corridors for fixation pins in other bones has been covered in the earlier chapter – Basic Principles for the Application of External Fixators). At each intended pin placement site, a liberal release incision at least 1 cm in length

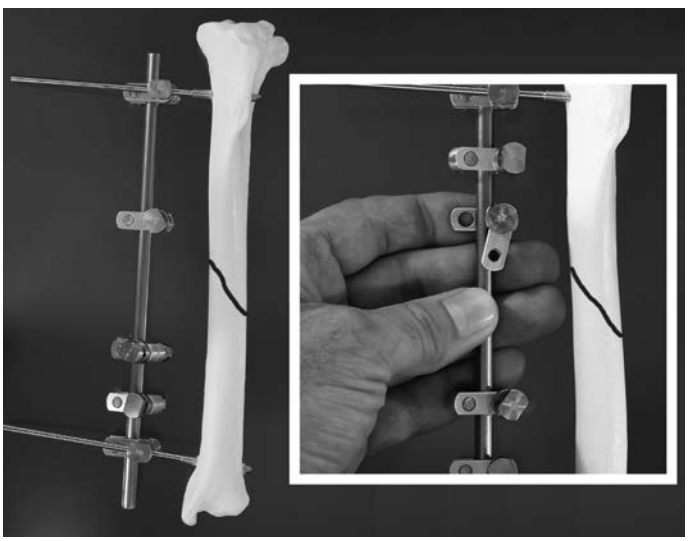


Figure 53-31. Completing the middle portion of the frame. The desired number of single clamps can be placed on the connecting rod prior to attaching it to the proximal and distal fixation pins (left image). In a typical case, 3 fixation pins should be placed both proximal and distal to the fracture. In the example shown, the surgeon has failed to place a sufficient number of clamps on the rod to accomplish this goal. This is easily corrected by assembling an additional clamp on the rod of the existing assembly (inset picture).

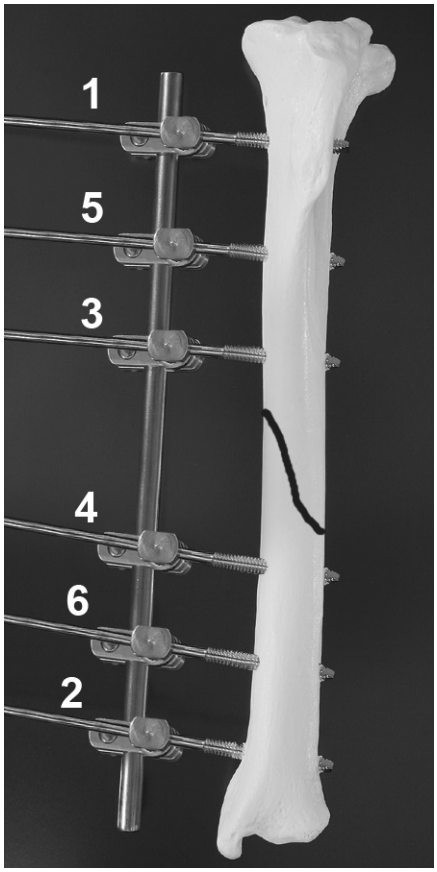


Figure 53-32. Far-far-near-near-middle-middle order of pin placement in the application of an external fixation frame. Fixation pins are initially placed at the ends of the bone *(pins 1 and 2)*. The next two pins are placed immediately above and below the fracture *(pins 3 and 4)*. The middle portion of each pin cluster is then completed *(pins 5 and 6)*.

is made through the skin and soft tissues over the center of bone. Placement of a miniature Gelpi retractor in the incision is helpful for maintaining exposure. Pre-drilling is done through the release incision using a drill sleeve to protect the soft tissues and a drill bit that is equal to the core diameter of the fixation pin. Each fixation pin is applied to the pre-drilled hole using slow speed power insertion technique. A connecting rod is secured to the first two pins using SK single clamps. Considerable torque force occurs as these clamps are tightened. A second wrench should be used to neutralize forces that could disrupt fracture alignment as the clamps are tightened.

Empty clamps to accommodate the anticipated number of additional fixation pins required can be pre-placed onto the connecting rod or added later (Figure 53-31). A release incision at least 1 cm in length is made at the next pin placement site. An empty clamp is positioned over the release incision and a drill sleeve is inserted through the hole in the clamp bolt down to the level of the bone. After the clamp and drill sleeve are oriented to provide proper centering of the hole that will be pre-drilled through the bone, this position is maintained by tightening the secondary bolt and gently tightening the nut on the primary bolt to secure the drill sleeve. Pre-drilling of the near and far cortex is done with a twist drill bit. The nut on the primary bolt is loosened to enable removal of the drill sleeve and a fixation pin is applied through the hole in the primary clamp bolt and advanced into the

pre-drilled hole in the bone using slow speed power insertion technique. It is important for the threads of the pin to fully engage the far side of the far cortex of the bone. In order to accomplish this, several millimeters of the tip of the pin must extend into the soft tissues beyond the far cortex. If vital anatomic structures are likely to be present in this location, a NP pin should be used. The clamp is secured by alternate tightening of the secondary bolt and the nut on the primary bolt. These steps are repeated at each pin placement site until at least three fixation pins have been placed both proximally and distally. The order of pin placement is generally as follows: the most-proximal and most-distal pins are placed first; the central pins immediately above and below the fracture region are placed next; and pins in intermediate locations are placed last (Figure 53-32). Fixation pins should not be trimmed until acceptable fracture alignment has been verified on post-operative radiographs. Each pin should then be trimmed such that the cut edge stops short of the outer surface of the clamp.

Application of a Type I-b Construct

For comminuted shaft fractures, a Type I-a construct may not provide sufficient stability. In these cases, a second Type I-a frame is applied in a different plane (orthogonal to the first frame is optimal mechanically). For the tibia this would involve application of fixation pins in a craniolateral plane through the cranial aspect of the bone (Figure 53-33).

Linkages are sometimes made between the lateral frame and the cranial frame to improve construct rigidity. These connections can be made proximally and distally (See Figure 53-33) or diagonally (Figures 53-34 and 53-35). Diagonal connections provide greater strength because they span the fracture region. Linkages can be built using double clamps (Figures 53-33 and 53-34) or by leaving selected fixation pins long and placing additional single clamps on the pins external to the frames (Figure 53-36) and connecting these "stacked" clamps with a rod.

Application of a Type II Construct

Some surgeons prefer to use a Type II frame (instead of Type I-b) for challenging shaft fractures. For the tibia, this entails application of at least two full-pins in a mediolateral plane through the medial aspect of the bone. The remainder of the frame is often built with medially applied half-pins resulting in a minimal or modified Type II construct (Figure 53-35).

A full-pin is applied using the same techniques described for the placement of a half-pin except that a second release incision must be made laterally to enable the full-pin to exit on the opposite side of the leg. After a full-pin has been placed in both the proximal and distal ends of the bone, these are connected medially and laterally with connecting rods and SK clamps (Figure 53-36). The remainder of the construct is completed by

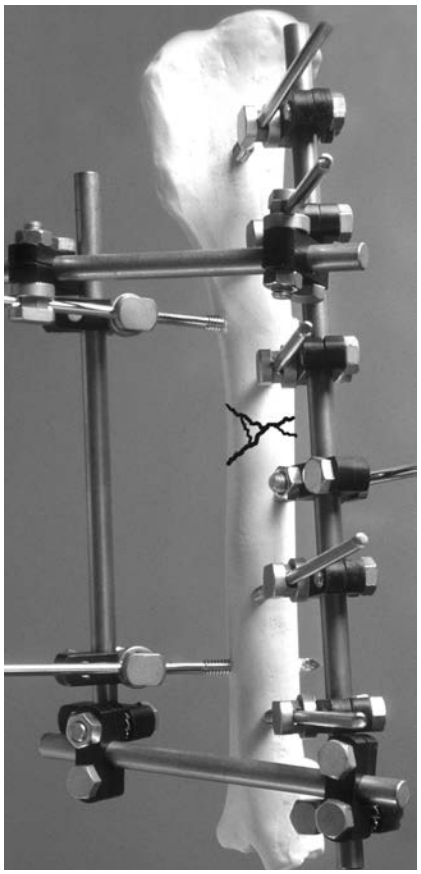


Figure 53-33. Medial view of a small SK Type I-b (unilateral-biplanar) external fixator on the tibia. A 6-pin frame has been applied medially, and a 2-pin frame has been applied cranially. The two frames have been interconnected with proximal and distal linkages using double clamps and titanium connecting rods.

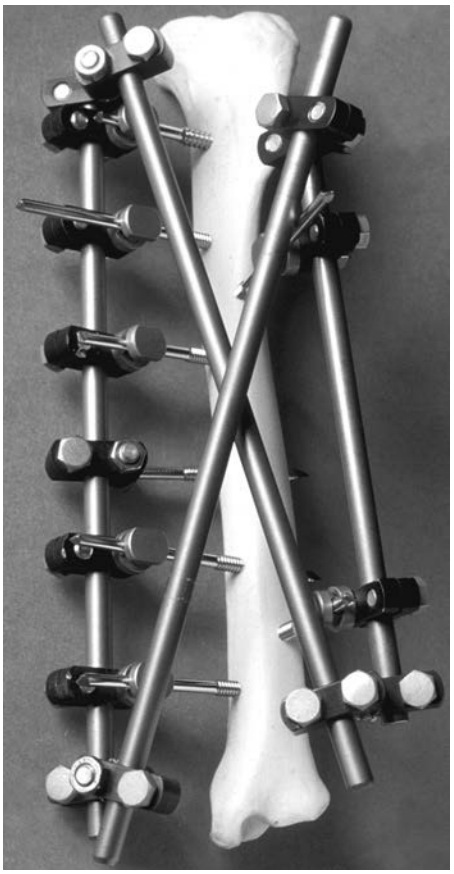


Figure 53-34. Craniomedial view of a small SK Type I-b construct on the tibia. Note that the medial and cranial frames have been interconnected with double diagonal linkages using double clamps and titanium connecting rods.

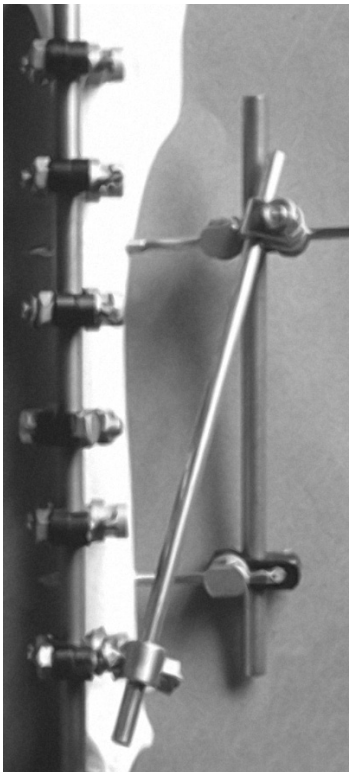


Figure 53-35. Medial view of a small SK Type I-b construct on the tibia. The medial and cranial frames have been connected with a single diagonal linkage using KE clamps and a stainless steel connecting rod. This same linkage could have been made with SK clamps and a titanium or carbon fiber composite connecting rod. Although KE components are weaker than SK components and should not be used for building frames, they may be safely used to apply more compact linkages to SK frames than is possible using SK components. This is due to the reduced height of the KE clamp compared to the SK clamp.

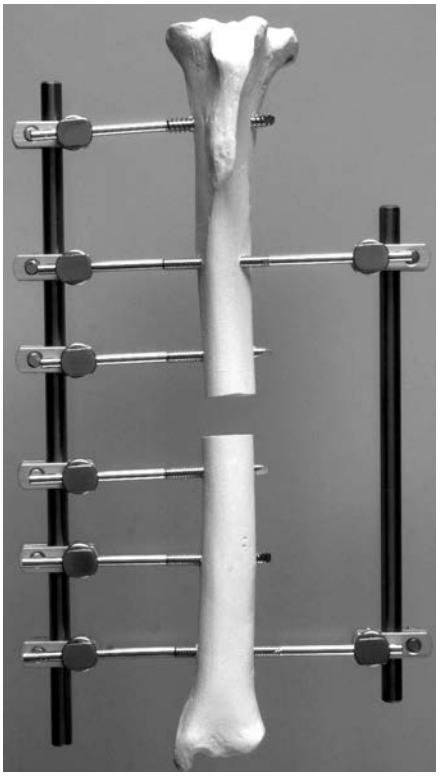


Figure 53-36. Cranial view of a small SK minimal Type II construct on the tibia. The proximal and distal full-pins were placed first and were connected with 6.3 mm carbon fiber composite connecting rods. The proximal-most half-pin was placed next and it should be noted that this is a cancellous thread pin due to the soft bone found in the metaphysis. The half-pins immediately above and below the fracture were placed next, followed by the remaining half-pin in the distal segment. Full-pins could have been safely used at every location except the most proximal pin site if additional frame stiffness was desired.

applying the required number of additional fixation pins from the medial side of the tibia. Half-pins or full-pins or a combination of these may be used to complete the fixator, however, a full-pin at the most proximal location on the tibia tends to cause higher postoperative morbidity than a medially placed half-pin at this position. This is due to the pin traversing a thick layer of soft tissue on the lateral aspect of the leg in a high motion area near the stifle joint.

Staged Disassembly of SK External Fixators

Rigid constructs benefit revascularization of the injured bone and other early fracture healing events, but high fixator stiffness may actually delay the later stages of bone healing and remodeling. Strategic reduction of external fixator rigidity to benefit the later stages of healing is accomplished by a process called staged disassembly. This can be done in several ways: 1) simplifying the frame configuration (e.g. conversion of a Type I-b to a Type I-a); 2) downsizing the frame by replacement of the connecting rods and clamps with smaller components (Table 53-7 and Figure 53-37); and 3) by removal of fixation pins from the central portion of a frame (strategy used for Type I-a fixators).

In skeletally mature patients, staged disassembly should be initiated at approximately 6 weeks after surgery. In adolescent patients, this process can often be started at 3 to 4 weeks

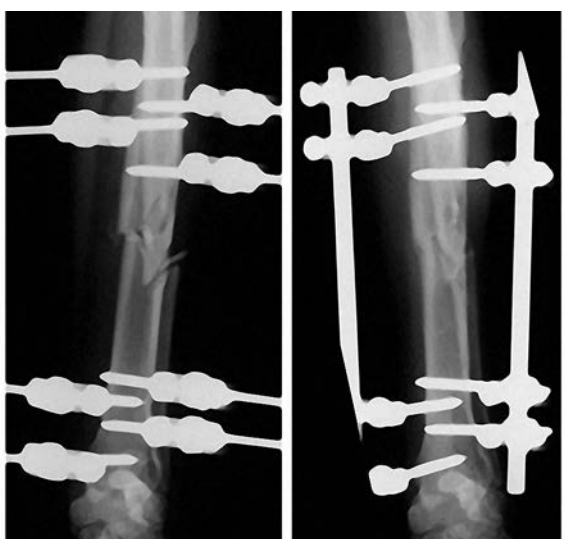


Figure 53-37. Staged disassembly of an external fixator shown in cranial-caudal radiographic projections of a comminuted fracture of the radius and ulna in 22 kg dog initially repaired with a Type I-b construct. The immediate post-operative radiograph (left picture) shows that large SK components were used (note the radiolucent 9.5 mm carbon fiber composite connecting rods). At 7 weeks after surgery (right picture) the large SK clamps and rods have been replaced with small SK clamps and 6.3 mm titanium connecting rods. Downsizing of the components of the fixator has reduced its frame stiffness by approximately four-fold.

Table 53-7. Staged Disassembly Strategies for SK Fixators Relative to the Size of Pins Used to Build the Fixator

IF = INTERFACE half-pin
CF = CENTERFACE full-pin
DF = DURAFACE half-pin

035" Miniature IF and CF
.045" Miniature IF and CF
.062" Miniature IF and CF

When any of these pin sizes are used to build the fixator:
Small SK constructs can be staged down to **Mini SK constructs** as part of the disassembly strategy

.078" Miniature IF
2.0 mm IF and CF & 2.5 mm DF
.094" Miniature IF
Small IF and CF

Small Plus IF and CF

3.2 mm DF
3.0 mm IF and CF & 3.5 mm DF
Medium IF and CF & 4.0 mm DF
Medium Plus IF and CF
Large IF and CF

When any of these pin sizes are used to build the fixator:
Large SK constructs can be staged down to **Small SK constructs** as part of the disassembly strategy

4.3 mm DF
4.8 mm DF

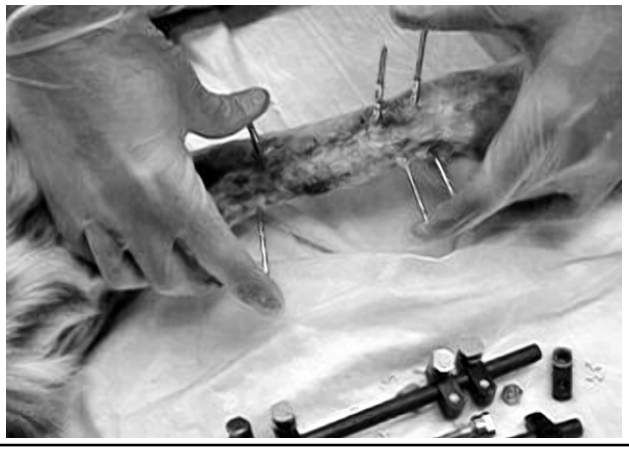


Figure 53-38. Staged disassembly of an external fixator. A Type I-b construct has been temporarily removed from this sedated patient. The surgeon is using the fixation pins to gently manipulate the fracture region to detect evidence of callus deposition. If callus is present, a frame with reduced stiffness will be applied to the fixation pins. If callus is not detected, the original frame will be rebuilt.

post-op. Staged disassembly can usually be done with the dog or cat under heavy sedation, but some patients may require brief duration general anesthesia with propofol. The fixation frame(s) should be temporarily removed to enable critical palpation of the fracture for evidence of callus formation (Figure 53-38). If the fracture feels "sticky" due to the presence of soft callus, it is appropriate to begin staged disassembly. If any of the fixation pins are causing morbidity, strongly consider removal of these fixation elements as part of the staged disassembly strategy. An example of this would be a Type I-b fixator applied to the radius in which fixation pins have been applied craniomedially and craniolaterally. Fixation pins of the craniomedial frame generally traverse less soft tissue than those of the craniolateral frame. On examination at 6 weeks after surgery, the pin tracts of the craniolateral frame might appear to be slightly inflamed compared to those of the craniomedial frame. If this was the case and the surgeon planned to convert the Type I-b frame to a Type I-a frame as part of the staged disassembly strategy, it would be logical to remove the craniolateral frame and its fixation pins.

Suggested Readings

Bronson DG, Toombs JP, Welch RD. Influence of the connecting rod on the biomechanical properties of five external skeletal fixation configurations. Vet Comp Orthop & Traumatol 16:8, 2003.

Lewis DD, Cross AR, Carmichael S, Anderson MA. Recent advances in external skeletal fixation. J Sm Anim Pract 42:103, 2001.

Toombs JP, Bronson DG, Ross D, Welch RD. The SK external fixation system: Description of components, instrumentation, and application techniques. Vet Comp Orthop & Traumatol 16: 76, 2003.

White DT, Bronson DG, Welch RD. A mechanical comparison of veterinary linear external fixation systems. Vet Surg 32:507, 2003.

Griffin H, Toombs JP, Bronson DG, et al: Mechanical evaluation of a tapered thread-run-out half-pin designed for external skeletal fixation in small animals. Vet Comp Orthop Traumatol 24:257, 2011.

Circular External Skeletal Fixation

Daniel D. Lewis and James P. Farese

Since the writing of the topic, methodology and nomenclature adopted from Dror Paley's Principles of Deformity Correction have been adapted and become accepted as the convention in small animal orthopedics.

Introduction

Circular external skeletal fixation (CESF) was pioneered by the Russian physician, Gavriil Ilizarov. These are modular systems which can be assembled in numerous configurations to stabilize fractures and arthrodeses, perform bone lengthening and transport as well as correct angular, translational and rotational deformities and are being used with increased frequency in dogs and cats. Circular fixator (CF) frames consist of a series of complete and/or incomplete external rings that are interconnected by multiple threaded rods. Rings are secured in position along these rods by placing nuts on opposing surfaces of each ring. Circular fixators are uniquely designed, allowing the frame to be elongated or shortened during or following surgery. Elongation of the frame during the convalescent period allows for distraction osteogenesis in which regenerate bone is formed within the osteotomy gap resulting from gradual separation of the secured bone segments.

Components, Implants and Instrumentation

The IMEX™ CESF System (IMEX™ Veterinary, Inc., Longview, TX) is the CF system used most commonly by North American veterinarians. This system was developed in conjunction with the Comparative Orthopedics Research Laboratory of the Texas Scottish Rite Hospital for Children in Dallas, Texas and is modeled after a device utilized in human patients. This system has several evolutionary advances which simplify frame construction, improve precision and decrease patient morbidity. The utilization of lighter metals and engineered plastics facilitated this process. Several new components have been developed which substantially decrease the total number of parts necessary for frame assembly, thereby reducing pre-operative frame preparation time.

Traditional CF constructs consist of supporting elements (complete rings, partial rings and arches), connecting elements (threaded rods, linear and angular motors and hinge assemblies), fixation elements (small diameter wires) and assembly elements (cannulated and/or slotted bolts, nuts, washers, plates and posts). The following section describes components of the IMEX™ CESF System.

Supporting Elements

Rings in this system are manufactured from a high-strength tempered aluminum alloy which imparts strength to the supporting elements while keeping the fixators weight-appropriate for use in dogs and cats (Figure 53-39). The rings have holes located about their circumference in which connecting and assembly elements are secured. Ring components are available in 50 mm, 66 mm, 84 mm and 118 mm internal diameters. While it is biomechanically preferable to utilize complete rings, anatomic constraints prohibit their use proximal to the elbow and stifle and often adjacent to other joints. Traditional CFs are mainly applicable for managing conditions involving or distal to the elbow or stifle, while hybrid linear-CF constructs (see section on Hybrid Constructs, Chapter 55) are typically used to manage injuries and abnormalities involving the humerus or femur. Five-eighths partial rings are often used to secure the proximal radius and distal tibia, while stretch ring arches have been developed which facilitate CF application to the proximal tibia and ulna. Stretch ring arches also simplify construction of CFs for transarticular stabilization of the hock and stifle regions. One-third partial ring arches are also available.

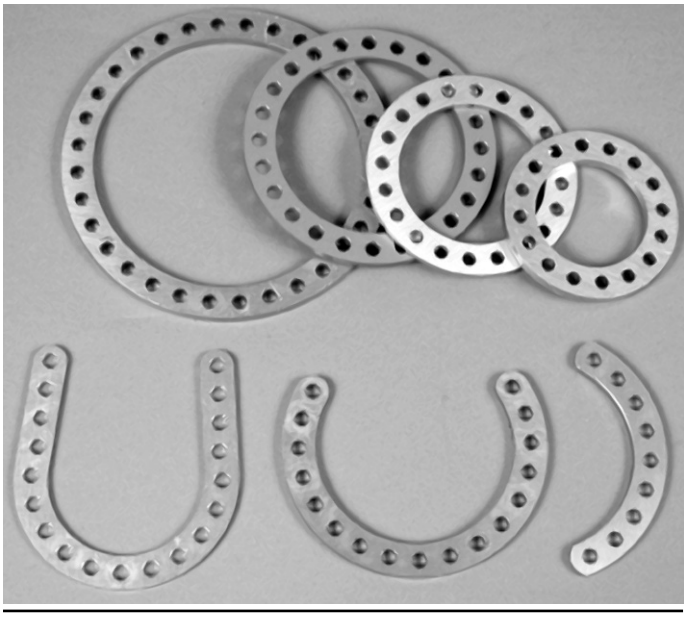


Figure 53-39. Supporting elements: complete rings (top row) are available in 118 mm, 84 mm, 66 mm and 50 mm internal diameter. Stretch and five-eighths partial rings and one-third ring arches (bottom row) are also available.

Connecting Elements

Threaded rods (6 mm thread diameter x 1 mm thread pitch) are the most commonly used connecting elements. Threaded rods are available in 60 mm, 80 mm, 100 mm 150 mm and 225 lengths with a 3 mm hex drive fitting at their ends to accommodate a 3 mm angled or straight hex driver. This hex broach fitting allows rapid replacement or exchange of rods if necessary.

A unique design feature of the IMEX™ CESF System is its zero tolerance, zero motion connecting elements (Figure 53-40). Adjustable components used for angular and linear distraction have nylon drive bushings or inserts between metal parts which prevent binding, allowing adjustments to be made without loosening and retightening nuts. This makes the distraction process simple and precise by eliminating frame instability which causes patient discomfort. Distraction or compression is performed simply with a wrench, facilitating client compliance and negating the need for prolonged hospitalizations.

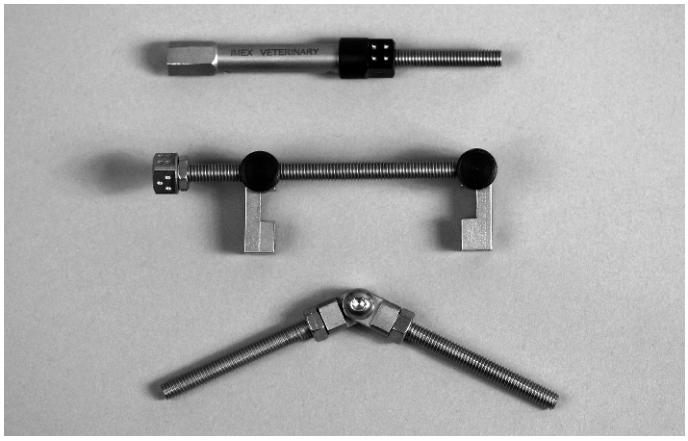


Figure 53-40. Connecting elements (from top to bottom): linear motor, angular motor and hinge assembly secured to short connecting rods with lock nuts.

Linear motors, available in 50 mm, 70 mm and 100 mm lengths are composed of a threaded rod encased in stainless steel housing and are used to perform linear distraction or compression. A nylon drive bushing is positioned between the stainless steel housing and threaded rod (6 mm diameter x 1 mm thread pitch). During distraction or compression, the drive bushing allows distraction or compression without loosening and retightening nuts, eliminating frame instability and thereby minimizing patient discomfort. Distraction or compression is performed simply by turning the clearly marked drive bushing with a 10 mm wrench. One complete revolution of the drive bushing produces 1 mm of linear movement.

Threaded rods can also be used for linear distraction/compression if 10 mm (6 mm thread diameter) paired nylon nuts are used to secure a ring to the rod. Simultaneous rotation of the paired nylon nuts with a double jawed 10 mm wrench which can engage nuts positioned on both sides of a ring will accomplish linear distraction/compression. The use of paired nylon nuts instead of linear motors to achieve linear distraction is most beneficial when adjacent rings are in close proximity. One complete revolution of the paired nylon nuts results in 1 mm of linear movement of the secured ring.

Connecting elements used for angular correction include hinge assemblies and angular motor assemblies. Hinge assemblies are used in pairs to provide pivot points between two rings. Angular motor assemblies provide asymmetric distraction of two rings articulated using paired hinge assemblies. Both elements have nylon inserts which confer zero tolerance, zero motion properties. Like the linear motor units, the angular motor assembly is clearly marked to aid in daily distractions during the convalescent period. Hinges and angular motor assemblies have a hex drive fastener which can be tightened once distraction is complete to lock the fixator in place. It should be noted that the hex drive fastener elements should be loosened prior to steam sterilization to prevent damage to the component as a result of expansion of the nylon insert.

Fixation Elements

Unlike linear fixator systems, traditional CFs use small diameter (1.0 or 1.6 mm) wires, rather than larger diameter pins, as fixation elements. Two wires are generally placed on each ring with the wires secured to opposing surfaces of the ring. The fixation wires are typically tensioned to improve their stiffness characteristics. Although standard Kirschner wires can be used as fixation wires, use of wires with an efficient single lip cutting point is recommended. Fixation wires are also available with olives (or stoppers) to increase stability of the construct and/or to manipulate and secure bone segments. Olive (or stopper) wires have a raised bead (olive) fixed along their length. This olive is brought into contact with the cortex of the bone. The olive can also be used to pull a bone segment into alignment and prevents translation of a secured bone segment along the wire. Inexpensive calibrated tensioning devices are now available to tension wires. Although not a part of Ilizarov's traditional armamentarium, positive and negative profile partially threaded (end threaded) half-pins and positive profile partially threaded (centrally threaded) full-pins can also be used as fixation elements.

Assembly Elements

All assembly elements have 10 mm wrench flats or 3 mm hexagonal recesses, thus keeping instrumentation to a minimum (Figure 53-41). Ten mm (6 mm thread diameter) stainless steel nuts are also used to secure connecting and assembly elements. Fixation wires are secured to the rings with 6 mm wire fixation bolts which are both slotted (for capture of wires that cross rings between holes) and cannulated (for capture of wires that cross rings over a hole). Slotted 6 mm washers are available to capture wires at sites occupied by connecting elements and 6 mm flat washers are available to be used as a spacer for capturing wires that are not inserted immediately adjacent to a ring. Pin fixation bolts are also available which allow the utilization of half-pins and full-pins. The pin fixation bolts accommodate fixation pins ranging from 2.3 mm to 5 mm in diameter and are similar in design to the pin-gripping bolt of IMEX™ SK™ fixation clamp.

Hemi-spherical washers and hemi-spherical nuts are also available. When used in combination the hemi-spherical washers and hemi-spherical nuts allow for angulation of connecting rods. Thus, rings can be secured to each other



Figure 53-41. Assembly elements (from left to right): top row: stainless steel nuts, nylon nuts, wire fixation bolts, pin fixation bolts. Middle row: hemi-spherical washers and nuts, stainless steel washers, slotted washers, and two-hole plates. Bottom row: one- and two-hole posts.

without being in exact parallel alignment. This permits minor adjustments in reduction of fracture segments and fine adjustments in correcting angular deformities. When utilized with two-hole plates, the hemi-spherical washers and hemi-spherical nuts can be used to connect adjacent rings without utilizing corresponding holes and are particularly useful in constructing complex or transarticular frames.

Two-hole plates are available to allow the use of different diameter rings within the same fixator frame. The plate is bolted to the ring extending away from its center. A connecting rod or motor can then be attached to the plate and linked directly to the next larger diameter ring. One- and two-hole posts are utilized to secure fixation wires and pins elevated remote to the surface of a ring, to create hinge assemblies and to secure connecting elements that are not positioned perpendicular to the surface of a ring. Plates and posts are extremely useful when constructing transarticular or other complex frames.

Biomechanics

Circular fixators possess biomechanical characteristics which purportedly enhance fracture healing as well as allow for distraction osteogenesis. The biomechanics of CFs differ primarily from linear fixators in that the tensioned wires stabilizing the bone segments adequately resist bending, shear, and torsional forces while maintaining some degree of axial elasticity. Load/deformation curves of CF constructs undergoing axial compression have a characteristic initial exponential increase in stiffness which is ascribed to tensioning of the wires when subjected to loading. Construct stiffness increases until the slope of the load/deformation curve becomes linear with continued loading, protecting the osteotomy or fracture gap from excessive strain during ambulation. The "axial micromotion" occurring at physiological loads purportedly creates a mechanical environment conducive to bone formation.

Numerous extrinsic (apparatus-related) factors have been shown to affect the stability of the fixation including the number, type, angle of intersection, applied tension and diameter of the fixation wires, as well as the number, conformation, diameter and position of the rings and connecting elements. Intrinsic factors which theoretically contribute to stability of the bone-fixator construct include the area of contact and nature of the interlock between bone segments, the modulus of elasticity of tissue between bone segments, and the tension of the regional soft tissues.

The number of levels of fixation influences the mechanical properties of any fixator construct. Ilizarov found that four-ring CFs (two rings per bone segment) were more stable than two-ring CFs (one ring per bone segment). Additional studies have shown that if a four-ring construct is used to stabilize a fracture, the stability of the CF is increased if the central two rings are positioned in close proximity to the fracture or osteotomy and the proximal and distal rings are positioned adjacent to the joints at the end of the each major bone segment. This distributes the weight-bearing forces evenly over the involved limb segment in a "far-near-near-far" arrangement.

Ring diameter is the single most important parameter influencing the biomechanical profile of any CF constructs. While ring diameter affects stability in all modes of loading, ring diameter has its greatest effect on axial stability. Ring diameter is selected based on anatomic constraints: the smallest diameter rings which can be accommodated should be selected; however, a minimum 1 to 2 cm of clearance should be maintained between the ring and the circumference of the limb to allow for soft tissue swelling and daily management of the wire-skin interfaces.

Since the diameter of rings used in dogs and cats is much smaller than those used in human patients, even children, the biomechanics of CFs used in dogs and cats are markedly different from those used in human patients. Several biomechanical studies have been done evaluating IMEX™ CF constructs and it appears that there is little need to tension wires when using the 50 mm and possibly the 66 mm rings (although wires are usually tensioned to 30 kg when using 66 mm rings). Tensioning of wires on larger diameter rings is warranted with the recommendation to apply 60 kg of tension when using 84 mm rings and 90 kg of tension when using 118 mm rings. Some surgeons advocate simultaneously tensioning wires secured to the same ring (Figure 53-42) and wires secured to partial rings or posts should not be tensioned beyond 30 kg to avoid deformation of the ring or posts.

Olive wires can enhance the stability of fixation. Placing two opposed olive wires to secure a bone segment can significantly improve bending stiffness and stability by minimizing translation of the secured bone segment along the wire. This is particularly important when wires are placed on the same ring with little divergency. Opposing interfragmentary olive wires can also be used to compress anatomically reduced long oblique or spiral fractures.

CF constructs utilizing tensioned wires in combination with half-pins or full-pins are being used with increasing frequency. The use of half-pins has been advocated in locations where divergent fixation wires would pass through prominent muscle

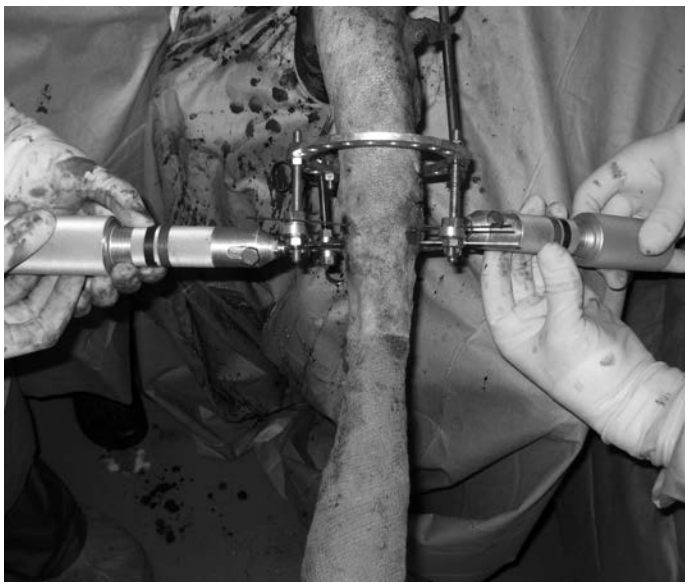


Figure 53-42. Simultaneous tensioning of fixation wires using calibrated tensioning devices.

masses, such as the proximal tibia, or near vital soft tissue structures. These constructs have been shown to have biomechanical characteristics intermediate between those of conventional linear fixators and traditional CFs. The combination of wire and half-pin fixation can be problematic. When used in combination with wires, a single or an inadequate number of half-pins may be subjected to excessive loading as the wires initially deform when subjected to loading. Thus, if the number of half-pins utilized is not sufficient, excessive stress occurs at the pin-bone interface. The use of three (or preferably more) evenly distributed, divergent half-pins per bone segment (depending on concurrent wire utilization) is advocated in these configurations to avoid problems associated with premature pin loosening and pin tract drainage.

Distraction Osteogenesis

Distraction osteogenesis describes the mechanical induction of new bone formation in the gap produced by the gradual separation of two bone segments. Much of what is known regarding the biology of distraction osteogenesis was elucidated by Ilizarov and his colleagues; however, recent investigations have focused on the cellular and molecular events of bone formation in both fracture healing and distraction osteogenesis. Distraction osteogenesis shares many morphologic and biomechanical similarities with early fracture healing. Bone retains the inherent capacity to remodel and repair and these processes are influenced by the local mechanical environment. The new bone which forms in the distraction gap during distraction osteogenesis is referred to as "regenerate" bone (Figure 53-43).

Cyclic axial loading is necessary for remodeling and maintaining bone mass and numerous experimental and clinical studies suggest that axial dynamization accelerates fracture healing. Traditional CFs allow some degree of axial micro-motion, while providing adequate bending and torsional resistance. Clinical studies evaluating the use of CFs to manage fractures in dogs and cats support the contention that CFs promote rapid fracture healing.

Ilizarov advocated performing a corticotomy, which preserved both periosteal and endosteal tissues, for optimal regenerate bone formation during distraction osteogenesis. Recent clinical and experimental studies, however, have shown that preservation of the periosteum has the most significant influence on regenerate bone formation: the method utilized to perform the osteotomy (Gigli wire, bone saw, drill holes-osteotome) has a nominal effect on regenerate formation as long as the periosteal envelope is preserved and most small animal surgeons perform subperiosteal osteotomies using a pneumatic oscillating saw.

Latency or delay refers to the time period following osteotomy before beginning distraction. The latency period used in human patients is typically 4 to 7 days. Several factors will influence the prescribed latency period: the patient's age, the bone involved, the location of the osteotomy, soft tissue trauma present prior to or incurred during surgery, and the primary condition necessitating treatment. Metaphyseal lengthenings produce higher

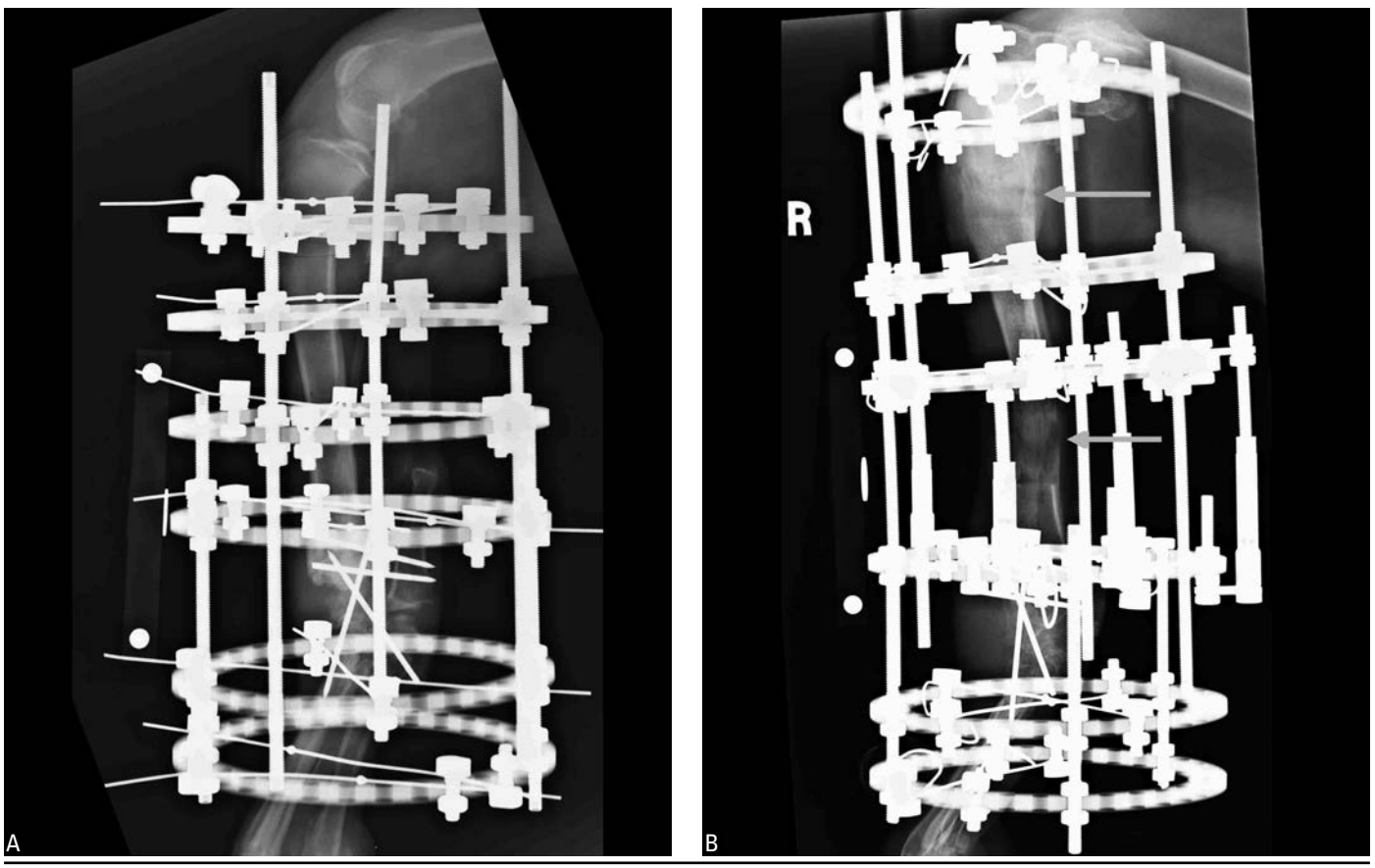


Figure 53-43. A. Pre- and **B.** post-distraction radiographs demonstrating regenerate bone formation (gray arrows in **B.**) in a dog undergoing bi-level distraction for lengthening of the crus.

quality regenerate bone than diaphyseal lengthenings. The metaphyseal region has a greater blood supply and bone surface area in comparison to diaphyseal bone. Proximally located osteotomies produce higher quality regenerate bone than more distally located osteotomies. The latency period allows early vascularization and soft callus formation before lengthening commences. Poor regenerate formation and non-union can occur if distraction is initiated too early. Premature consolidation can occur if the latency period is too prolonged, particularly in young or skeletally immature animals.

The recommended latency period prior to initiating distraction is typically short in dogs undergoing lengthening or angular correction. In young dogs in which the periosteal sleeve was well preserved, a delay period may be unnecessary. Most small animal surgeons generally initiate distraction 1 to 3 days following surgery in dogs in this age group. It is prudent to observe a 3 to 5 day delay before initiating distraction with animals that are 3 to 8 years of age. Longer delay periods may be advisable in older dogs or if the periosteum had been damaged substantially prior to or during surgery.

Rate refers to the amount of distraction that will be performed over a 24 hour period. Experimental and clinical studies indicate that the amount of lengthening performed should be in the range of 0.5 to 2.0 mm/day to promote viable regenerate bone formation. The formation of regenerate bone can be monitored radiographically and the rate adjusted accordingly. Rates for skeletally immature patients undergoing metaphyseal osteotomies may be near the higher limit as these animals have a greater osteogenic potential.

Rhythm describes the frequency (number of fractionations) at which the distractions are performed during a 24 hour time period. Ilizarov had reported that increasing the rhythm from 1 or 2 times per day up to 60 times per day significantly increased regenerate formation and decreased consolidation times; however, studies evaluating rhythms of 1, 4, and 720 times per day in a caprine lengthening model found no significant effects of rhythm on radiographic, mechanical, or histomorphologic regenerate parameters. Increased rhythms, however, allow for superior accommodation of the regional soft tissues, decreasing morbidity during the distraction period. In our clinic we generally perform distractions at a rate of 1.0 to 1.5 mm/day using a rhythm of three or four distractions/day.

Clinical Applications in Dogs and Cats

Circular fixators have been used to manage a number of developmental and traumatic orthopedic conditions in dogs and cats. The most notable of these being limb deformity correction, most frequently antebrachial limb deformity correction. Pre-operative assessment and planning, a thorough knowledge of the instrumentation and its application and conscientious post-operative patient care are essential for a successful outcome. Traditional CFs have also been used to perform deformity corrections and lengthenings of the crus and pes. These systems are also useful for stabilizing complex fractures of the antebrachium and crus, as well as transarticular stabilization, particularly in performing arthrodeses. Frames utilizing hinges allow the surgeon the latitude to adjust the angle of arthrodesis during the early convalescent period and the use of these devices facilitates the removal of all implants following fusion. Finally, CFs can be used to perform bone transport to resolve large traumatic segmental bone defects and oncologic surgeons are now utilizing bone transport in limb salvage procedures in dogs with appendicular bone tumors (see section on Distraction Osteogenesis as an Alternative to Bone Grafting in Chapter 56).

Fracture Management

Circular external skeletal fixation has been utilized extensively for fracture management in human patients and there are recent reports describing the use of CFs for fracture management in dogs and cats. Traditional CFs are most applicable for the stabilization of non-articular antebrachial and crural fractures. Circular fixators are particularly useful for stabilizing fractures with short juxta-articular fracture segments as the divergent placement of small diameter wires provides multiplanar stability. With experience, a surgeon can achieve accurate closed reductions of both simple and complex fractures with relatively short operative times.

Frames are constructed prior to surgery based on preoperative radiographs of the fractured and contralateral intact (if applicable) limb segment. When constructing the fixator, complete rings are generally used to secure the middle and distal portions of the limb segment. Partial rings are used proximally to avoid soft tissue impingement or compromised joint mobility. Stretch rings are useful for securing the proximal ulna and tibia, while 5/8th rings can be used to secure the proximal radius or if the most distal ring interferes with carpal or hock motion. The smallest diameter rings that can be comfortably placed about the circumference of the limb, allowing for post-operative swelling without soft tissue impingement, should be selected. Pre-construction of a frame greatly reduces surgical time. Minor adjustment of the frame should be anticipated and performed as necessary at the time of surgery.

A standard frame configuration consists of three or four rings. A single ring or pair of rings that engage a fracture segment and which are secured together by connecting elements constitute a functional unit referred to as a ring block. While it is preferable to use two or more rings to construct a ring block, there may only be sufficient room to accommodate a single ring in fractures with a short proximal or distal segment. A typical CF construct that would be used to stabilize a crural fracture is composed of two independent ring blocks articulated by linear motors or threaded connecting rods which are secured only to the rings positioned adjacent to the fracture site. This arrangement allows simple adjustment of the distance between the two ring blocks, allowing the major fracture segments to be distracted or compressed. Thus, the frame can be used intra-operatively to distract the fractured limb segment to its normal length which greatly facilitates reduction.

When constructing a CF that will be used to distract a crural fracture out to length, the two ring blocks are constructed based on the length of the major fracture segments. Appropriate length

of each ring block is confirmed by measuring each ring block against the fracture segment it will be used to stabilize on the lateral view radiograph. The articulating intermediate linear motors or connecting rods are then placed between the two ring blocks and the construct is placed over a lateral view radiograph of the contralateral intact limb segment (if available) to assess appropriate frame length (Figure 53-44A). The most proximal and distal rings should be placed at or near their respective metaphyses. The CF is then positioned so that the lateral radiographic image of the intact tibia is appropriately situated within the frame and each ring should be marked, both medially and laterally, along the tibia's central longitudinal axis with a permanent marker. Thus reasonable reduction can be achieved at surgery by placing fixation wires through the tibia in a medial-to-lateral plane and attaching each wire to its corresponding ring at the marked location, if the limb segment has been distracted out to normal length. The frame is then placed over the lateral view radiograph of the fractured limb segment and the intermediate linear motors or connecting rods are compressed to account for shortening of the limb segment as the result of the fracture. The frame is then sterilized in preparation for surgery.

When applying the fixator at surgery, the dog is positioned in dorsal recumbency and the CF construct is slid over the limb and a wire is placed in each metaphysis, parallel to both the proximal and distal joint surfaces. These wires should be placed in the medial-to-lateral plane. The use of intra-operative fluoroscopy, if available, facilitates proper wire placement. These initial two wires are then attached to the abaxial surface of the most proximal and distal rings at the predetermined locations as marked on the frame prior to surgery (Figure 53-44B). The wires are tensioned if indicated depending on ring diameter. If the fracture is over-ridden, the distance between the proximal and distal ring blocks, which are now secured to the bones via the fixation wires, can be increased by turning the intermediate linear motors or the nuts securing the intermediate connecting rods to bring the limb segment out to length. Distraction will create tension in the regional soft tissues which will help reduce the fracture (Figure 53-43C). An attempt should be made to "over-distract" the fracture by a couple of millimeters. Alignment of the fracture can be assessed by palpation, or by fluoroscopy if available.

The next two wires should be placed in the medial-to-lateral plane through the longitudinal axis of the tibia adjacent to the intermediate rings (Figure 53-44D). Attaching (and, if necessary, tensioning) these wires at the predetermined locations as marked on the frame prior to surgery, should result in reasonable craniocaudal alignment of the fracture (Figure 53-44E). If one or both fracture segments need(s) to be transposed in a medial or lateral direction, the segment(s) can be translated along the initial fixation wire(s) by simply applying digital pressure to the bone segment(s) (Figures 53-44F and G). Alternatively, olive wires can be used to translate bone segments. An olive wire is placed on the appropriate, intermediate ring in the medial-to-lateral plane with the olive positioned adjacent to the cortex on the side of the bone which is to be pulled into place. By using the tensioner, which is placed on the exposed end of the wire opposite the olive, the olive wire along with the bone segment can be translated toward the tensioning device.

If a bone segment needs to be translated cranial or caudal, again an olive wire can be used, but this can cause unnecessary impingement of the regional soft tissues. Alternatively, reattaching one or potentially both of the wires on the intermediate ring at holes immediately cranial or caudal (direction opposite of the displacement) to its original position will result in bowing of the wire as it is reattached to the ring with fixation bolts. As the wire is retensioned, the bow in the wire will be eliminated and the bone segment will be translated in the desired direction.

If the fracture was slightly over-distracted, the distance between the ring blocks should be decreased, restoring normal length to the limb segment. Once reduction is acceptable, the remaining fixation wires are placed to complete the construct. Two additional wires should be placed on each ring. These wires should be oriented at 45° to 90°, to each other and olive wires should be used to minimize translation of bone segments. Fixation wires should be placed parallel to the surface of the rings. Wires that are not in immediate contact with the surface of the ring should be secured with flat washers placed subjacent to the wire when it is secured with a fixation bolt. If the wire is bowed as it is attached to the ring, displacement of the bone segment will occur. Proper tensioning of wires will also maximize stability. It is prudent not to cut the fixation wires too short or to bend the wires over until the fracture reduction is evaluated radiographically. This makes any necessary post-operative adjustments simpler to perform.

Isolated double ring block constructs are generally not used to stabilize radius and ulnar fractures as suspension of the limb can be used to facilitate reduction of antebrachial fractures. A typical CF construct that would be used to stabilize an antebrachial fracture consists of three or four rings, all of which are interconnected by long threaded connecting rods which span the entire length of the frame. The construct is assembled and laid on the lateral radiographic view of the contralateral intact limb segment (if available) to assess that the frame length is appropriate with the most proximal and distal rings positioned at or near their respective metaphyses. Position of the intermediate ring is confirmed by comparing its distance from the corresponding proximal or distal ring to the length of the fracture segment those two rings will secure. The frame is then repositioned over the lateral radiographic image of the intact antebrachium such that the radius is appropriately situated within the frame and each ring should be marked, both medially and laterally, along the radius' central longitudinal axis with a permanent marker. Again reasonable reduction should be achieved at surgery by placing fixation wires through the radius in a medial-to-lateral plane and attaching each wire to its corresponding ring at the marked location, but in this case suspension of the limb will be used to distract the limb segment out to normal length. The frame is then sterilized in preparation for surgery.

The dog is positioned in dorsal recumbency for surgery and the CF construct is slid over the limb. The limb is then suspended from the ceiling to distract the limb segment out to length. Tension in the regional soft tissues should again help reduce the fracture (Figure 53-45A). Wires are placed in each metaphysis, parallel to both the proximal and distal joint surfaces. These wires should

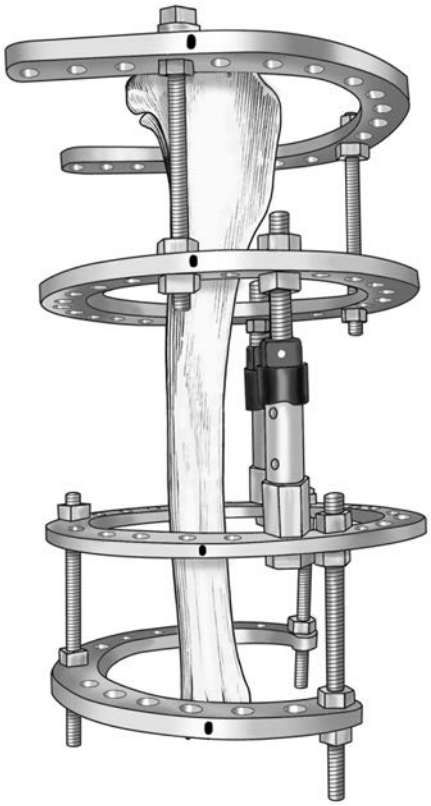


Figure 53-44A. Construction of CF for stabilization of a crural fracture. The individual ring blocks are constructed according to the lengths of the major fracture segments. Overall frame length is based on the length of the intact tibia. The frame is placed over the lateral view radiograph of the intact tibia and the optimal position of each of the medial-to-lateral fixation wires are marked on the frame.

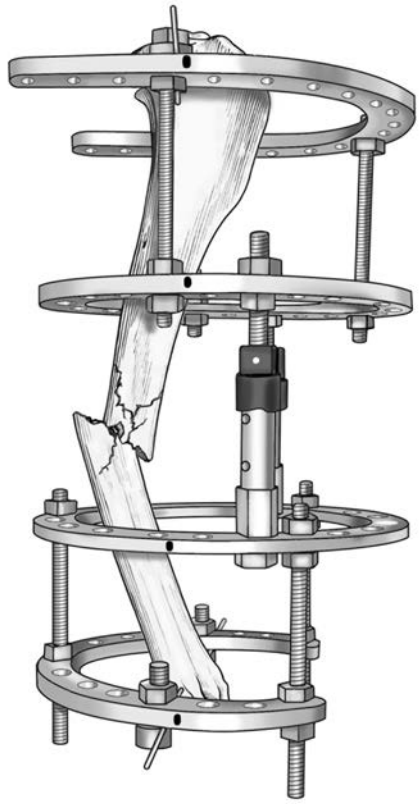


Figure 53-44B. Application of the CF. Medial-to-lateral fixation wires are placed proximally and distal and attached to the frame at the marked positions. The linear motors (that were previously collapsed) positioned between ring blocks will be used to distract the fracture out to length.

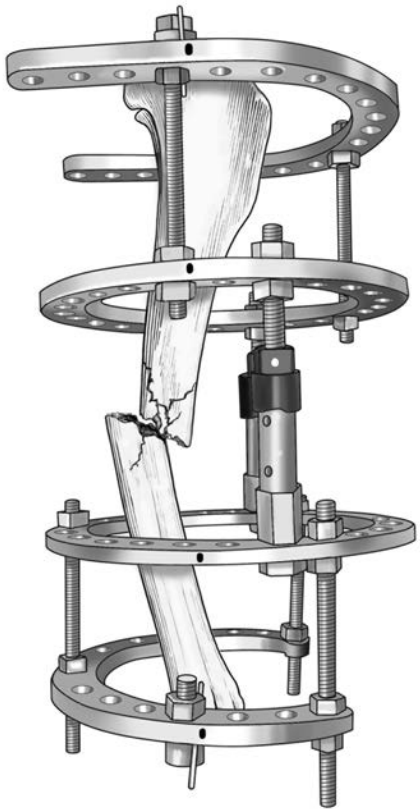


Figure 53-44C. Distraction of the linear motors has brought the fracture out to length and improved craniocaudal alignment.

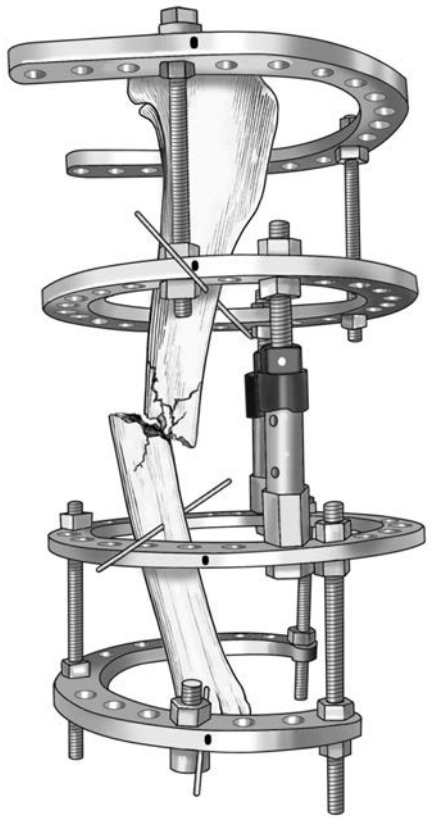


Figure 53-44D. Medial-to-lateral fixation wires have been placed adjacent to the central two rings.

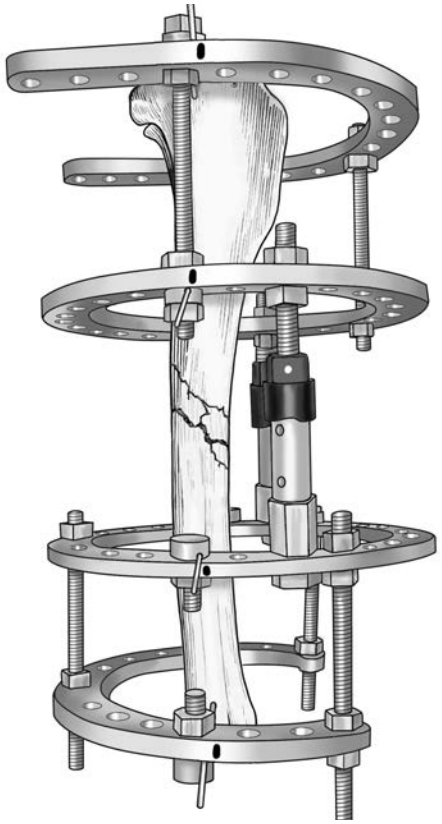


Figure 53-44E. Attachment of these wires at the perviously marked locations results in good craniocaudal alignment of the fracture.

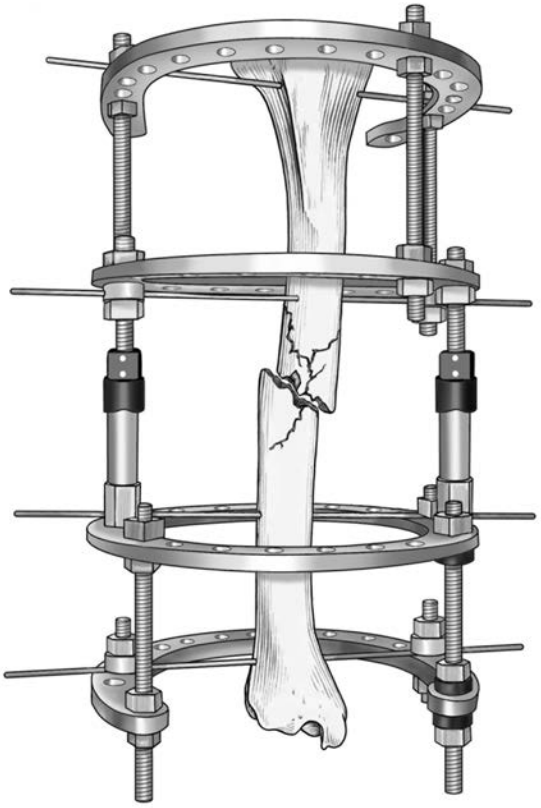


Figure 53-44F. Mediolateral reduction can be improved by translation of the fracture segments (in this case medial translation of the distal segment along the fixation wires).

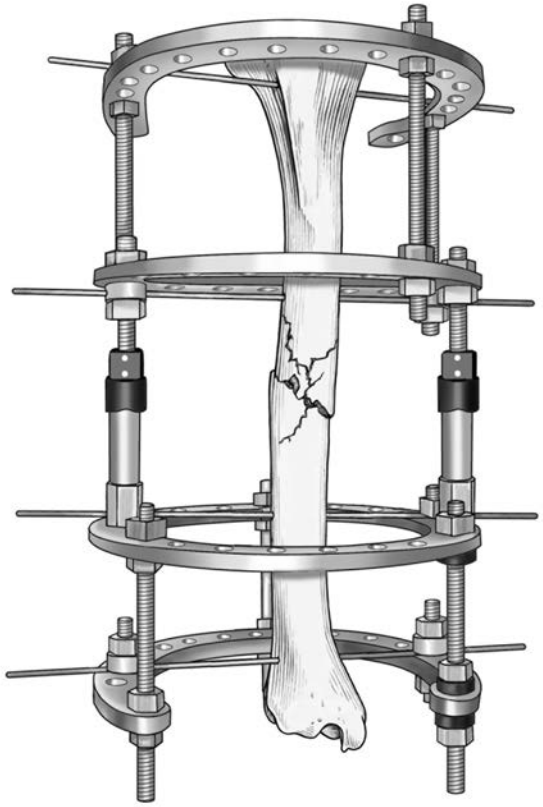


Figure 53-44G. After the final reduction, additional fixation (preferably olive) wires would be placed on each ring.

be placed in the medial-to-lateral plane (Figure 53-45B). The use of intra-operative fluoroscopy, if available, facilitates proper wire placement. These initial two wires are then attached to the abaxial surface of the most proximal and distal rings at the predetermined locations as marked on the frame prior to surgery. The wires are tensioned if indicated depending on ring diameter. If the distraction created by suspending the limb is not sufficient to produce an acceptable reduction, the distance between the proximal and distal rings, which are now secured to the bones via the fixation wires, can be increased by turning the nuts securing one of these rings. An attempt should be made to "over-distract" the fracture by a couple of millimeters. If fluoroscopy is available, alignment of the fracture can be visually assessed. If fluoroscopy is not available, alignment is assessed by palpation. The remainder of the process is similar to that described for reduction and stabilization of crural fractures (Figure 53-45C).

Limb Deformity Corrections

The most common limb deformity occurring in dogs results from premature closure of the distal ulnar physis. Premature distal ulnar physeal closure typically produces valgus and caudal angular deviation with external rotation and procurvatum of the distal radius. Concurrent proximal subluxation of radial head is often present in these dogs which can result in failure of the anconeal process to unite with the remainder of the ulna. Eccentric or complete closure of the distal radial physis can also be a sequella to premature distal ulnar physeal closure. Premature distal radial physeal closure is the second, but less common, limb deformity

occurring in dogs. Affected dogs have a shortened radius, and often shortening of the entire antebrachium, with distal subluxation of the radial head. Angular and rotational deformities can be present in more severely affected dogs. Premature proximal radial physeal closure occurs infrequently, but will produce distal subluxation of the radial head.

Acute correction of limb deformities with bone plates or *linear* external fixators may be limited by tension in the regional soft tissues. The use of CFs and the methods of Ilizarov allow for acute or progressive correction of angular, rotational and translational deformity as well as length discrepancies. Circular fixators also allow the surgeon to make precise adjustments following surgery and throughout the convalescent period.

Limb Lengthening

Limb lengthening is warranted when length discrepancies produce a gait abnormality that impairs limb function. Lengthening may be done as an isolated procedure or in conjunction with angular, translational and/or rotational corrections. Since the radius and/or ulna are the bones which are most frequently lengthened, this discussion will focus on longitudinal antebrachial lengthenings. Craniocaudal and mediolateral view radiographs of both antebrachii, including the manus, should be obtained prior to surgery and length discrepancies between limbs measured. Premature closure of the distal radial physis can require lengthening of the entire antebrachium and is generally done using a three ring construct (Figure 53-46). The proximal ring is positioned near the radial head, the central ring is positioned over the mid-antebrachium and the distal ring at the distal metaphysis. If the radial head is subluxated distally (as an isolated abnormality or in conjunction with abnormalities of the distal antebrachium), a subperiosteal osteotomy is made at the proximal metaphyseal-diaphyseal junction (distal to the position of the proximal ring) and the fixation wires on the proximal ring should only engage the radius. It is helpful to isolate the proximal radius and initiate, but not complete the osteotomy before placing the fixator on the limb. This limits the amount of surgery that must be performed within the frame, but allows the fixation wires to be placed into a stable bone segment. Once the frame and fixation wires are placed and the bone segments are stable, the osteotomy is completed. The proximal ring should be articulated with the central ring using linear motors or threaded rods secured with nylon nuts. This will allow distraction of the proximal radius to correct the existing elbow incongruency. To lengthen the entire distal antebrachium the wires attached to the distal ring should engage both the distal radius and ulna. Subperiosteal osteotomies are made at the distal radial and ulnar metaphyseal junction, proximal to the position of the distal ring. Performing the distal ulnar osteotomy and approaching and initiating the distal radial osteotomy prior to placing the frame over the limb, again simplifies the procedure. The distal ring should be articulated to the central ring using linear motors or threaded rods secured with nylon nuts. When applying the frame, the connecting elements should be positioned parallel to the longitudinal axis of the radius and ulna to produce the most functional lengthening.

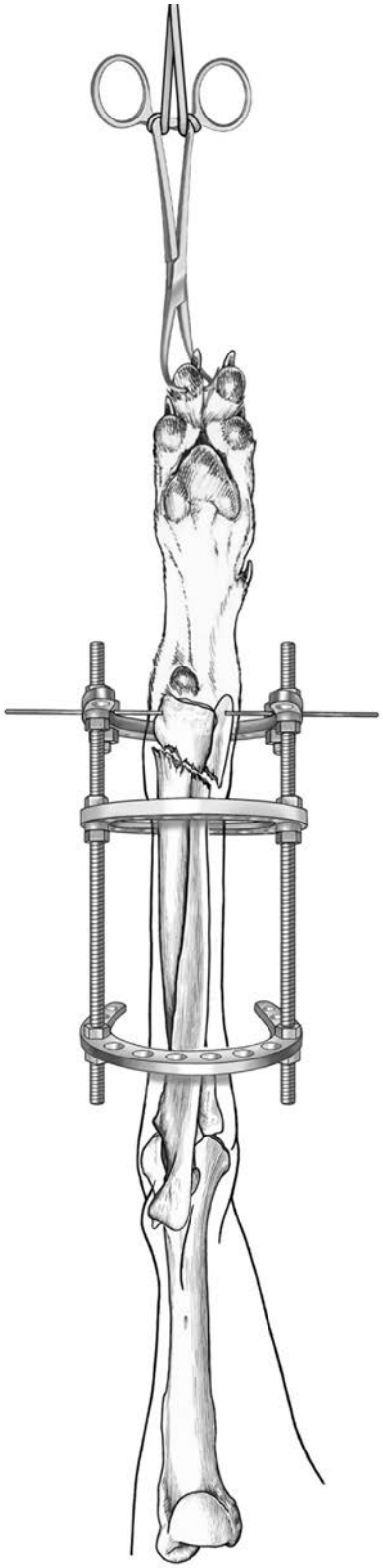


Figure 53-45A. Reduction and stabilization of an antebrachial fracture by suspending the limb. Reduction is nearly anatomic as the result of the traction applied and the initial fixation wire is placed perpendicular to the longitudinal axis of the radius. The frame is attached to the initial fixation wire such that the connecting elements are in alignment parallel with the radius.

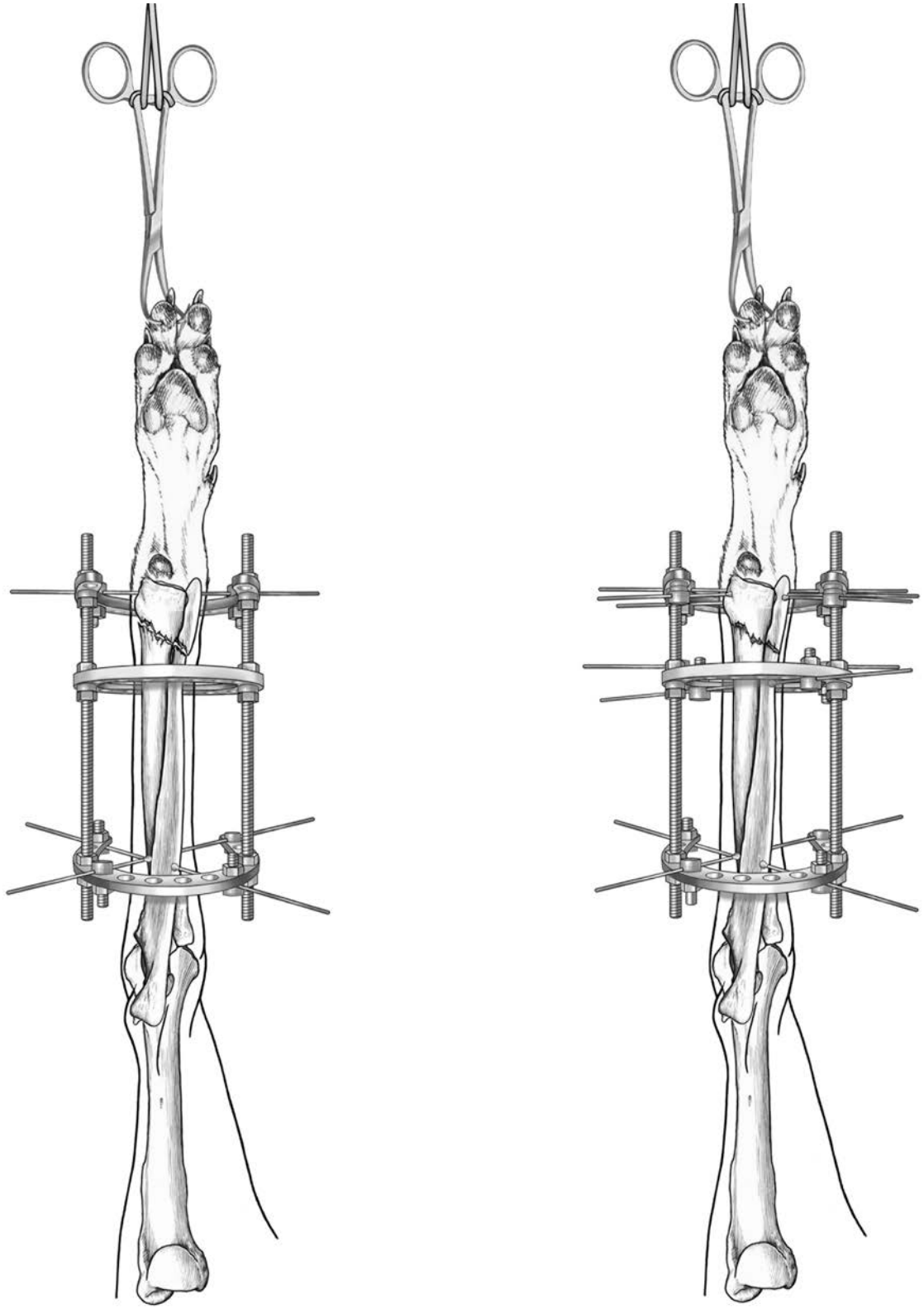


Figure 53-45. B and **C.** The construction is completed with paired divergent olive wires at each level..

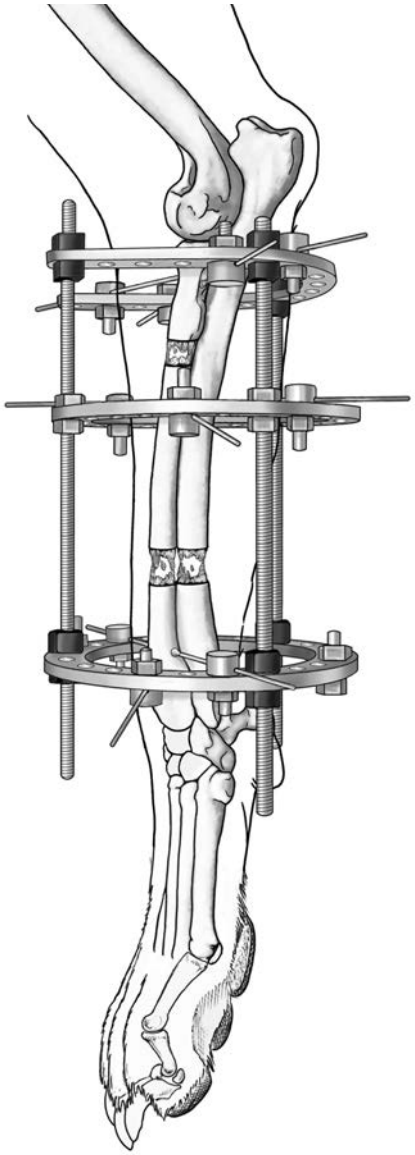


Figure 53-46. Lengthening of the distal antebrachium with concurrent correction of distal subluxation of the radial head. Proximal and distal radial osteotomies and a distal ulnar osteotomy have been done. The proximal radius will be lengthened to restore elbow congruency and the distal radius and ulna distracted to lengthen the antebrachium. Note that nylon nuts have been used to secure both the proximal and distal rings to facilitate distraction.

Angular and Rotational Correction

The discussion will focus on correction of an antebrachial deformity resulting from premature closure of the distal ulnar physis as this abnormality constitutes the most common deformity correction performed in dogs. Pre-operative planning is critical to obtaining optimal results. Although trigonometric preoperative planning methods have been described, a simplified graphic method is preferred to define both the apex and plane of the angular deformity (Figure 53-47). Craniocaudal and mediolateral view radiographs of the entire limb including and distal to the elbow are obtained and tracings of these radiographs should be made in order to plan the procedure. Although the antebrachium is a paired bone system, the radius is the principle weight-bearing bone and the deformity is characterized according to conformational abnormalities of the radius. Straight lines are drawn through the axial plane of the proximal and distal radial segment. These lines are centered through the metaphysis and perpendicular to the adjacent articular surface. The intersection of these two lines denotes the apex of the deformity. It should be noted that in some animals, the apex of the deformity may not be isotopic in orthogonal planes.

To define the plane of the deformity, the mediolateral and craniocaudal components of the deformity, which are vectors and thus have both direction and magnitude, must be calculated. A line is drawn connecting the center of the proximal and distal articular surface of the radius on the tracings of both the craniocaudal and mediolateral radiographs: these lines represent the mechanical axis of the radius. Another line is drawn from the previously defined apex of the deformity perpendicular to the mechanical axis on the tracing on each radiographic projection. The measured length of the line on the craniocaudal radiograph constitutes the medial (varus) or lateral (valgus) component of

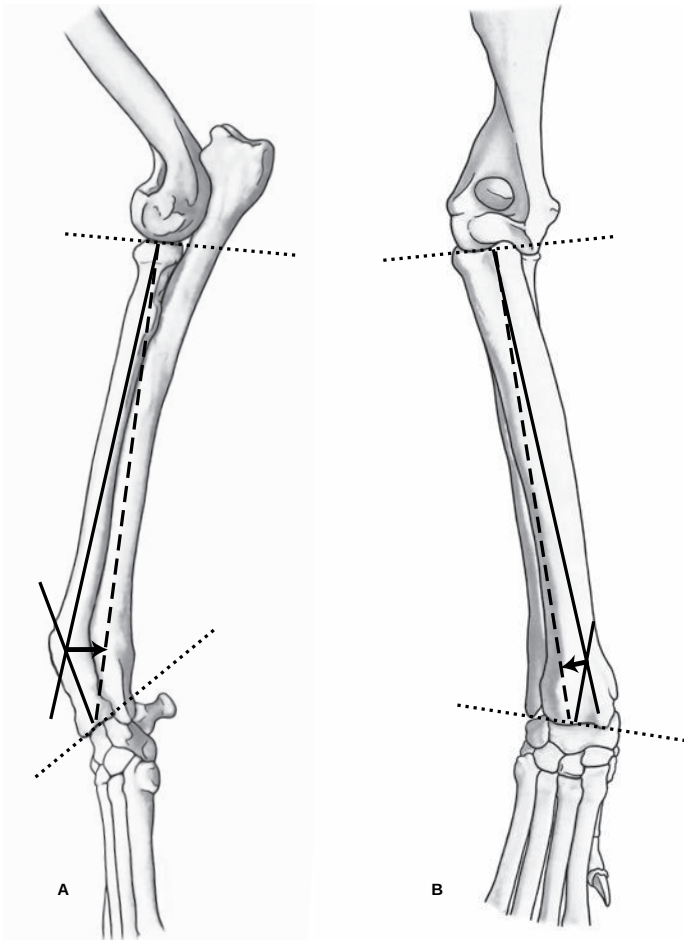


Figure 53-47. Graphic method for defining deformity parameters. Tracing made from radiographs of the right antebrachium. The lines longitudinal axis of the proximal and distal radial segments. The intersection of these two lines denotes the apex of deformity. The dotted line connecting the centers of the articular surfaces of the radius represents the bone's mechanical axis. Vectors (arrows) are drawn from the apex of the deformity back toward the mechanical axis. The vector measured on the mediolateral view radiograph constitutes the craniocaudal component of the deformity, while the vector measured on the craniocaudal view radiograph constitutes the mediolateral component of the deformity.

the deformity. The measured length of the line on the mediolateral radiograph constitutes the cranial or caudal component of the deformity. These same measurements are obtained from line drawings developed from tracings of radiographs of the contralateral normal limb, and the component vectors measured on the normal limb are subtracted from those obtained from the abnormal limb. A tracing (or photocopy) of an appropriate diameter ring (Figure 53-48) which will be used to construct the fixator is made. An X (mediolateral)/Y (craniocaudal) grid is constructed with its origin centered in the ring. This drawing represents the proximal surface of the rings of the proximal ring blocks and should be marked correctly with respect to medial, lateral, cranial and caudal for the limb (left or right) that is being corrected. The plane of deformity is determined by plotting the two adjusted (abnormal minus normal) vector components of the deformity on the X/Y grid. The resultant vector defines the plane of deformity.

A drawing representing an outline of a transverse section of the radius, based on measurements of the craniocaudal and mediolateral dimensions of the radius obtained at the level of the apex of deformity on the pre-operative radiographs, is centered over the X-Y intersection. The circumferential position of the hinges can now be determined. A line drawn between the centers of the paired hinges constitutes the hinge axis. The plane of deformity is located along the concave surface of the radius and the hinges need to be located on the opposite side (convex surface) of the radius in order to correct the deformity. Thus the hinge axis should be positioned roughly perpendicular to the plane of the deformity and tangent to the outline of the radius opposite the plane of the deformity. The tangential location of the hinge axis will result in angular correction without additional lengthening. The two holes on the ring that are intersected by the hinge axis mark the position at which the hinges should be placed. A single angular motor is placed opposite the hinge axis, approximately equal distant from two hinges, which will be located on the concave surface of the deformity.

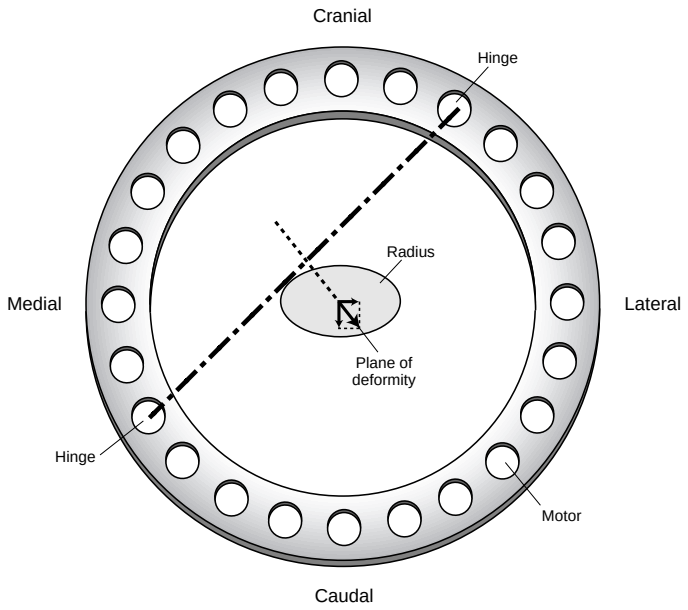


Figure 53-48. Drawing of the radius (based on dimensions obtained at the apex of deformity) centered within a tracing of the proximal surface of an appropriate diameter ring. The smaller arrows radiating along the X and Y axis out from the origin represent the adjusted (abnormal minus normal) mediolateral and craniocaudal vector components of the deformity. The larger arrow represents the resultant vector and the plane of the deformity. The hinge axis (dotted-dashed line) is positioned roughly tangential to the convex surface of the radius (roughly perpendicular and opposite the plane of the deformity), to determine the circumferential location of the hinges.

The fixator is assembled prior to surgery. A three ring construct is used in most dogs with two rings used to secure the proximal radial segment and a single ring used to secure the distal radial segment (Figure 53-49). It is advisable to mark the medial, lateral, cranial and caudal positions of the proximal surface of each ring appropriately for the limb that is to be corrected. The paired

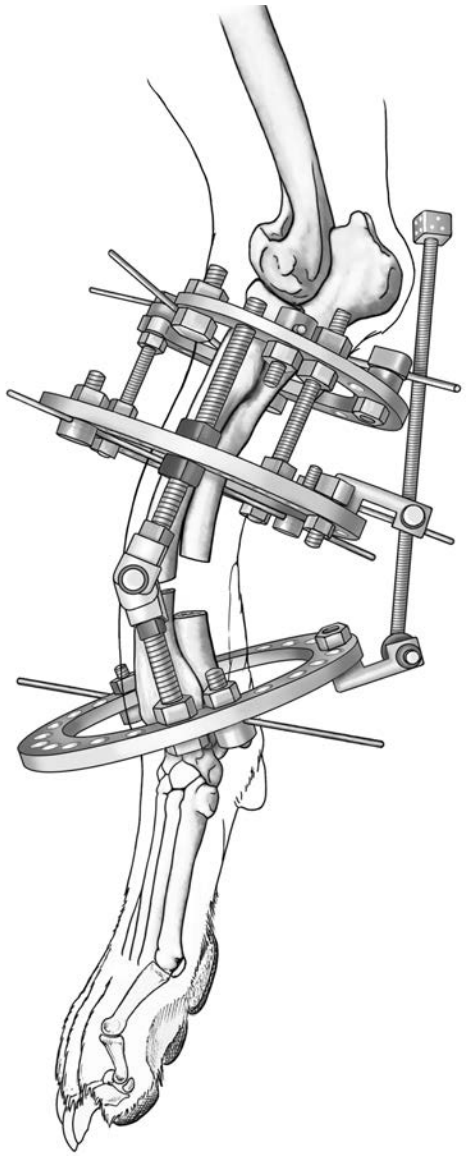


Figure 53-49. Application of a three ring construct for correction of an antebrachial angular deformity. The hinge axis (the two hinges are superimposed in this picture) is located at the apex of the deformity, roughly perpendicular to the plane of deformity and tangential to the convex cortex of the radius. The rings of the proximal ring block have been secured by multiple divergent wires. The distal radial segment is secured with a single wire which will simplify rotational correction.

angular hinges and an angular motor are placed between the ring blocks at the appropriate holes as determined on the pre-operative drawing. The hinges can be bolted directly to the distal ring if the apex of deformity is located at or near the distal epiphysis, but the hinges are usually secured to both rings using short threaded rods at the holes as determined on the pre-operative drawing. Paired nylon nuts can be used to secure the rods to one of the rings if lengthening is anticipated. The longitudinal position of the hinges is located at the apex of the deformity. Construct dimensions, ring position and hinge position are determined by laying the frame directly over the lateral view radiograph of the deformed antebrachium. Frame angulation can be adjusted to conform to the deformity by adjusting the angular motor.

At surgery the entire forelimb is clipped and prepared for aseptic surgery and the dog is positioned in dorsal recumbency. A 2 to 4 cm subperiosteal segmental ostectomy of the distal ulna is performed at the level of the apex of the deformity. Following closure of the ulnar approach, subperiosteal isolation of the distal radius is performed exposing the location of the apex of the deformity. An osteotomy is initiated, but not completed, perpendicular to the longitudinal axis of the distal radial segment and parallel to the plane of the deformity. The longitudinal location of the radial osteotomy will influence the impact acute rotational correction will have on the plane of deformity. The plane of deformity should not be changed appreciably by acute rotational correction if the radial osteotomy is performed at or preferably slightly distal to the apex of the deformity. Performing the radial osteotomy proximal to the apex of the deformity is not advised if acute rotational correction is to be done, as the plane of deformity will be altered by rotational correction.

The frame is then placed on the limb and a fixation wire is placed in the proximal radius in the medial-to-lateral plane, perpendicular to the longitudinal axis of the radius. This wire is secured to the proximal surface of the proximal ring of the fixator and the longitudinal position of this wire should place the hinge axis at the apex of the deformity. Consideration should be given to placing this wire the day prior to surgery and then radiographing the limb, as constructing the fixator based on tracings of radiographs obtained with the first wire already in place simplifies placement of the hinge axis precisely at the apex of the deformity at surgery. The wire can then be bent over against the antebrachium and the limb coapted until surgery. At surgery the wire can be straightened out and tensioned or carefully replaced by inserting a new wire through the same hole in the radius. The connecting elements of the frame should be aligned parallel to the longitudinal axis of the radius and the hinges positioned at the apex of the deformity. The frame is rotated about the antebrachium until the hinge axis is positioned perpendicular to the plane of deformity and tangential to the convex cortex of the radius. It is important to center the radius, rather than the antebrachium, within the frame. A fixation wire is then placed parallel to the distal surface of the distal ring. This wire should be placed in the "true" mediolateral plane (from styloid process to styloid process) which will not be co-planar with the wire in the proximal radius if rotational deformity is present. Two divergent olive wires should then be placed on each of the rings of the proximal ring block to stabilize the proximal radial segment and the radial osteotomy is then completed.

Rotational deformity, if present, should be corrected before additional fixation wires are placed in the distal radial segment (Figure 53-50). Rotational deformity is estimated by comparing the planes of flexion and extension of the ipsilateral elbow and antebrachiocarpal joint. The plane of extension of the elbow (which is caudal) is marked on the distal surface of the distal ring. The antebrachiaocarpal joint is then flexed so that the paw

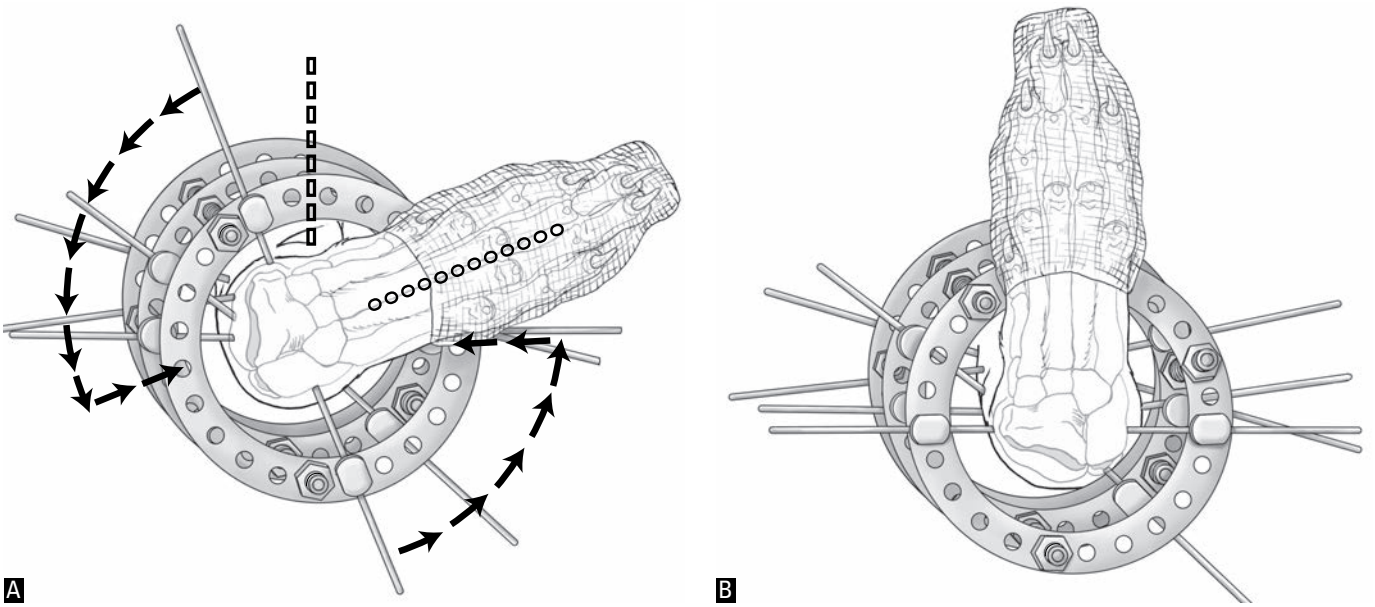


Figure 53-50. Acute correction of rotational deformity. **A.** This dog is positioned in dorsal recumbency and has approximately 60° of external rotation. The line of small open circles represents the plane of flexion and extension of the carpus. The line of small rectangles represents plane of flexion and extension of the elbow. There is nearly a five hole discrepancy (on the surface of the distal ring) between these the two planes of flexion and extension. The wire stabilizing the distal radial segment needs to be repositioned five holes in a counter clock-wise direction to resolve the rotational deformity as indicated by the heavy arrows. **B.** The wire has been rotated to correct the rotational deformity.

is positioned parallel with the distal surface of the distal ring. The location of the division between metacarpal bones III and IV is marked on the distal surface of the distal ring. The number of holes between these two marks is counted and this represents the amount of rotation the wire securing the distal radial segment must be rotated about the surface of the distal ring to have the elbow and antebrachiocarpal joint flex and extend through the same plane. It is highly advisable to mark this wires' position, and the position where the wire will be resecured at on the ring, before loosening and moving the fixation bolts.

Once rotational correction has been performed and the wire is secured to the distal ring, flexion and extension of the elbow and antebrachiocarpal joint should be compared. Adjustments can be made if deemed necessary. Two divergent olive wires should be placed to secure the distal radial segment to the distal ring. Following surgery in addition to obtaining standard craniocaudal and mediolateral view radiographs of the antebrachium, a radiograph centered through the hinge axis should also be obtained. The hinges should be superimposed over one another on this view and the entire frame should be visible on the film so that the distraction protocol can be calculated. Distraction is measured along the concave cortex of the radius and a rate of 0.75 to 1.50 mm/day fractionated into three or four incremental distractions is considered acceptable. The amount of distraction of the angular motor that will produce the appropriate amount of distraction at the osteotomy can be calculated using the method of similar triangles (Figure 53-51). Once the distraction period is completed and the deformity is corrected the hex drive fastener elements on the hinge assemblies and the angular motor should be tightened to lock the frame in position.

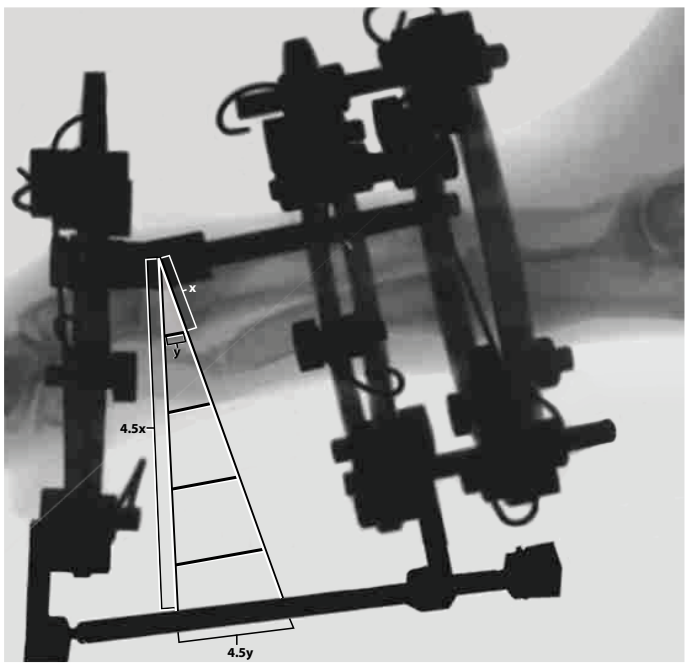


Figure 53-51. Post distraction radiograph demonstrating the method of similar triangles used to determine proper distraction ratio. The distance from the hinge axis to the angular motor is approximately 4.5 times that of the distance from the hinge axis to the surface of the concave cortex of the radius. Thus, the angular motor would need to be distracted 4.5 mm to produce 1 mm of distraction along the concave cortex of the radius.

Bone Transport

Bone transport is a specific application of distraction osteogenesis used to resolve large segmental bone defects. With this technique an intercalary bone transport segment is created by performing a transverse osteotomy in the viable bone segment 1 to 2 cm adjacent to an osseous defect. Regenerate bone is produced in the distraction gap which develops as the transport segment is sequentially moved across the bone defect. Longitudinal bone transport is typically performed using a five ring construct, with two rings securing both the proximal and distal bone segments and the intermediate ring securing the transport segment. The transport ring is secured to the frame using paired nylon nuts which allow the ring to be moved precisely along the threaded rods at a rate of 0.5 to 2.0 mm per day. A delay period of 5 to 7 days may be warranted depending upon the age of the animal, the condition of the regional soft tissues and the location of the osteotomy. Radiographs should be obtained bi-weekly during the distraction process and the rate increased or decreased if necessitated by the appearance of the regenerate bone. Docking refers to the process of the transport segment contacting and eventually obtaining union with the bone at the opposite end of the osseous defect. Obtaining union at the docking site can be facilitated by placing a cancellous bone graft at the site several days prior to docking and constructing the fixator such that the transport ring can be moved several mm beyond the bone defect, thus facilitating in compression of the docking site.

Bone transport has been used in dogs to resolve large segmental defects resulting from highly comminuted fractures, following sequestrectomy in infected fractures and in performing limb salvage procedures in dogs with appendicular bone tumors. These large segmental defects have traditionally been managed with massive bone allo- or autografts or prostheses, which are prone to infection and implant failure. Regenerate bone is highly vascular and resistant to infection and all implants can be removed once the docking site has achieved union and the regenerate bone has consolidated (Figure 53-52).

Postoperative Management and Complications

Management of animals with CFs is similar to that of animals with traditional linear fixators. Following surgery, the CF is wrapped to limit postoperative swelling and to protect any incisions, open wounds and wire/pin insertion wounds. Sterile gauze is placed over any wounds and the insertion sites and the foam portion of recycled disposable surgical scrub brushes which are impregnated with chlorhexidine are packed between the skin and the frame to limit postoperative swelling. Care must be taken not to pack the sponges too tightly within the frame or edema and swelling of the distal limb may be aggravated. Cast padding and Vetwrap tape is then used to apply a bandage around the entire fixator. The CF is initially unwrapped and the limb and surgical sites assessed for swelling or complications on a daily basis. The wire/pin-skin interfaces are cleaned aggressively with a gauze or cotton tip applicator and diluted chlorhexidine solution. The CF is then re-wrapped. When the acute swelling and edema has subsided and the wire/pin-skin insertion sites heal sufficiently, packing sponges within the frame can be discontinued. The



Figure 53-52. Bone transport being utilized for a limb salvage procedure in a dog with a distal radial osteosarcoma. The distal two-thirds of the radius have been excised and the transport segment has been moved approximately half the distance across the segmental defect with early regenerate bone forming in the distraction gap. (Radiograph courtesy of Dr. Nicole Ehrhart)

owners should be directed to construct a shroud or sleeve that fits securely over the entire fixator, but can be easily removed for daily cleaning of the wire/pin-skin interfaces.

Performing intensive, frequent (a minimum of three times a day) physical therapy is important during lengthening and correction of angular deformities to reduce the development of muscle (especially flexor muscles) contracture. Contracture is less of a problem with higher rhythms (more fractionated distractions). The administration of nonsteroidal anti-inflammatory drugs is also beneficial in encouraging weight-bearing, mitigating contracture during the distraction period.

The most common complication associated with the use of CFs is wire/pin tract drainage and bone lysis surrounding the fixation elements. Inflammation associated with wire/pin tract drainage typically develops several weeks after surgery and generally does not influence the final outcome even when the fixator must be maintained for an extended period of time. Minor wire/pin tract drainage may resolve with broad spectrum antibiotic administration. If drainage is substantial and/or purulent and/or there is substantial bone lysis and proliferation adjacent to a wire/pin, that fixation element should be removed and replaced if necessary. Proper insertion techniques and meticulous, appropriate daily care can greatly decrease the incidence of wire/pin tract complications.

Suggested Readings

Anderson GM, Lewis DD, Radasch RM, *et al.:* Circular external skeletal fixation stabilization of antebrachial and crural fractures in 25 dogs. *J Am Anim Hosp Assoc* 39:479, 2002.

ASAMI Group. Basic principles of operative technique. *In:* Bianchi-Maiocchi A, Aronson J, eds.: Operative Principals of Ilizarov. Milan, Italy, Medi Surgical Vido, 1991, p 65.

Bianchi-Maiocchi A: The Ilizarov compression-distraction apparatus. *In:* Bianchi-Maiocchi A, ed.: Advances in Ilizarov Apparatus Assembly. Milan, Italy, Medi Plastic Sri, 1994, p 5.

Bronson DG, Samchukov ML, Birch JG, *et al.:* Stability of external circular fixation: A multi-variable biomechanical analysis. *Clin Biomech* 13:441, 1998.

Catagni M: Fractures of the leg (tibia). *In:* Bianchi Maiocchi A, Aronson J, eds.: Operative Principles of Ilizarov. Milan, Italy, Medi Surgical Vido, 1991, p 91.

Collins KE, Lewis DD, Lanz OI, *et al.:* Use of a circular external skeletal fixator for stifle arthrodesis in a dog. *J Sm Anim Pract* 41:312, 2000.

Cross AR, Lewis DD, Murphy ST, *et al.:* Effect of ring diameter and wire tension on the axial biomechanics of four-ring circular external skeletal fixator constructs. *Am J Vet Res* 62:1025, 2001.

Cross AR, Lewis DD, Rigaud S, *et al.:* Effect of wire tension on the biomechanics of asymmetric four-ring circular external skeletal fixator constructs. *Vet Comp Orthop Traumatol* 15:44, 2002.

Egger EL, Histand MB, Norrdin RW, *et al.:* Canine osteotomy healing when stabilized with decreasingly rigid fixation compared to constantly rigid fixation. *Vet Comp Orthop Traumatol* 6:182, 1993.

Ehrhart N: Longitudinal bone transport for treatment of primary bone tumors in dogs: technique description and outcome in 9 dogs. *Vet Surg* 34:24, 2005.

Elkins AD, Morandi M, Zembo M: Distraction osteogenesis in the dog using the Ilizarov external ring fixator. *J Am Anim Hosp Assoc* 29:419, 1993.

Farese JP, Lewis DD, Cross AR, *et al.:* Use of IMEX SK-circular external fixator hybrid constructs for fracture stabilization in dogs and cats. *J Am Anim Hosp Assoc* 38:279, 2002.

Ferretti A: The application of the Ilizarov technique to veterinary medicine. *In:* Bianchi-Maiocchi A, Aronson J, eds.: Operative Principles of Ilizarov. Milan, Italy, Medi Surgical Vido, 1991, p 551.

Goodship AE, Kenwright J: The influence of induced micromotion upon the healing of experimental tibial fractures. *J Bone Joint Surg* 67[B]:650, 1985.

Green SA, Harris NL, Wall DM, *et al.:* The Rancho mounting technique for the Ilizarov method. *Clin Orthop* 280:104, 1992.

Halling KB, Lewis DD, Jones RW, *et al.:* Use of circular fixator constructs to stabilize intertarsal/tarsometarsal arthrodeses in three dogs. *Vet Corp Ortho Traumatol* 17:204, 2004.

Ilizarov GA: The apparatus: Components and biomechanical principles of application. *In:* Ilizarov GA ed.: Transosseous Osteosynthesis.

Theoretical and Clinical Aspects of the Regeneration and Growth of Tissue. Berlin, Springer-Verlag, 1992, p 63.

Jerram RM, Walker AM, Sutherland-Smith J, *et al.:* Treating pedal shortening in a dog by metatarsal distraction osteogenesis. *J Sm Anim Pract* 26:191, 2005.

Kenwright J, Goodship AE: Controlled mechanical stimulation in the treatment of tibial fractures. *Clin Orthop* 241:36, 1989.

Kenwright J, Goodship AE, Kelly DJ, *et al.:* Effect of controlled axial micromotion on healing of tibial fractures. *Lancet* 8517(2):1185, 1986.

Kummer FJ: Biomechanics of the Ilizarov external fixator. *Clin Orthop* 280:11, 1992.

Langley-Hobbs SJ, Carmichael S, Pead MJ, *et al.:* Management of antebrachial deformity and shortening secondary to a synostosis in a dog. *J Sm Anim Pract* 37:359, 1996.

Leuno, CY, Ma RYP, Clark JA, *et al.:* Viscoelastic behavior of tissue in leg lengthening by distraction. *Clin Orthop* 139:102, 1979.

Lewis DD, Bronson DG, Cross AR, *et al.:* Axial characteristics of circular external skeletal fixator single ring constructs. *Vet Surg* 30:386, 2001.

Lewis DD, Bronson DG, Samchukov ML, *et al.:* Biomechanics of circular external skeletal fixation. *Vet Surg* 27:454, 1998.

Lewis DD, Radasch RM, Beale BS, *et al.:* Initial clinical experience with the IMEX Circular External Skeletal Fixation System. Part I: Use in fractures of arthrodeses. *Vet Comp Orthop Traumatol* 12:108, 1999.

Lewis DD, Radasch RM, Beale BS, *et al.:* Initial clinical experience with the IMEX Circular External Skeletal Fixation System. Part II: Use in bone lengthening and correction of angular and rotational deformities. *Vet Comp Orthop Traumatol* 12:118, 1999.

Marcellin-Little DJ: Treatment of bone deformities with circular external skeletal fixation. *Comp Cont Ed Pract Vet* 21:481, 1999.

Marcellin-Little DJ: Fracture treatment with circular external fixation. *Vet Clin N Am: Sm Anim Pract* 29:1153, 1999.

Marcellin-Little DJ, Ferretti A, Roe SC, *et al.:* Hinged Ilizarov external fixation for correction of antebrachial deformities. *Vet Surg* 27:231, 1998.

Orbay GO, Kummer FJ, Frankel VN: The effect of wire configuration on the stability of the Ilizarov external fixator. *Clin Orthop* 279:299, 1992.

Owen MA: Use of the Ilizarov method to manage a septic tibial fracture nonunion with a large cortical defect. *J Sm Anim Pract* 41:124-127, 2000.

Paley D: Biomechanics of the Ilizarov-external fixator. *In:* Bianchi-Maiocchi A, Aronson J, ed.: Operative Principals of Ilizarov. Milan, Italy, Medi Surgical Vido, 1991, p 31.

Paley D, Fleming B, Catagni M, *et al.:* Mechanical evaluation of external fixators used in limb lengthening. *Clin Orthop* 250:50, 1990.

Stallings JT, Lewis DD, Welch RD, *et al.:* An introduction to distraction osteogenesis and the principles of the Ilizarov method. *Vet Comp Orthop Traumatol* 11:59-67, 1998.

Tommasini Degna M, Ehrhart N, Ferretti A, *et al.:* Bone transport osteogenesis for limb salvage following resection of primary bone tumors: Experience with six cases (1991-1996). *Vet Comp Orthop Traumatol* 13:18, 2000.

Welch RD, Lewis DD: Distraction osteogenesis. *Vet Clin N Am: Sm Anim Pract* 29:1187, 1999.

Application of Hybrid Constructs

Robert M. Radasch

Introduction

Hybrid circular external skeletal fixation (HCESF) combines the fixator components, methodology of application, and biomechanics of traditional linear and circular external fixation devices. The benefits of both systems are enhanced when a hybrid circular fixator (HCF) is properly applied in appropriate situations. Hybrid fixators have been used clinically to manage long bone and spinal fractures, as well as bone deformities. The circular components of a HCF allow adequate fixation of small juxta-articular bone segments using two to three narrow (1.0 -1.6 mm) tensioned transfixation wires secured to a ring. The linear components of the frame are then applied to the primary bone segment using traditional positive profile half-pins or full-pins. The basic components of a HCF are the supporting, connecting, fixation and assembly elements (Figure 53-53). All components, except the fixation elements (wires and pins) are

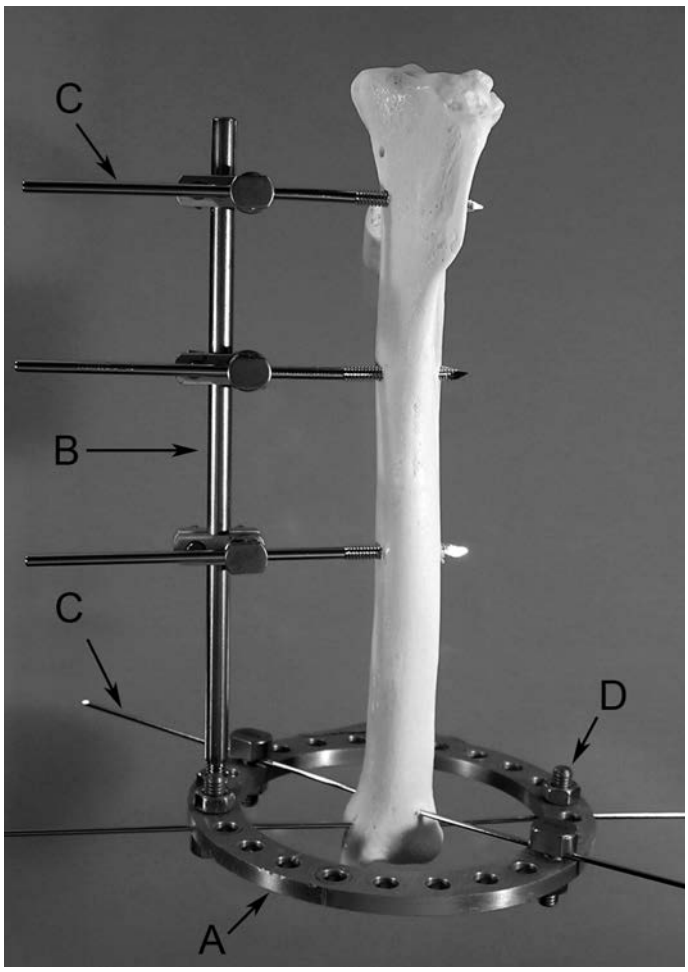


Figure 53-53. A basic HCF allows stabilization of small juxta-articular bone segments with two or three tensioned narrow transfixation wires, while the primary bone segment is stabilized with positive profile half-pins or full-pins. The basic components are the supporting *(A)*, connecting *(B)*, fixation *(C)*, and assembly *(D)* elements.

reusable numerous times, making HCESF economically practical for veterinary practice. The only HCF currently available in veterinary orthopedics is manufactured by the IMEX Company (Longview, Texas). Therefore, this section will concentrate on the application of the IMEX HCESF system utilizing IMEX-SK components, pins, wires and rings.

Indications

Fractures involving the metaphyseal region of all long bones are relatively common in veterinary medicine. These fractures frequently have a short juxta-articular bone segment precluding the use of many implant systems (Figure 53-54), and are often comminuted, making anatomical reduction of the bone fragments impossible and of questionable mechanical benefit. A HCF can be applied using closed, or "mini-approach" techniques utilizing the principles and benefits of biological osteosynthesis, while still allowing manipulation of the main bone segments to achieve adequate fracture reduction or alignment. In addition, adjustments of the frame can be performed during the postoperative period to improve reduction or to stimulate the later stages of bone healing.

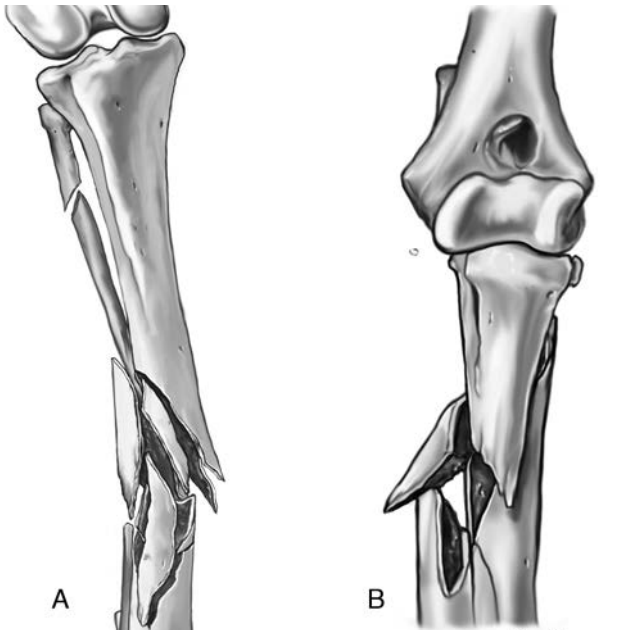


Figure 53-54. Typical fractures with short juxta-articular components involving the distal tibia **A.**, and proximal radius/ulna **B.** that are easily stabilized with a HCF.

Hybrid Circular Fixator Components

The majority of components used to create a HCF frame have been thoroughly described in the proceeding sections. However, there are several unique components used almost exclusively with HCF frames. Successful management of juxta-articular fractures while minimizing complications depends upon a thorough knowledge of how each individual component affects the overall mechanical characteristics of the HCF. In addition, a working understanding of how each component can be used and integrated into the system will allow manipulation of the juxta-articular and primary bone segments to achieve proper fracture reduction or alignment.

Supporting Elements

A full ring is the most commonly used supporting element of a HCF. Partial or stretch rings and arches are often used instead of a full ring to prevent interference with joint motion (Figure 53-55). Partial rings and arches are very useful in managing fractures involving the proximal tibia, proximal radius, spine, distal femur, and humerus. Rings (partial or full) and arches are available with 35, 45, 50, 66, 84, and 118 mm internal diameters. The appropriate ring or arch size chosen will depend upon the animal's weight as well as the diameter of the regional anatomy. The inner ring diameter should be approximately 2.0 cm larger than the regional anatomy at the level where the ring will be positioned. This diameter will allow for typical postoperative soft tissue swelling without the ring compressing or cutting into the underlying soft tissues.

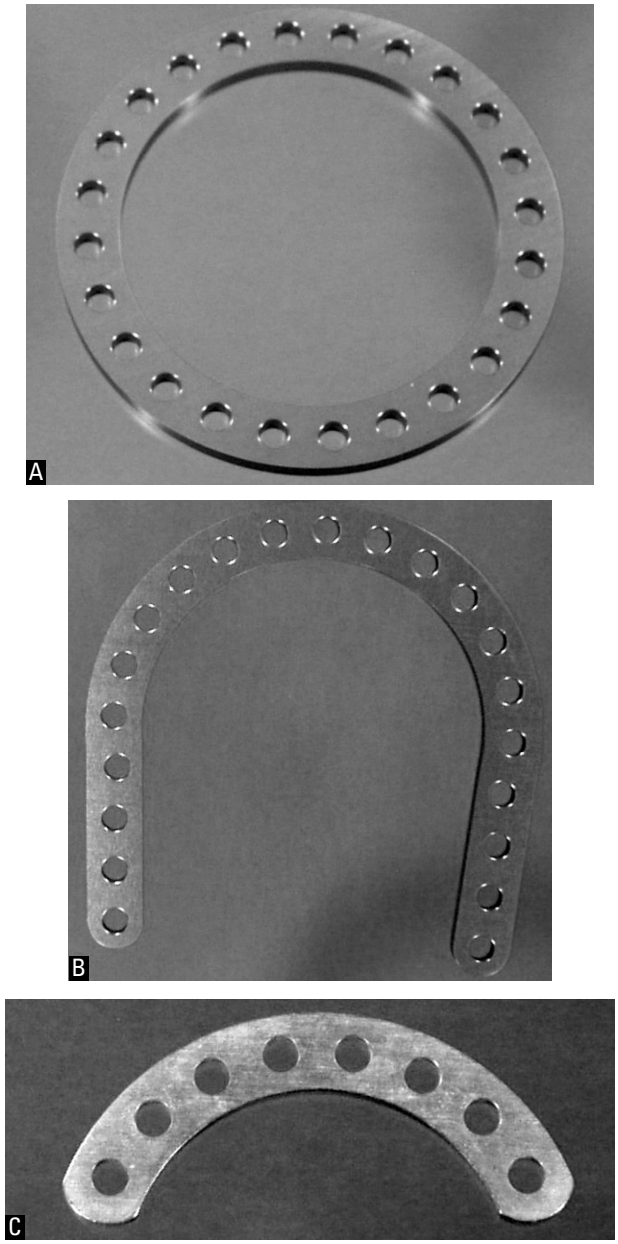


Figure 53-55. Supporting elements of a HCF. Full ring **A.**, partial or stretch ring **B.**, and arch **C.**

Connecting Elements

The standard connecting element of the IMEX HCF is the small 6.3 mm hybrid rod, currently available in 50, 75, 100, 150, 200, and 250 mm lengths (Figure 53-56). Hybrid rods are also available in 9.5 mm diameter (lengths = 50, 75, 100, 150, 200, 250, 300, and 350 mm) and 3.2 mini (length = 125 mm). Large and small hybrid rods are made of titanium, and mini hybrid rods are made of stainless steel. The hybrid rod serves the same function as the connecting rod in a linear external fixator. IMEX-SK clamps attach along the smooth shaft of the hybrid rod to secure fixation pins to the frame. Large, small, and mini SK clamps are used with the large, small and mini hybrid connecting rods, respectively. In the author's experience, the small hybrid rod (6.3 mm diameter) and SK clamps are used most commonly to create a HCF for both dogs and cats. The large hybrid rod and SK clamps would be used for giant breed dogs, while the mini system would be reserved for toy breed dogs and small cats.

One end of the hybrid rod is threaded, allowing it to be secured to the supporting element (ring, arch or partial ring). The large and small hybrid rods have 6.0 mm thread diameter and therefore are secured to the supporting element with two 6.0 mm nuts. The mini hybrid rod has a 4.0 mm thread diameter and is secured using two 4.0 mm nuts. The threaded section of the large and small hybrid rods can be placed into the holes of the 50, 66, 84, and 118 mm rings or arches. The mini hybrid rod can only be used with the mini 35 or 45 mm rings and is placed through either the slots or holes of the mini ring.

The hybrid rods can also be attached to the supporting ring or arch using paired 6.3 mm (used with small and large hybrid rods) HEMI-spherical washers and nuts, which allow the rod to be angulated approximately 7.5° in relationship to the ring surface (Figure 53-57). Advantages of angulating the hybrid rod include: 1) facilitating manipulation of bone segments to achieve fracture reduction; 2) allowing small angular corrections; and 3) enabling biomechanical improvement of frame stiffness by reducing fixation pin working length (distance between the hybrid connecting rod, pin-gripping bolt of the SK clamp, and the near cortex of primary bone segment). The hybrid rod can be positioned anywhere on the supporting ring or arch. However, the hybrid rod should be positioned so that the fixation pins, attached to the rod, will pass through safe soft tissue corridors (as described in previous sections), in order to minimize postoperative pin tract morbidity.

An alternative to a threaded hybrid rod, is the use of a 6.3 mm titanium or radiolucent carbon fiber SK™ linear external fixation connecting rod, connected to the ring element using a Universal SK™ Hybrid Adapter (Figure 53-58). The Universal SK™ Hybrid Adapter allows the connecting rod to be angulated approximately 32.5°, in any direction to the ring surface. The Universal SK™ Hybrid Adapter is secured to the ring element using two 6 mm bolts and nuts. The two 8 mm bolts of the rod-gripping element, when tightened, lock the connecting rod into the desired orientation, by compressing the broach surrounding the

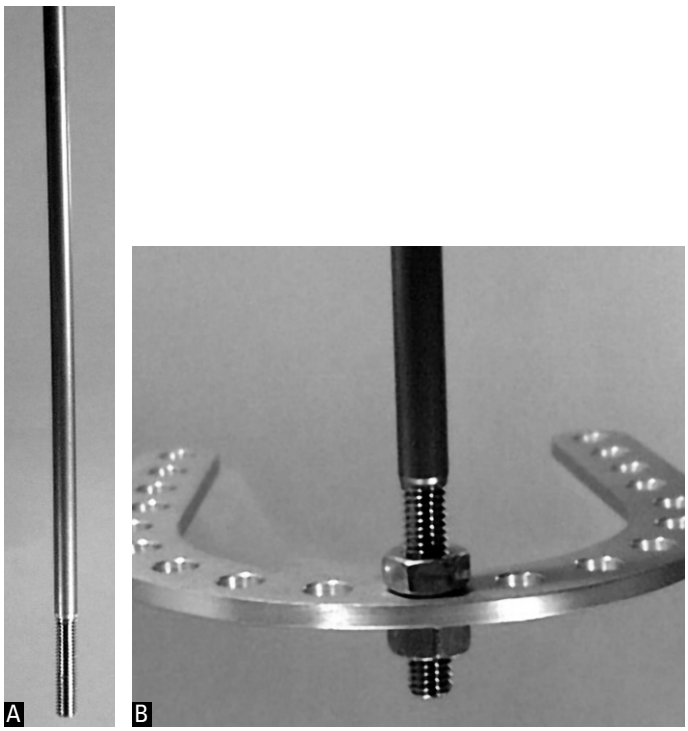


Figure 53-56. Connecting element of a HCF is the hybrid connecting rod **A.** One end of the rod is threaded allowing it to be secured to a ring with two nuts **B.**

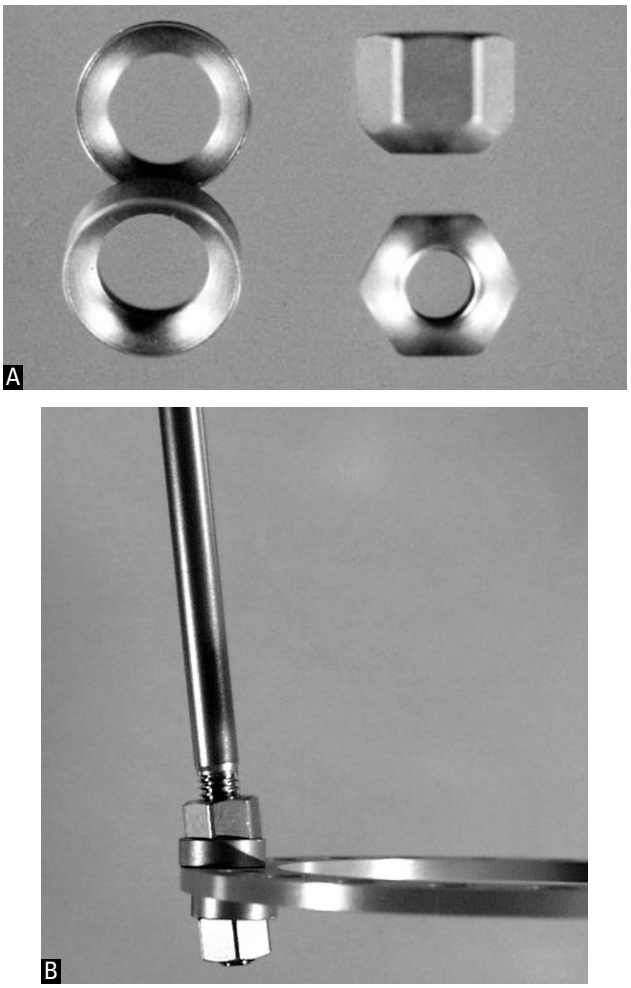


Figure 53-57. Spherical nuts and washers **A.** connecting a hybrid rod to a ring will allow approximately 15 degrees of angulation of the rod in relationship to the ring **B.**

connecting rod. The Universal SK™ Hybrid Adapter provides the same benefits of the hemispherical washer and nuts with the additional advantages of: 1) greater range of angulation of the connecting rod in relationship to the ring (32.5° vs. 7.5°) and 2) use of radiolucent carbon fiber connecting rods which can facilitate imaging the fracture. The Universal SK™ Hybrid Adapter can only be used on 50-118 mm ring diameters.

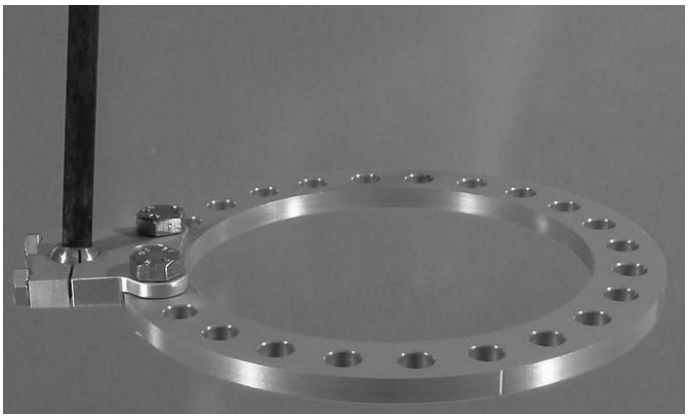


Figure 53-58. Universal SK™ Hybrid Rod Adapter allows up to 32.5° of angulation of a smooth 6.3 mm titanium or carbon fiber connecting rod in relationship to the ring surface.



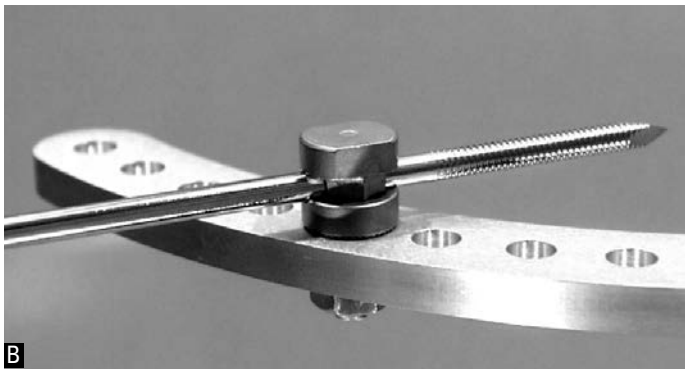
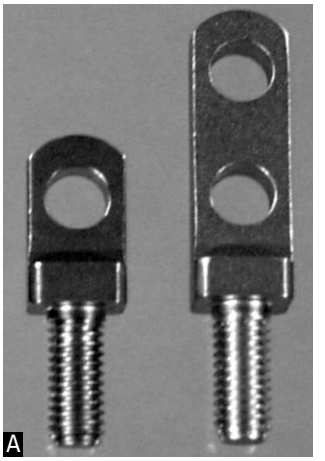


Figure 53-59. A pin fixation bolt **A.** allows half-pins or full-pins to be placed directly onto a ring or arch **B.**

Assembly Elements

Assembly elements unique to an IMEX HCF include pin fixation bolts, one and two hole posts, two hole plates, and threaded SK clamps. Pin fixation bolts allow 3.0 to 4.8 mm half-pin or full-pins to be placed directly on a 50, 60, 84 or 118 mm ring or arch (Figure 53-59). Juxta-articular fractures involving the femur, humerus or spine are best stabilized with half-pins or full-pins instead of divergent narrow wires. Divergent wires in these locations can penetrate large muscle masses, or result in impingement of normal flexion and extension of the associated joint. A pin fixation bolt is secured to a ring or arch with a 6.0 mm nut. The supporting element then serves as a platform for pin insertion into the juxta-articular bone segment. The basic anatomy and mechanics of the pin fixation bolt is identical to that of the pin-gripping bolt/washer assembly of the linear SK clamp. As the 6.0 mm nut attaching the fixation bolt to the ring is tightened, the fixation pin is trapped and secured between the hole in the head of the bolt and the meniscus of the sliding washer. The pin fixation bolt will accept the IMEX drill sleeve, which should be used to minimize soft tissue trauma during pre-drilling of holes prior to pin insertion.

One and two hole posts serve several important functions (Figure 53-60). The threaded portion of the post allows it to be secured to the ring using a nut. The hole(s) in the post will accept the threaded portion of a wire fixation bolt, a pin fixation bolt, or a hybrid rod. These components are secured to the post with appropriate size nuts. Two posts, on opposite sides of the ring, can be used to place an additional wire above or below the ring to improve fracture stability. The wire is secured to the post using wire fixation bolts and nuts. A wire attached to a post is referred to as a "drop wire". Fixation pins can also be placed above or below a ring using a single post and a pin fixation bolt. However, there should never be a combination of



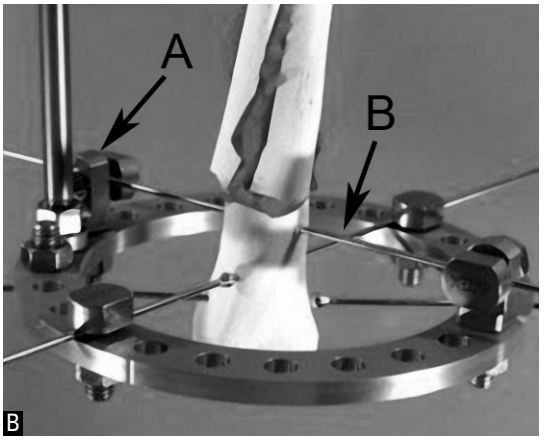
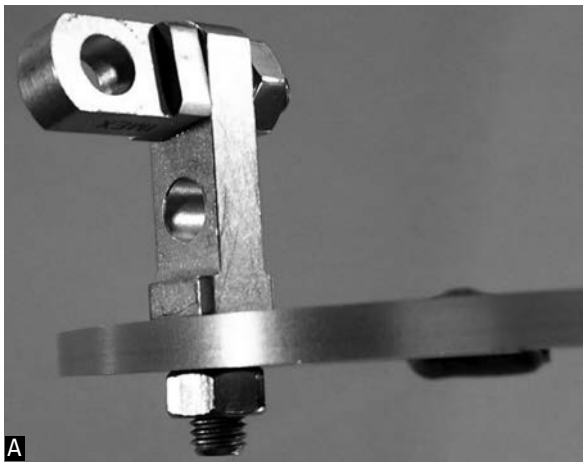


Figure 53-60. One or two hole posts **A.** allow fixation elements (pins or wires) to be placed above or below the ring surface for additional support. A wire placed above or below the ring is called a "drop wire "**B.**

wires and pins secured to the same bone segment. Axial micromotion occurs with bone segments secured to a ring with two or more narrow wires during weight bearing. Fixation pins rigidly secure bone segments and do not allow for micromotion in any plane. Therefore if a juxta-articular bone segment is secured to a ring with wires and a single fixation pin, the axial micromotion provided by the wires will result in cyclic bending forces at the fixation pin-bone interface. This may result in premature loosening of the fixation pin with subsequent pin tract drainage, sepsis and patient discomfort.

Two posts can also be connected to each other with a nut to create an adjustable articulation (Figure 53-61). Alternatively, a hybrid rod can be connected to a ring or arch with an angular hinge assembly to also create an adjustable articulation (Figure 53-62). Articulations will allow diagonal struts to be constructed using small or large hybrid rods. Diagonal struts improve the stiffness of a HCF frame allowing the use of a simple type I-a frame when appropriate. Furthermore, a diagonal can be removed 6 to 8 weeks after surgery to destabilize the frame and stimulate the later stages of bone healing. To construct a diagonal, the threaded end of a hybrid rod is placed through a hole in one of the posts of the articulation, and secured using two nuts. The threaded end of the other post is secured to the ring or arch with a nut. The smooth shaft of the hybrid diagonal rod can be secured utilizing the "stacked clamp" technique (as described in the previous section: Basic Principles for the Application of External Fixators) to a fixation pin using a SK single clamp. Alternatively, the diagonal strut can be attached to the hybrid connecting rod of the HCF frame using a SK double clamp.



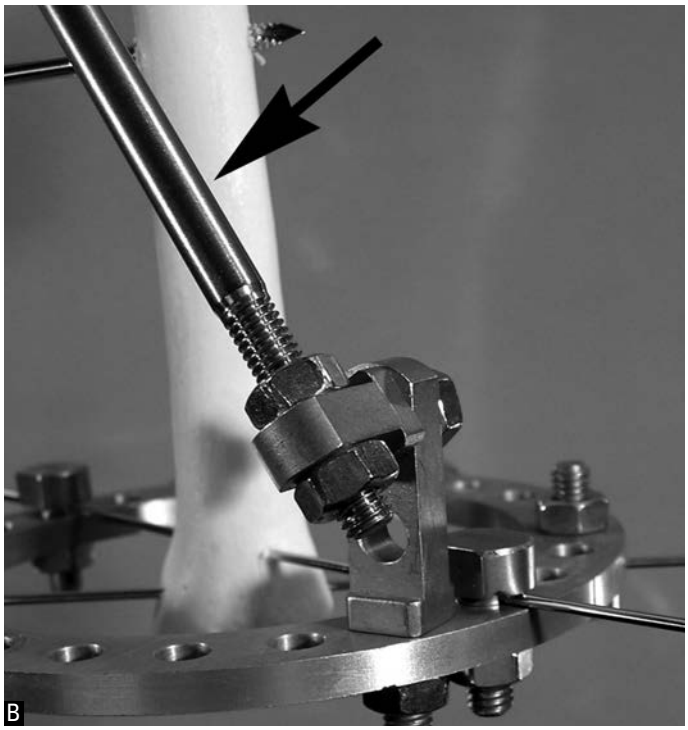


Figure 53-61. An articulation **A.** can be constructed from two posts. Articulations allow placement of a diagonal strut *(arrow)* to improve frame stiffness **B.**



Figure 53-62. An angular hinge used to create an articulation(photo courtesy of Dr Alan Cross). The threaded end of a hybrid connecting rod is screwed into one end of the angular hinge and secured with a single nut. The hinge is attached to a 50-118 mm ring with a single 6mm bolt.

A two-hole plate can be used to offset a small or large hybrid connecting rod from the ring (Figure 53-63). This may be necessary if the hybrid connecting rod and associated SK clamps are too close to the limb and could potentially result in pressure necrosis of the underlying soft tissues. One hole of the plate is attached to the ring using a 6.0 mm bolt and nut. The threaded portion of a large or small hybrid connecting rod is secured to the second hole in the plate using two 6.0 mm nuts. Alternatively, the hybrid rod can be attached to the plate using paired 6.0 mm spherical nuts and washers, to allow angulation of the rod up to 15° away from perpendicular relative to the plane of the ring. The design of the spherical nuts and washers allows for angulation of the rod in any direction that is desired.

A modified threaded small SK single clamp is available for placement of half pins from all-thread connecting rod elements (Figure 53-64). This 6 mm clamp is identical to the linear SK clamp, except that the portion secured to the connecting element is threaded instead of smooth. The thread pitch and size of the threaded SK clamp correlates to the 6.0 mm thread on the all-thread connecting rod. The threaded SK clamp is extremely useful when creating a hybrid spinal frame. Threaded SK clamps can be positioned anywhere along the all-thread connecting rod of a spinal frame. Half-pins can be angulated proximal,

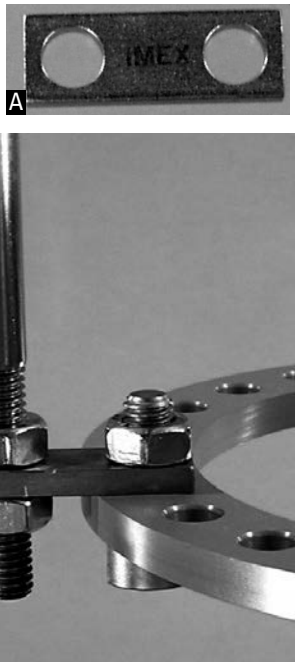


Figure 53-63. Two hole plates **A.** allow hybrid rods to be offset from the ring **B.**

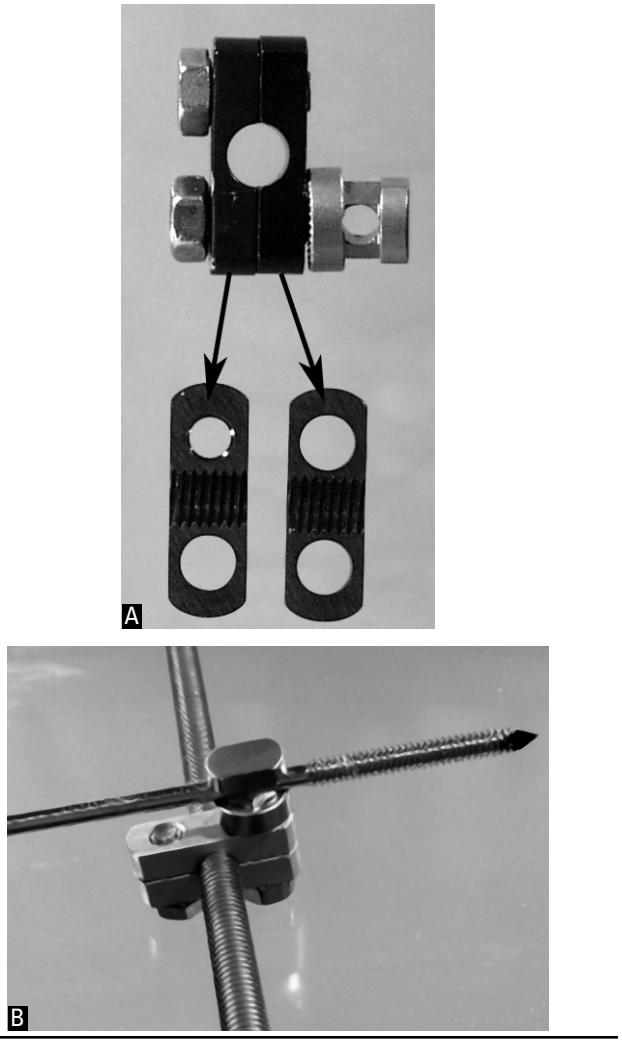


Figure 53-64. Modified threaded SK clamps **A.** allow half pins to be placed along all-threaded connecting rods **B.**

distal, dorsal, and ventral; in addition, the clamp can be moved forwards or backwards to facilitate placement of half pins into vertebral bodies.

Hybrid Circular Fixator Frame Design

The same nomenclature used to describe linear external fixator frames has been adopted for description of HCF frames. HCF frames can be uniplaner (type I-a, or type II); biplaner or modified multiplaner (type I-b) (Figure 53-65). The number and position of hybrid rod(s) utilized in fixator construction are the principle differences between the frames. Insertion of the fixation pins should always be through safe soft tissue corridors, thus dictating the possible positions of the hybrid rod(s) and the frame configurations available for a particular bone.

The most basic frame is the unilateral-uniplaner type I-a frame. This frame is most commonly used to manage fractures or simple bone deformities involving the radius/ulna or tibia in small to medium sized patients. Additional frame stiffness should be created by the addition of a diagnol strut to all type I-A frames, improving bending, torsional and axial stiffness. A type I-b frame utilizes two hybrid rods placed 60 to 90° apart. Hybrid I-b frames are often used to manage comminuted fractures of the radius/ulna or tibia, especially in large and giant breeds. A type I-b frame can easily be converted to a type I-a frame, by removing a hybrid connecting rod, and the associated SK clamps and fixation pins. This is referred to as staged disassembly or destabilization of the frame, and may stimulate the later stages of bone healing.

Type II HCF frames can be used to manage fractures of the tibia. **However application of type II frames to the radius is not recomended** because full pins passed through the bone may result in iatrogenic pin tract fractures. Furthermore, full-pins passed in the proximal half of the antebrachium penetrate large muscle masses and generally cause substantial pin tract morbidity and patient discomfort. If a type II hybrid frame is necessary for the management of a fractured tibia, half-pins should be placed in the proximal-medial aspect of the bone and the full-pin(s) placed in the distal two-thirds of the bone. This pin orientation will help reduce pin tract morbidly by keeping fixation pins out of the large proximal-lateral musculature of the tibia. **Therefore, to minimize pin tract complications without jeopardizing stability, hybrid 1-b frames are usually preferred over hybrid II frames for tibial fractures.** The hybrid type I-b frame offers mechanical characteristics similar to a type II frame. Additionally, the type I-b frame allows more freedom of placement of the two hybrid connecting rod, so that half pins can be placed through safe soft tissue corridors with minimal soft tissue penetration.

Multiplaner type I-b frames can be applied to metaphyseal fractures of the femur and humerus. However, full rings cannot be used to create a HCF for fractures involving these bones due to the extensive musculature surrounding the elbow, shoulder, stifle, and hip joint. Arches and partial rings are easily positioned near these joints without impinging joint function or encroaching upon regional soft tissues. Articulations and diagonal struts are generally incorporated to create multiplaner type I-b frames in the humerus and femur, in order to improve frame stiffness.

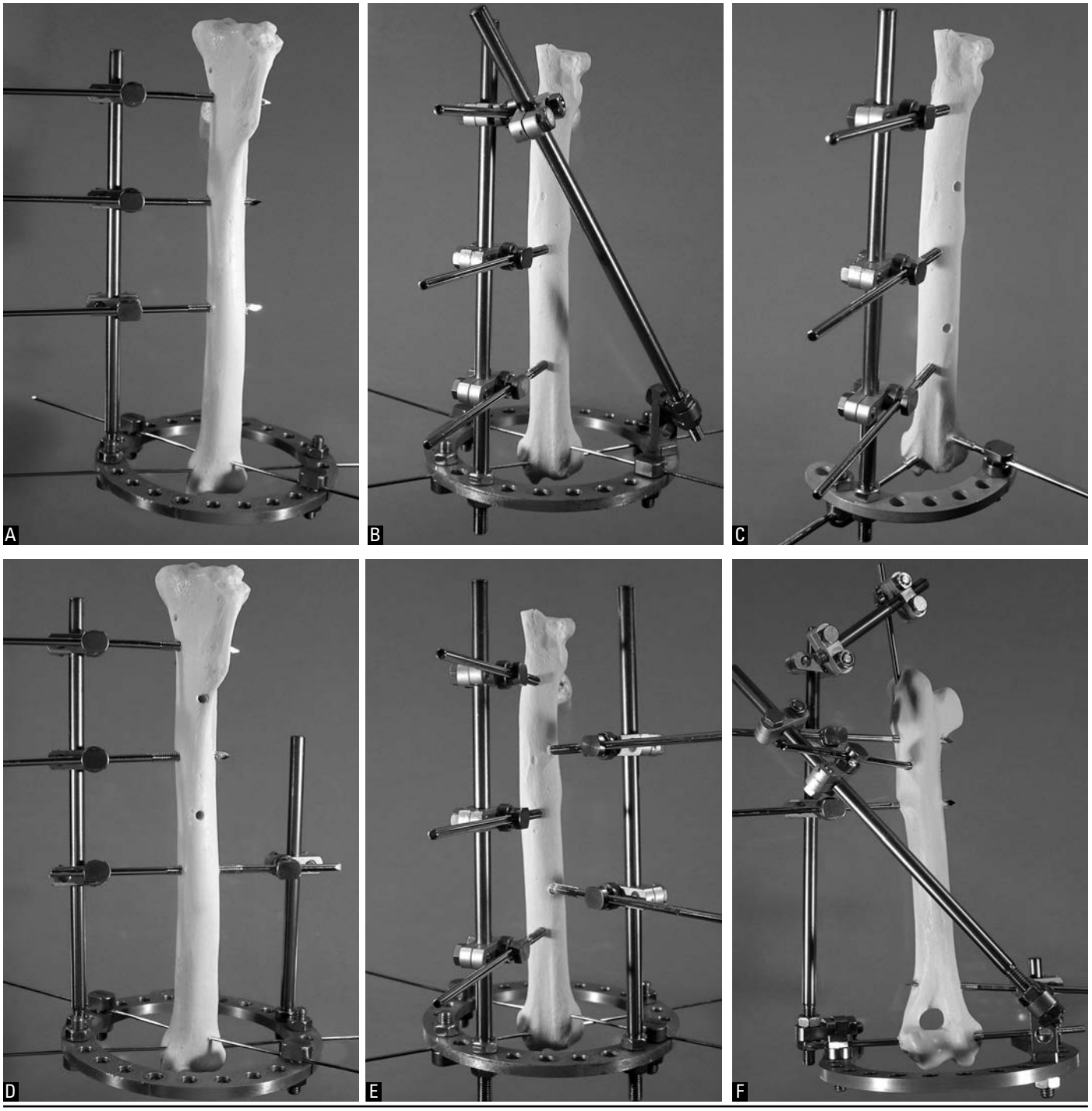


Figure 53-65. Common HCF frame designs. Type I-a frame **A.** Type I-a frame with diagonal strut **B.** Type I-a frame using arch and half-pins **C.** minimal Type II frame **D.** Type I-b frame **E.** and multiplaner Type I-b frame **F.**

Parabolic shaped arches with 140 and 220 mm internal diameters are available to create spinal HCF frames (Figure 53-66). Two to four spinal arches can be connected with three or four sections of 6.0 mm all-thread connecting rod. Half pins can then be placed into the vertebral bodies and secured to the arches using half pin fixation bolts. Modified threaded small SK clamps are positioned along the all-thread connecting rods of the frame. Half pins can be placed into vertebral bodies from the threaded SK clamps, as well as from the spinal arches using pin fixation bolts. In the author's experience a simpler two arch spinal frame used in conjunction with threaded SK clamps is easier to position on the spine, and place fixation pins into vertebral bodies, than the multi arch frame.

Application of a HCF

The application of a HCF is relatively easy; however, close adherence to basic linear and circular fixator application principles should be followed to improve clinical results and reduce postoperative complications. One primary advantage of any external fixation device, is that it can be applied using the principles of biological osteosynthesis. Whenever possible, the HCF should be applied using a closed technique. If necessary, to adequately reduce or align the major bone segments, a mini-approach can be used. However, the local fracture hematoma should not be disrupted. If a mini-approach is used, addition of an autogenous

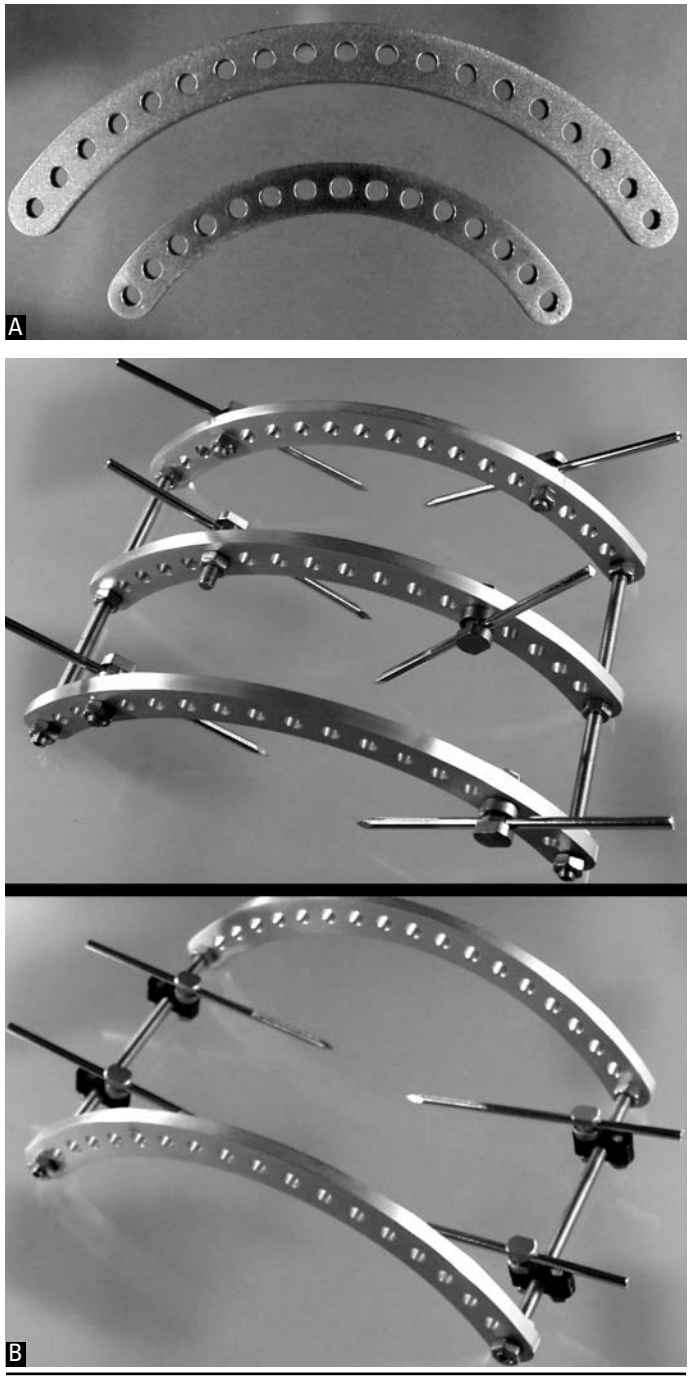


Figure 53-66. Parabolic arches **A.** with 140 and 220 mm internal diameters are used to create spinal frames **B.**

cancellous bone graft at the fracture site is recommended. Fixation pins should always be placed into appropriately sized pre-drilled holes using low speed insertion to avoid mechanical and thermal bone damage. Fixation pins should either be positive profile or tapered Thread-Run-Out (TRO) and inserted perpendicular to the diaphysis. Cortical thread pin design is used in all locations except the proximal tibia, distal femur, and proximal humerus. A cancellous thread profile is preferred in these locations where the cortex is thin and the bone is relatively soft. The threaded diameter of the fixation pin should not exceed twenty-five percent of bone diameter. Pins should be placed a distance of at least 1-bone diameter from the fracture region or fissures. A minimum of three positive profile fixation pins should be inserted into the primary bone segment.

Fixation wires are inserted into the small juxta-articular bone segment at divergent angles. The wires should be placed through the juxta-articular bone segment in regions with minimal overlying soft tissues. Care should be taken to prevent placement of wires through extensor and flexor tendons and major muscles. One wire should be placed on each surface of the ring. If possible, a third "drop wire" should be integrated into the short bone segment to improve resistance to bending and torsional forces. The use of counter-opposed stopper wires (described in the section: Application of Ring Fixators) will also improve fracture stability by minimizing bone translation along the wires. Special 1.0 to 1.6 mm transfixation wires with a free cutting point that easily penetrates cortical bone are recommended instead of trocar pointed K-wires. Wires placed on 66, 84, and 118 mm rings should be tensioned to approximately 90 Kg. "Drop wires" and wires placed on 50 mm rings should not be tensioned. Full rings should be used whenever possible to improve fracture stability. Several lengths of sterile hybrid rods should always be available for intra-operative frame construction and modification if necessary. The hybrid rod should be at least the same length as the fractured bone once axial reduction is achieved. Slightly longer hybrid rods may be needed if diagonal struts will be created. Release incisions in the skin should always be created around each fixation wire and pin. The skin release incision should be 1 to 2 cm long for fixation pins and 0.5 cm for fixation wires. The skin release incisions should be deepened down to the level of the bone by blunt dissection using a hemostat.

The overall goal of fracture reduction and stabilization using a HCF is to, 1) restore the bone to its normal axial length, 2) position the proximal and distal joint surfaces in normal anatomical alignment to each other, and 3) prevent any translational malalignment of the primary and juxta-articular bone segments. Orthogonal radiographs of the normal limb can help determine the correct angular alignment of the proximal and distal joint surfaces, as well as the normal axial length expected of the fractured bone once reduction is complete. Intra-operative fluoroscopy, if available, can assist with wire and pin placement as well as for assessment of fracture reduction and joint alignment. If fluoroscopy is not available, joint surfaces can be "mapped-out" by inserting several 22 to 24 gauge needles into the corresponding joints in several different planes. The "hanging leg prep," (as described in the Basic Principles for the Application of External Fixators), is very useful to reduce fractures involving the radius and ulna when applying a HCF. If a full ring is used to construct the frame, it must be placed over the limb prior to hanging the limb. **The "hanging leg prep" in the author's experience, often makes reduction of juxta-articular tibial fractures difficult and therefore is not recommended.**

Application of a HCF to a Tibial Fracture

The following description applies to the placement of a type I-a or a type I-b HCF frame to a fractured tibia with a short juxta-articular component. Several factors need to be considered to determine if a hybrid type I-a or a type I-b frame should be used to manage the fracture. These factors include: 1) the fracture configuration (two or three piece fracture with load sharing versus a commi-

nuted fracture with no load sharing); 2) patient weight; and 3) patient age. As a general rule, a type I-a HCF frame is applied to fractures with some degree of load sharing by the primary and juxta-articular bone segments, immature or young patients, and fractures in small to medium sized patients. To minimize bending forces acting on the fracture and frame components, a diagnol articulation ("strut") is always recommended when using a type I-a HCF frame. A type I-b HCF frame is usually reserved for large and giant breeds, or comminuted juxta-articular, non-load sharing fractures configurations. If a type I-a HCF frame is applied to the tibia, the hybrid rod should be positioned over the medial aspect of the limb. If a type I-b HCF frame is used, hybrid rods are placed over the medial and anterior regions of the limb.

General Application Steps for a Fractured Tibia

1) The patient is positioned in dorsal recumbency, at the end of the table to facilitate traction on the tibia in order to achieve fracture reduction. If a full ring is used for frame construction, it should be placed over the limb prior to any wire or pin insertion. The hybrid rod does not need to be attached to the ring if it will interfere with reduction or initial wire placement.

2) A 1.0 to 1.6 mm transfixation wire, preferably with a stopper (olive wire), is passed through the juxta-articular bone segment. The wire should be parallel to the corresponding joint surface, perpendicular to the longitudinal axis of the tibia, and placed in the true medial-lateral plane of the juxta-articular bone segment (Figure 53-67). **Positioning of this first wire is critical.** The wire should be placed 5 to 10 mm from the joint surface.

3) The juxta-articular bone segment is centered within the ring. The wire is secured to the outside ring surface with two wire fixation bolts or a bolt and slotted washer. The wire should be tensioned. If a hybrid rod has not already been attached to the ring it should be positioned on the medial aspect of the ring and secured with paired nuts or spherical nuts and washers (Figure 53-68).

4) A pilot hole is pre-drilled into the primary bone segment after creating a release incision in the regional soft tissues, approximately 1 to 2 cm from the associated joint surface. A drill sleeve should be used while pre-drilling to protect the surrounding soft tissues. The pilot hole should be created parallel to the corresponding joint surface, perpendicular to the tibial diaphysis and placed in the true medial-lateral plane of the primary bone segment (Figure 53-69). **Proper positioning of the pre-drilled pilot hole is critical.**

5) A positive profile or a tapered Thread-Run-Out (TRO) half-pin is inserted, using low speed into the pilot hole until several threads penetrate the far cortex. **Note: at this stage, a half-pin should be positioned in the primary bone segment, and a wire placed through the short juxta-articular segment. The pin and wire should be parallel to their corresponding joint surfaces, perpendicular to the longitudinal axis of the tibia and in the true medial-lateral plane of their corresponding bone segments (Figure 53-70).**

6) Axial reduction is achieved by placing traction on the ring (Figure 53-71A). Rotational and angular corrections are accomplished by rotating and manipulating the ring until the wire and half pin are parallel and in the same sagittal plane to each other (Figure 53-71B). If necessary, a mini-approach to the fracture can

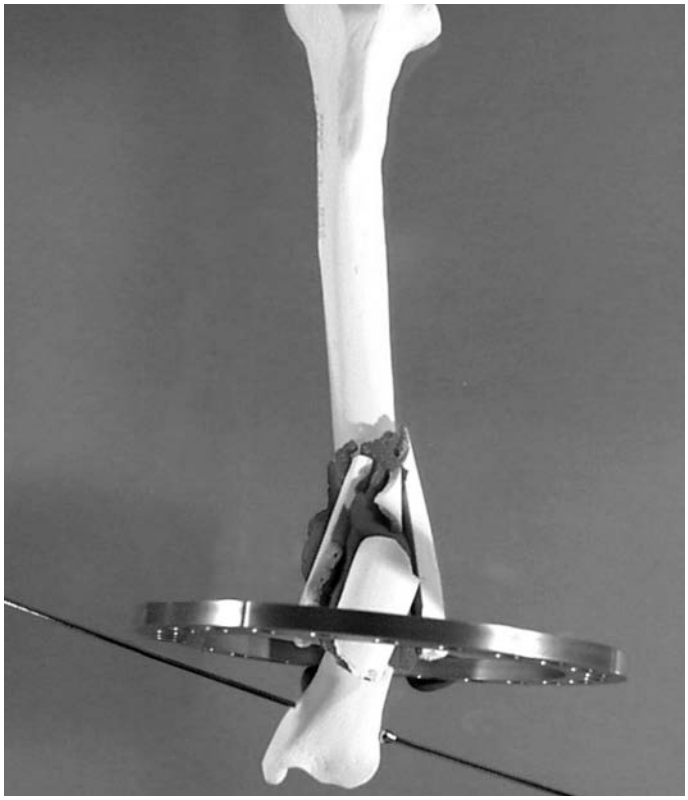


Figure 53-67. The initial transfixation wire is placed through the juxta-articular bone segment. The wire is placed 5-10 mm above and parallel to the joint surface. In addition, the wire is inserted in the true medial-lateral plane and perpendicular to the longitudinal axis of the bone segment.

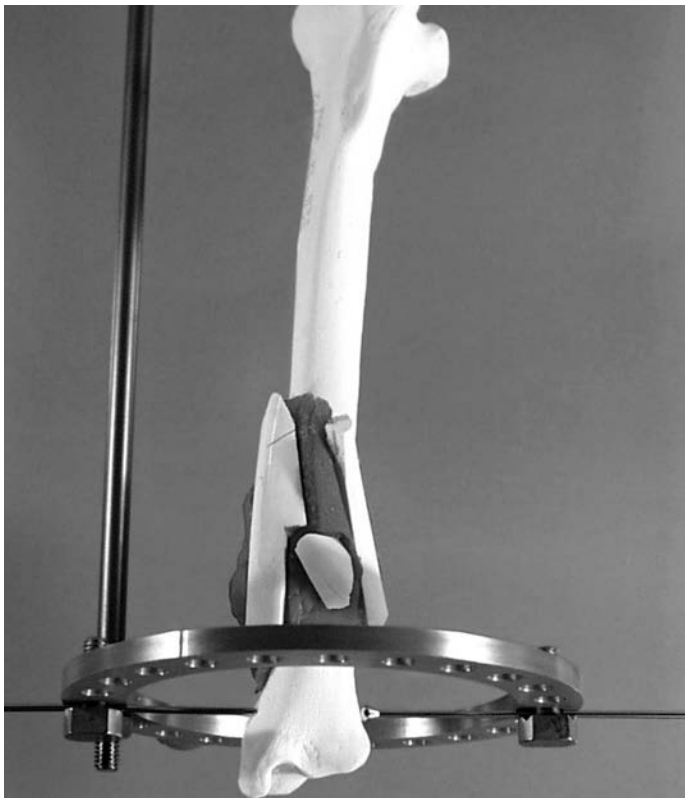


Figure 53-68. The juxta-articular bone segment is centered within the ring and secured with two wire fixation bolts. The hybrid connecting rod is placed on the medial aspect of the ring using two nuts.

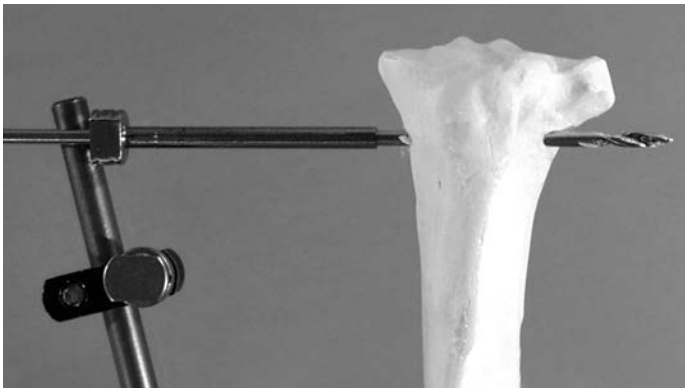


Figure 53-69. A pre-drilled pilot hole is created in the primary bone segment parallel to the corresponding joint surface. The hole is orientated perpendicular to the tibial diaphysis and in the true medial-lateral plane of the bone segment.

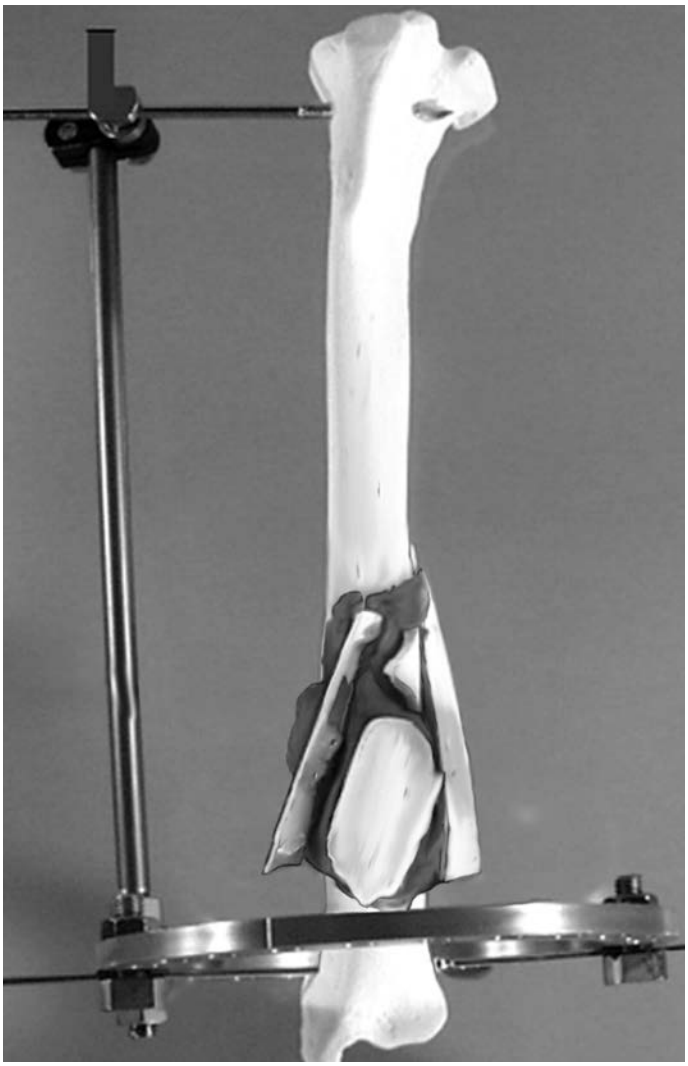


Figure 53-70. The correct position of the trasfixation wire and the positive profile half-pin. Each fixation element is parallel to the corresponding joint surface, perpendicular to the longitudinal axis of the tibia, and in the true medial-lateral plane of the bone segments.

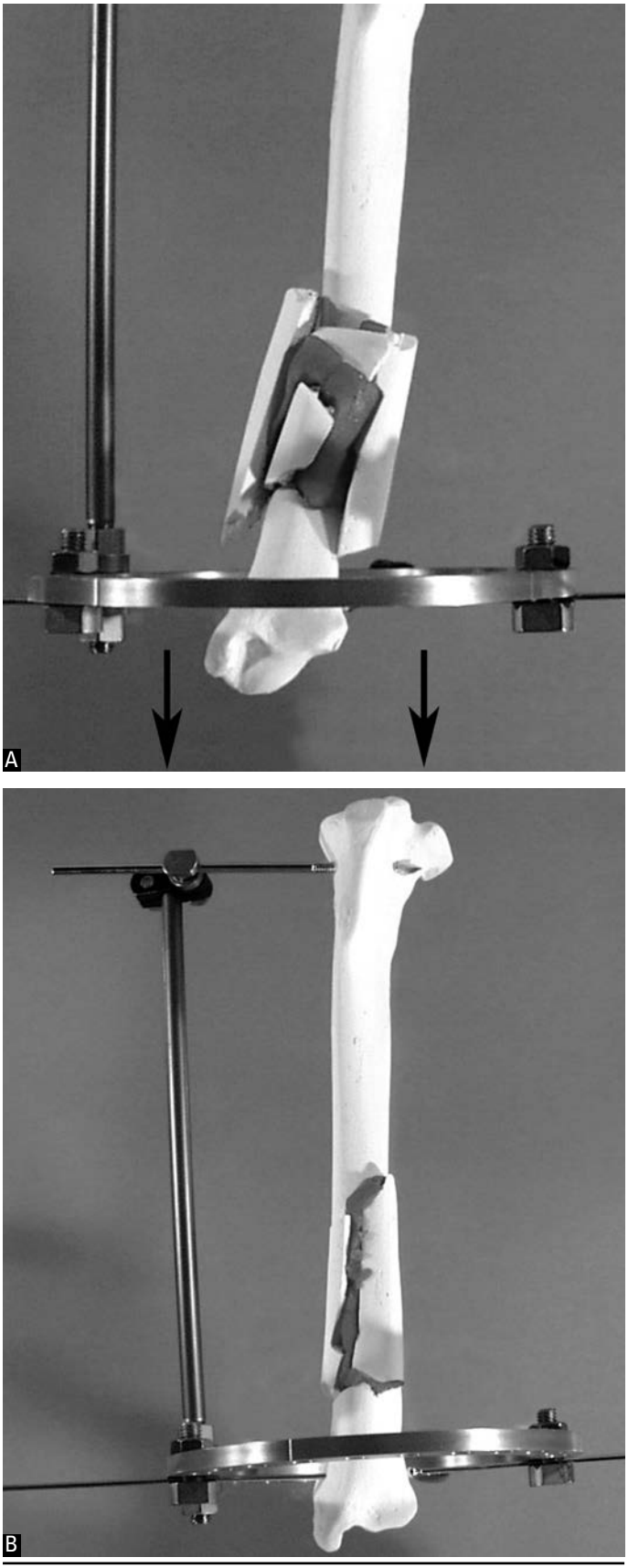


Figure 53-71. Digital traction placed on the ring **A.** with the SK clamp loosely attached to the hybrid connecting rod and fixation pin will result in axial reduction of the fracture **B.** Once reduction is accomplished the SK clamp is re-tightened to the connecting rod.

be made to facilitate reduction.

7) The half-pin is attached to the hybrid connecting rod, using an SK clamp while maintaining axial, rotational and angular alignment. If necessary, the position of the hybrid rod can be changed on the ring to improve reduction or to allow subsequent fixation pins to be passed through safe soft tissue corridors. If spherical washers and nuts or a universal hybrid rod adapter were used in frame construction, the hybrid rod can be angulated to improve reduction. However, the orientation of the pin and wire to each other should not be altered, assuming they were correctly positioned initially.

8) If substantial medial-lateral translational malalignment of the juxta-articular and primary bone segment exist, the SK clamp can be loosened and the half pin translated medial or lateral, as needed to improve reduction (Figure 53-72). Likewise, the wire fixation bolts can be loosened and the juxta-articular bone segment translated medial or lateral. However, the orientation of the pin and wire to each other should not be altered. **Note: at this stage: 1) the proximal and distal joint surfaces should be parallel; 2) the primary bone segment and the short juxta-articular segment aligned in the medial-lateral and anterior-posterior planes; 3) anatomical axial length re-established; and 4) rotational malalignment corrected.**

9) A second wire, preferably with a stopper, is passed through the juxta-articular bone segment. This wire should be orientated approximately 40-60° to the first wire, parallel and flush to the inner ring surface. Before placing the second wire, it is imperative that the juxta-articular bone segment is not tilted in an anterior-posterior direction. Digital pressure placed on the malaligned bone segment will improve reduction. The wire should be passed through regions with minimal soft tissue coverage over the bone. Using counter-opposed stopper wires will help prevent translation of the short juxta-articular bone segment. The wire is then secured to the ring with wire fixation bolts and tensioned (Figure 53-73).

10) Place two or three additional SK clamps on the hybrid connecting rod. Position a clamp over the primary bone segment near the fracture site. Digitally correct any anterior-posterior tilting of the primary bone segment at the fracture site. Insert a positive profile half-pin into the primary bone segment at a distance of at least one times the diameter of the bone at the fracture, after creating a pre-drilled pilot hole. The SK clamp can be used as a drill guide with the aid of a drill sleeve. Secure the SK clamp and pin to the hybrid connecting rod. Place additional half-pins into the medial aspect of the primary bone segment. The half-pins should be equally spaced along the medial shaft of the tibia (Figure 53-74). Typically three to four positive profile fixation pins should be placed into the primary bone segment.

11) Add a "drop wire" to the ring using two posts if sufficient bone is available. Do not tension this wire. If possible, the drop wire should be placed in a different plane than the previous two wires placed on the ring, to improve bending and torsional stability.

12) A diagonal strut can be created if additional frame stiffness is necessary.

13) A type I-b HCF frame can be created, if necessary, by attaching a second hybrid rod to the anterior surface of the ring using two nuts. Position two to four SK clamps along its shaft and insert half-pins into the anterior surface of the tibia, as previously described. These pins should be passed between the half pins inserted from the medial hybrid rod (Figure 53-75).

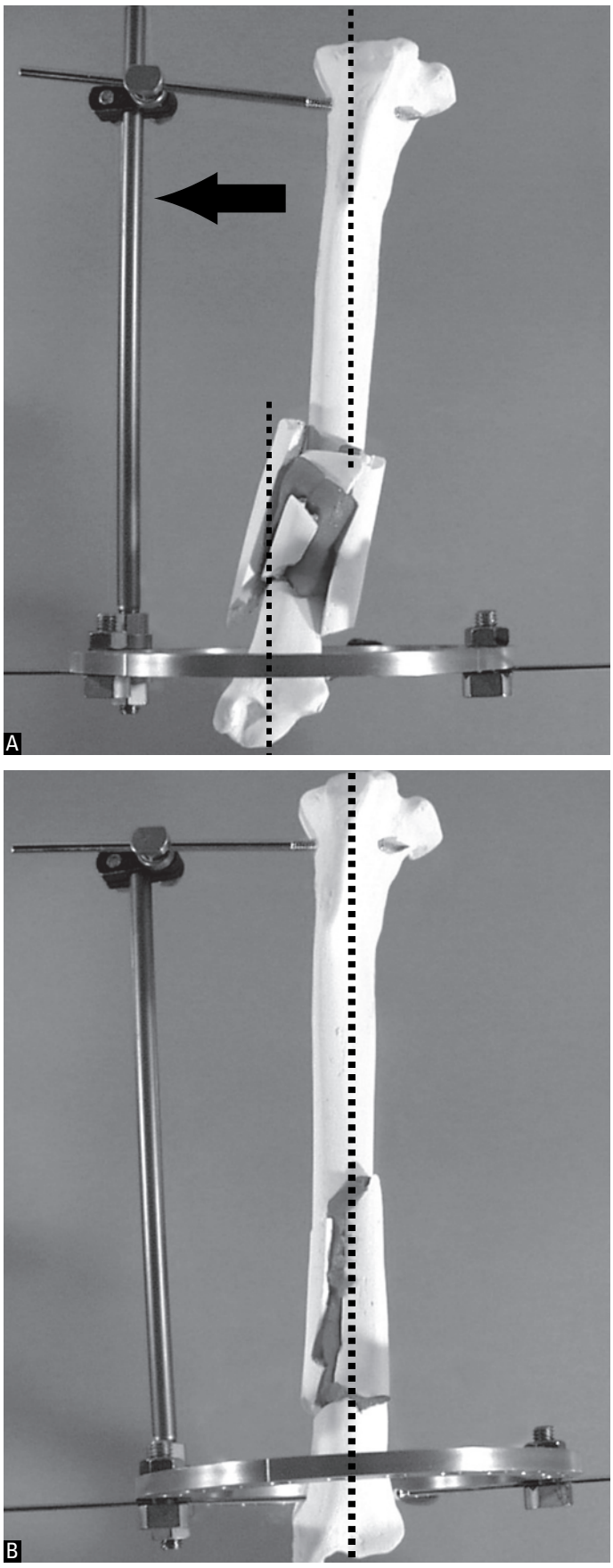


Figure 53-72. Medial-lateral translational malalignment **A.** is corrected by loosening the SK clamp and moving the half pin and primary bone segment in the appropriate direction to improve alignment **B.** Once alignment is achieved, the SK clamp is re-tightened.

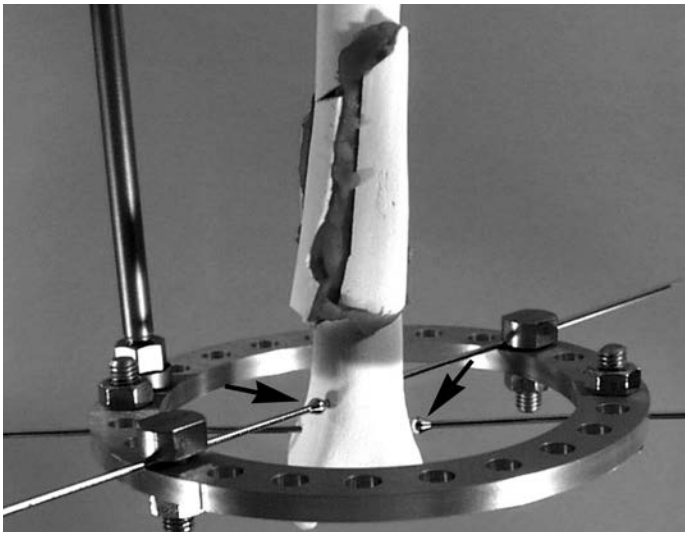


Figure 53-73. A second transfixation wire is passed through the short juxta-articular bone segment and secured to the ring. Counter-opposed olive wires *(arrows)* will help prevent translation of the bone segment, improving resistance to bending and torsional forces.

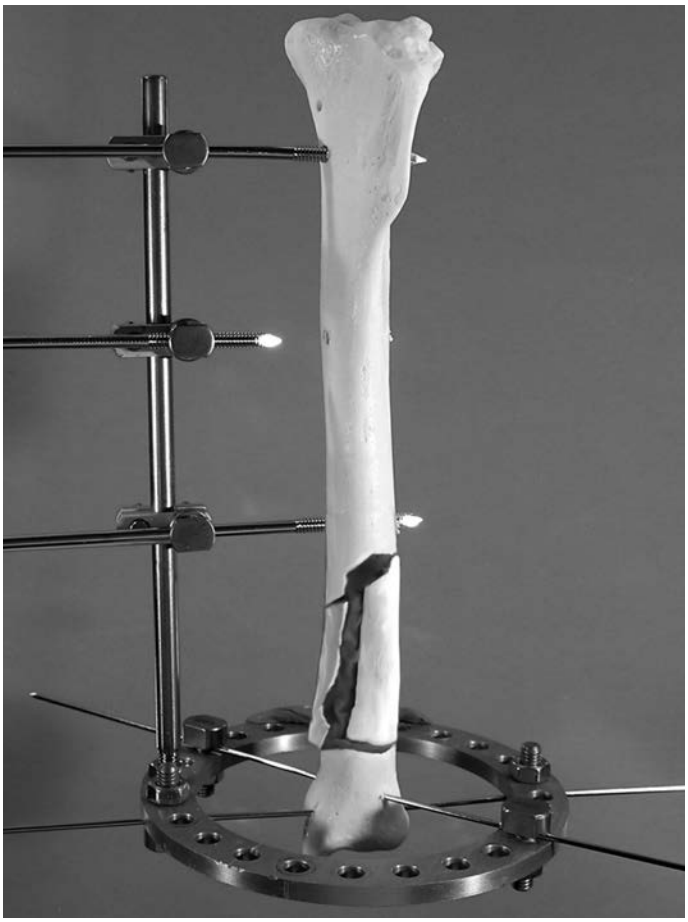


Figure 53-74. Additional SK clamps are equally spaced along the hybrid connecting rod and additional half pins are placed into the primary bone segment after pre-drilling pilot holes.

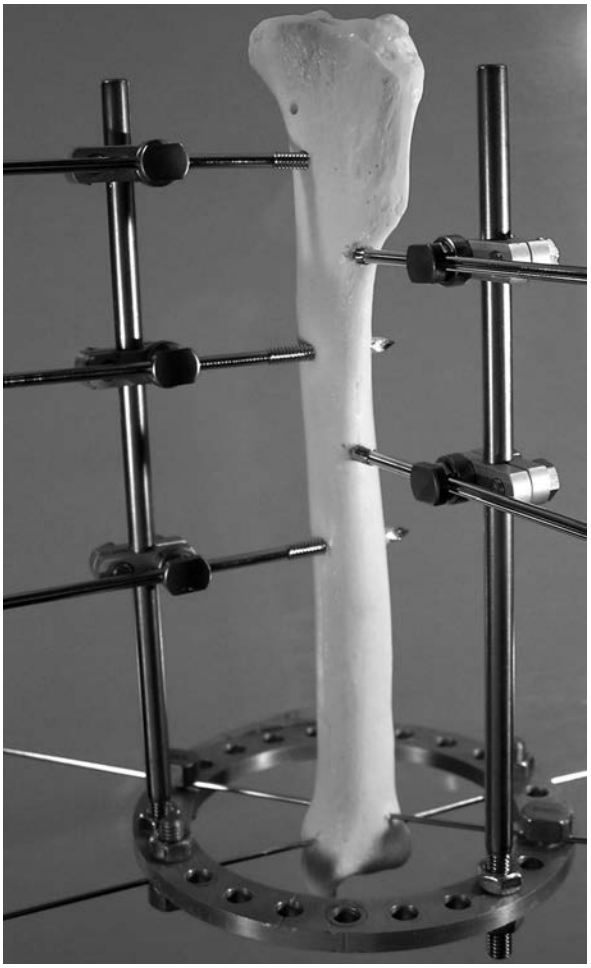


Figure 53-75. A hybrid Type I-b frame can be created by adding a second hybrid connecting rod, SK clamps and half-pins to the anterior aspect of the ring.

Application of a HCF to a Radius/Ulna Fracture

A "hanging leg prep" will often facilitate re-establishment of axial limb length of radial/ulnar fractures. If a full ring is used, it must be placed over the antebrachium prior to hanging the limb. A more detailed description of the "hanging leg prep" can be found in the Basic Principles for Application of External Fixators section. The basic steps used to apply a HCF to the tibia can be followed for the radius with only several modifications. **One primary difference is that the position of the hybrid connecting rod(s) in relationship to the limb will be altered to allow placement of half pins through safe soft tissue corridors.** Due to the flat ovoid shape of the radius it is difficult to pass fixation pins in the medial-lateral plane. However, the bone is a relatively easy target to insert half pins in the cranial-medial and cranial-lateral planes. Fixation pins placed in these locations will pass through safe soft tissue corridors. Similar to the tibia, the decision to use a type I-a frame (with or without a diagonal), or a type I-b frame will be dependent upon the fracture configuration (load or non-load sharing), patient's age and weight. **Hybrid type II frames are not recommended on the radius.** To place a hybrid type I-a frame on the radius, the hybrid connecting rod should be positioned over the cranial-medial aspect of the antebrachium. If a hybrid type I-b frame is used, hybrid connecting rods are

positioned over the cranial-medial and cranial-lateral aspect of the antibrachium, approximately 60° to each other.

General Application Steps for a Fractured Radius/Ulna

1) With the leg suspended, and axial length re-established, the carpus and elbow should be flexed and extended to determine if any rotational or angular joint malalignment exists. Any malalignment should be corrected as described for application of a linear fixator. The ring or partial ring is positioned over the juxta-articular bone segment and secured to the bone with a stopper wire. The wire should be positioned parallel to the joint, perpendicular to the longitudinal axis of the bone, and in the medial-lateral plane of the juxta-articular bone segment.
2) A half-pin is inserted into the primary bone segment through a release incision and a pre-drilled hole placed over the cranial-medial aspect of the antebrachium. This pin should be placed 1 to 2 cm from the corresponding joint surface. The half-pin should be positioned parallel to the joint surface and perpendicular to the longitudinal axis of the bone.
3) The half-pin is connected to the cranial-medial hybrid connecting rod using an SK clamp. The elbow and carpus should again be flexed and extended to evaluate and correct any rotational or angular malalignment, if present.
4) An additional wire is passed through the juxta-articular bone segment approximately 60° to the first wire and on the opposite flat surface of the ring. This wire is secured to the ring using wire fixation bolts and nuts. Both wires connected to the ring should be tensioned. A "drop wire" should be placed if the length of the short bone segment will allow.
5) Two or three additional SK clamps are placed on the hybrid connecting rod and half-pins inserted into the cranial-medial aspect of the radius to complete the frame.
6) Additional frame stiffness should be created by the addition of a diagnol strut.
7) A hybrid type I-b frame can be created by positioning a second hybrid connecting rod, approximately 60° from the first rod, over the cranial-lateral aspect of the antibrachium. The rod is connected to the ring. Additional SK clamps are added to the rod and half-pins are inserted into the cranial-lateral aspect of the radius through release incisions and pre-drilled pilot holes. These half-pins should be placed between the half- pins placed from the cranial-medial hybrid rod (Figure 53-76).

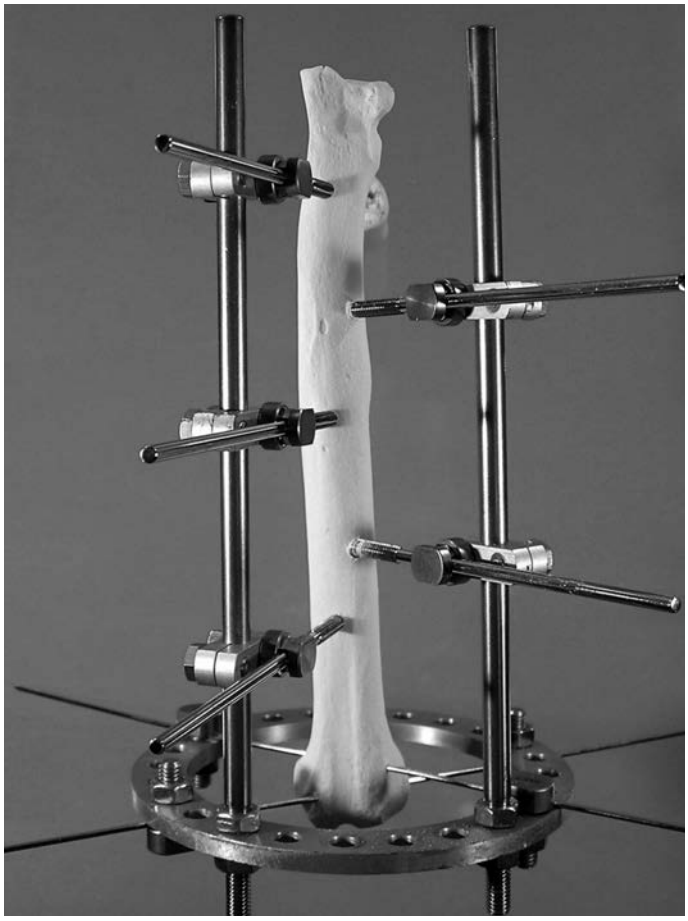


Figure 53-76. Hybrid Type I-b construct used to stabilize a distal radial fracture.

Application of a Multiplaner 1-B HCF to a Distal Humeral or Femur Fracture

Due to the extensive soft tissues surrounding the stifle and elbow joint, a full ring cannot be positioned over the distal humerus or femur without impingement of joint motion. Partial or stretch rings are used instead. Furthermore, placement of divergent wires from a ring in these locations causes substantial penetration of the flexor and extensor muscle groups. In the author's experience, this often results in **significant permanent** loss of joint motion. However, if fixation elements are only placed in the medial-lateral plane of the juxta-articular bone segment, joint motion is preserved in both the elbow and stifle joints. In addition, fixation pins should only be placed into the proximal-lateral and cranial-lateral regions of the humerus and femur to minimize penetration of major muscles near the hip and shoulder joint. Safe soft tissue corridors have been described for the humerus and femur in the linear external fixation section.

General Application Steps for a Distal Humeral or Femur Fracture

1) A pilot hole is pre-drilled through the condyle in the true medial-lateral plane of the distal juxta-articular bone segment. A **positive profile full-pin** with cortical (humerus) or cancellous (femur) thread profile is inserted through the condyle using low speed.
2) The full-pin is attached to the medial and lateral aspect of a stretch ring using two pin fixation bolts and 6.0 mm nuts. The open surface of the ring can be directed cranial or caudally to allow normal motion of the joint. The author preferes to direct the open surface of the ring caudaully in order to provide an anterior platform available for additional connecting elements (Figure 53-77). Alternatively, the open end of the ring can be orientated cranial.
3) An intramedullary pin is inserted in a normograde manner from the proximal aspect of the bone the intramedullary pin can be retrograded from the fracture site, through a mini-approach. The pin is inserted into the center of the femoral condyle or into the medial half of the humeral condyle. If necessary, a mini-approach can be used to facilitate placement of the intramedullary pin into the condyle. The pin is advanced until the axial length of the bone

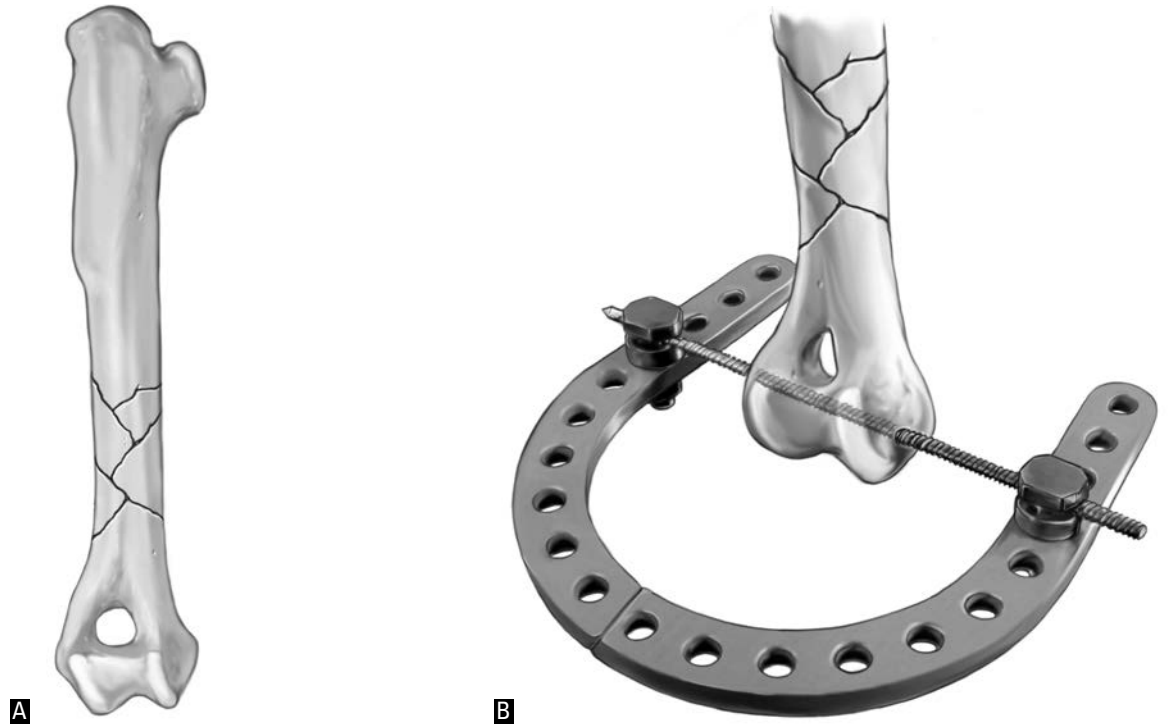


Figure 53-77. Application of a multiplaner Type I-b hybrid construct to a distal humeral fracture **A.** A transcondylar positive profile center threaded full-pin is secured to a stretch ring using two half-pin fixation bolts **B.** The open end of the ring has been directed caudally to prevent impingement of joint function, and allow an anterior platform for other connecting elements.

is re-established. The pin also prevents translational malalignment of the condyle and the primary bone segment. Once the fracture is aligned, the pin is then passed distally into the condyle.

4) The stretch ring is manipulated to correct rotational and angular malalignment of the condylar bone segment. A hybrid connecting rod is secured to the lateral aspect of the stretch ring using two 6.0 mm nuts. To allow proper angulation of the hybrid rod, it may be necessary to attach the hybrid rod to the ring using either paired spherical nuts and washers, or by creating an articulation using two posts.

5) The proximal end of the hybrid rod is attached to the proximal aspect of the primary bone segment using two - three positive profile half-pins and SK clamps. The hybrid rod can be tied into the intramedullary pin using an articulation. Alternatively the IM pin can be contoured and directly attached to the hybrid rod with an SK clamp (Figure 53-78).

6) To provide additional support of the condyle, a positive profile half-pin is inserted into the condylar or supracondylar region, distal to the fracture. The pin can be inserted into either the medial or lateral aspect of the condyle. The author has found that a medially placed half-pin is clinically well tolerated, penetrates less soft tissue and results in less restriction of joint motion than a laterally placed pin. The half-pin is placed from either a post or a short hybrid connecting rod (Figure 53-79).

7) One or two diagonal struts can be created using articulations secured to the anterior region of the stretch ring to improve frame stiffness. Additional half-pins can be placed into the proximal cranial-lateral aspect of the humerus or femur from SK clamps positioned along the diagonal strut (Figure 53-80).

8) The frame can easily be destabilized to enhance fracture healing postoperatively by: a) removal of the intramedullary pin; b) removal of diagonal struts; or c) by converting the HCF into a lateral 1-a linear external fixator by removing the ring, diagonals, medial half-pin, and cutting the medial aspect of the full pin.

Postoperative Care of the HCF

Postoperative care of a HCF is similar to the care previously described for circular and linear fixators. If destabilization of the frame is desired, it is generally performed 6 to 8 weeks after surgery. Staged disassembly is usually not necessary if fixation wires have been used in the short bone segment. If a wire or pin causes significant drainage or becomes loose it should be removed, or replaced if necessary. Orthogonal radiographs should be performed every 6 to 8 weeks until fracture healing is complete and the frame removed. The supporting, connecting and assembly elements of the HCF can be cleaned and reused numerous times.

Suggested Readings

Cross AR, Lewis DD, Rigaud S, Rapoff AJ: Effect of various distal ring-block configurations on the biomechanical properties of circular external skeletal fixators for use in dogs and cats. *J Am Vet Res* 65; 4: 393, 2004.

Lewis DD, Bronson DG, Cross AR, *et al.:* Axial characteristics of circular external skeletal fixator single ring constructs. *Vet Surg* 30: 386, 2001.

Marcellin-Little DJ, Roe SC, Rovesti GL, *et al.:* Are circular external fixators weakened by the use of hemispherical washers? *Vet Surg* 31: 367, 2002.

Toombs JP, Bronson DG, Ross D, Welch RD: The SK™ external fixation system: description of components, instrumentation, and application techniques. *Vet Comp Ortho Traumatol* 2:76, 2003.

Worsar MA, Marcellin-Little DJ, Roe SC: Influence of bolt-tightening torque, wire size, and component reuse on wire fixation in circular external fixation. *Vet Surg* 31: 571, 2002.

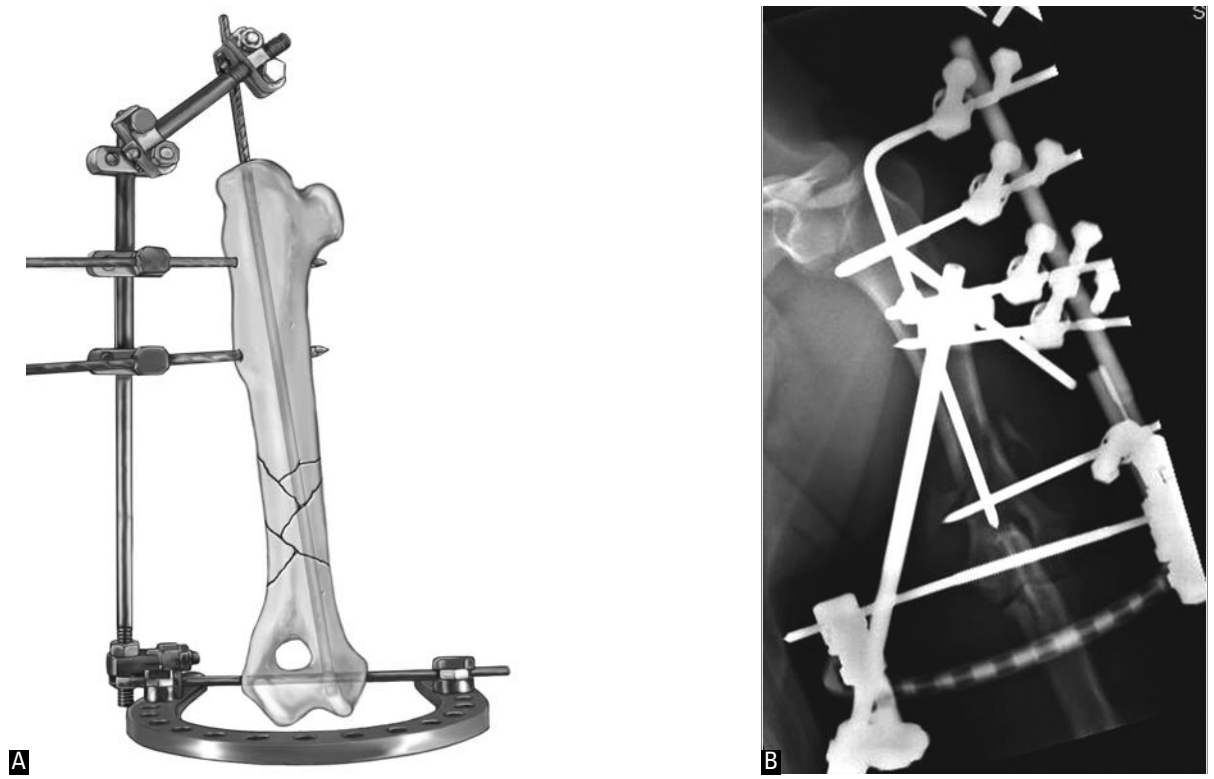


Figure 53-78. The proximal aspect of the hybrid rod is secured to the primary bone segment with two or three half-pins. **A.** The hybrid rod can be "tied" into the intramedullary pin using a linear articulation. **B.** Alternatively the IM pin can be bent and directly attached to the hybrid rod using an SK clamp.

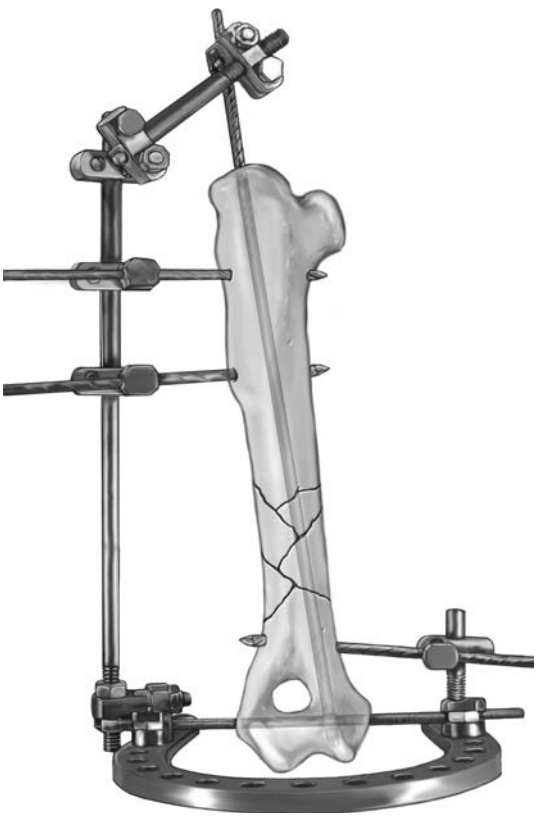


Figure 53-79. A half-pin is inserted into the medial aspect of the condyle or supracondylar region from either a post or a short hybrid rod connected from the medial aspect of the ring.



Figure 53-80. A diagonal strut is created on the anterior or anterior-medial aspect of the ring using an articulation. The strut is connected to a proximal half-pin using a "stack clamp" technique. Additional half-pins can be placed into the proximal-lateral aspect of the humerus from an SK clamp positioned on the diagonal strut.

Chapter 54

Bone Grafts and Implants

Harvesting and Application of Cancellous Bone Autografts

James P. Toombs

Introduction

Application of a freshly harvested cancellous bone autograft is considered to be the "gold standard" treatment for promoting the healing of bony defects. In spite of this, cancellous bone grafting is one of the most underutilized procedures in veterinary orthopedics.

Cancellous bone grafts benefit healing by three different mechanisms: 1) the matrix of cancellous bone contains bone morphogenetic proteins that stimulate uncommitted mesenchymal cells to differentiate into bone forming cells at the injury site (osteoinduction); 2) the trabecular surfaces of the cancellous bone graft allow invasion of the graft by newly formed blood vessels and provide a surface or scaffold upon which new bone can be deposited (osteoconduction); and 3) bone forming cells in the graft which survive transplantation may participate directly in early formation of bony callus (osteogenesis). The delicate trabecular structure of cancellous bone does not enable it to bear weight or support fixation devices (structural support function).

Clinical Indications for Cancellous Bone Grafting

Specific clinical indications for cancellous bone grafting fall into two major categories: 1) conditions where bone healing requires enhancement (nonunions, potential nonunions, highly comminuted fractures, and osteotomy procedures that depend upon rapid new bone formation for a successful outcome – e.g. triple pelvic osteotomy); and 2) treatment of bone loss secondary to trauma (high energy open fractures), disease (osteomyelitis and bone cysts), or surgical resection (arthrodeses, empty holes in bone after bone plate removal, and limb salvage procedures in patients with bone neoplasia).

Nonunions

Most nonunion fractures seen in dogs and cats are hypertrophic and are attributable to inadequate stabilization. Application of appropriate internal or external fixation improves the mechanical environment such that many of these fractures will heal successfully without bone grafting. Avascular nonunions, however, do require bone grafting. The sclerotic ends of such fractures are debrided back to bleeding bone using either a bone curette or rongeurs, and a Steinmenn pin, K-wire, or drill bit is used to reopen the medullary cavity. Fibrous tissue at the fracture site should also be resected. A liberal amount of freshly harvested cancellous autograft should be packed into the resulting defect to enhance bone healing.

Potential Nonunions

Decreased vascular density in the distal radius of small breed dogs has been implicated in the higher frequency of nonunion seen in these patients. Treatment usually involves open reduction, fixation with a bone plate and screws, and application of canellous bone autograft to the fracture region.

Comminuted Fractures

Highly comminuted fractures have avascular fragments that have a tendency to be resorbed. Additionally, fixation devices applied to such fractures must function in buttress mode, thus provision of optimal stability can be challenging. Vigorous early production of bridging callus stimulated by liberal application of cancellous autograft over the fracture region is often critical to a successful outcome in these cases.

Osteotomy Procedures

Rapid formation of bridging callus is critical to a successful outcome in canine patients that have undergone triple pelvic osteotomy (TPO). As most TPO patients are young dogs with relatively soft bone, pullout of fixation screws and loss of reduction can occur with repetitive loading. Liberal application of cancellous bone graft at the ilial osteotomy site facilitates rapid production of bridging callus thus promoting successful healing before implant loosening can occur. Corticocancellous bone removed from the pubis and the triangular piece of bone removed from the dorsal aspect of the caudal ilial bone segment can be cut into small pieces and mixed with the graft as a cancellous bone extender.

High Energy Open Fractures

Bone loss is a common feature of high energy open fractures, especially those accompanied by significant soft tissue shearing injuries. Initial treatment includes wound debridement and stabilization of the fracture. Cancellous bone grafting is often delayed for about 14 days to allow the surrounding soft tissue to recover sufficient vascularity to be supportive of the bone graft. If the graft cannot be covered with skin or muscle, it can be protected with a sterile nonadherent dressing followed by a bandage. If the cancellous bone graft fails, it is generally resorbed or expelled through the wound. Cancellous bone is the only type of bone graft that can be safely applied to contaminated or infected fractures, as grafts containing cortical elements will generally sequestrate.

Osteomyelitis

Chronic bone infection is characterized by large areas of avascular bone and dense scar tissue, which can be impenetrable barriers to parenterally administered antibiotics. When avascular bone and scar tissue are removed by debridement, this results in a large bony defect that is slow to heal and is prone to reinfection. Packing such a defect with freshly harvested cancellous bone is helpful in resolving infection and promoting

bone healing. Rigid stabilization and appropriate antibiotic therapy are required in addition to the graft in order to obtain a successful outcome.

When cancellous autograft is applied to a contaminated or infected host bed, care must be taken to avoid contamination of the donor site. In this situation, the following procurement and application procedure is recommended: 1) perform the host site surgical procedure and any necessary debridement, lavage, obtain a sample for culture, and then cover the repair site with moist sponges; 2) change gloves and use a separate set of surgical instruments to harvest the cancellous bone graft; 3) close the donor site; 4) apply the cancellous graft to the recipient site; and 5) close the repair site.

Bone Cysts

Bone cysts are benign fluid-filled lesions of unknown etiology that may be monostotic (involving a single bone) or polyostotic (involving more than one bone). Clinical signs include pain and swelling, but cystic bone lesions can be asymptomatic until they reach a fairly large size or until a pathologic fracture occurs. Treatment involves curettage of the walls of the cyst, filling of the resulting defect with cancellous bone graft, and stabilization of the bone until healing occurs.

Arthrodesis

When arthrodesis is performed, stable bony union of multiple, often complex joint surfaces must be achieved as quickly as possible. A successful outcome depends upon adherence to the following principles: 1) removal of all cartilage from the surfaces that must undergo bony healing; 2) liberal application of cancellous bone graft to fill defects and to promote early callus formation; 3) rigid fixation; and 4) healing of the joint in a functional anatomic position.

Bone Plate Removal

Implant removal is performed in some patients that have undergone longbone fracture repairs with bone plates and screws. Implant removal results in a variable number of empty holes that can act as stress concentration points until healing occurs. Some surgeons advocate packing the empty bone holes with cancellous autograft bone to speed the healing of these defects.

Limb Salvage

Animals with a neoplastic lesion involving the distal radius are the best candidates for limb salvage. Wide resection of the neoplastic portion of the bone produces a defect that is too massive to be filled with cancellous bone alone. Typically, an allogeneic cortical bone segment is cut to fit the defect. Rigid stabilization is accomplished with bone plate and screw fixation that extends from the proximal radial host segment to the distal portion of the 3rd metacarpal bone. To promote rapid healing at the alloimplant-host bone junctions, freshly harvested cancellous autograft is packed into the medullary cavity at the proximal and distal ends of the alloimplant (composite grafting). Cancellous bone is also liberally applied over the proximal and distal interfaces of the alloimplant segment. Further discussion of this technique can be found in the section "Harvesting, Storage, and Application of Cortical Allografts" in a later section of this chapter. Distraction osteogenesis provides an alternative solution for dealing with large bony defects in limb salvage patients and this technique is covered in the last section of this Chapter.

Donor Sites for Cancellous Bone Grafts

In young adult animals, the metaphyseal regions of most major longbones can provide graft material with high osteogenic potential. With progressing age, bone marrow at some of these sites undergoes a slow transformation from hematopoietic marrow to fatty marrow. Cancellous bone obtained from areas where the bone marrow is still hematopoietic provides the highest level of osteogenic function. In this regard, the best sites for obtaining cancellous autografts in mature dogs are the proximal humerus, proximal femur, distal femur, and the wing of the ilium. Cancellous bone taken from these sites has a rich, deep reddish brown appearance. In contrast, cancellous bone taken from the proximal metaphysis of the tibia, a site where marrow becomes fatty, has more of a yellowish or tan appearance (Figure 54-1).

The 3 most commonly used sites for obtaining cancellous bone grafts in dogs are the craniolateral aspect of the proximal metaphysis of the humerus, the dorsal aspect the wing of the ilium, and the caudomedial aspect of the proximal metaphysis of the tibia. In terms of both the quality and the quantity of graft material that can be obtained, the proximal humerus is the best of these three alternatives. The proximal humerus is also an easily accessible site. The quality of cancellous bone from the wing of the ilium is quite good, but the volume of material that can be obtained is significantly less than for the humerus, and it is not as easily accessible. Although the proximal tibia is easily accessible, cancellous autograft from this site tends to provide less volume and lower quality material compared to the other two sites. If additional graft material is needed from the same donor site at a later date, restoration of cancellous bone is more rapid and complete in the proximal humerus compared to the proximal tibia. The recommended waiting time before returning to a site for a second graft harvest is 2 months.



Figure 54-1. Split sections of the humerus and tibia from a 5 year old mixed breed dog. Abundant cancellous bone with a dark reddish-brown appearance is present in the proximal humerus. Much less cancellous bone is seen in the proximal tibia and it has a yellowish-tan appearance due to the absence of hematiopoietic bone marrow.

The femur offers two additional donor sites for obtaining cancellous bone. A greater quantity can be obtained from the condylar region of the distal femur compared to the greater trochanteric region of the proximal femur. Graft quality is good at both locations. Access to these sites requires more dissection than is needed for access to the proximal humerus and proximal tibia. The distal femur offers a convenient location for harvesting cancellous bone graft to be used for a triple pelvic osteotomy procedure.

Obtaining a large amount of cancellous bone graft material is problematic in cats. The proximal metaphyseal region of the humerus is the preferred donor site, similar to dogs. Rib grafts can provide a larger volume of material and these can be harvested and cut into small chips with rongeurs. This cortico-cancellous graft material can be mixed with cancellous bone to fill large bony defects in feline patients.

Surgical Approaches to Donor Sites

Proximal Humerus

A 2 to 3 cm long skin incision is made over the craniolateral aspect of the greater tubercle, just cranial to the palpable acromial head of the deltoideus muscle. Subcutaneous tissue is separated by sharp dissection to reveal the periosteal surface of the bone. Exposure is maintained by insertion of a small Gelpi self-retaining retractor. An access hole is made with a Steinmann pin or drill bit through the thin outer layer of cortical bone in the proximal metaphyseal region of the humerus (Figure 54-2). It is important to maintain a safe distance from the growth plate in skeletally immature animals. It is also important to make the access hole in the metaphysis rather than in the hard cortical bone of the diaphysis. An access hole in this later location increases the risk of a postoperative iatrogenic fracture of the donor bone.



Figure 54-2. Craniolateral access hole in the proximal humerus.

Proximal Femur

A 2 to 3 cm long skin incision is made directly over the lateral aspect of the greater trochanter. The subcutaneous tissues and the superficial gluteal muscle are sharply incised to reveal the surface of the bone. Exposure is maintained with a Gelpi retractor. An access hole is made with a Steinmann pin or drill bit.

Distal Femur

A 2 cm long incision is made over the bone halfway between the fabella and the proximal patella, parallel to the margin of the patella. The incision is made from the skin to the bone on either the medial or the lateral aspect of the femoral condyle. A Gelpi retractor is applied to maintain exposure, which reveals the stifle at the caudal margin of the reflection of the joint capsule. An access hole is made through the cortex of the condyle with a Steinmann pin or drill bit at the location shown in Figure 54-3.



Figure 54-3. Lateral access hole in the distal femur. Medial access to the distal metaphysis of the femur is an acceptable technique as well.

Proximal Tibia

A medial skin incision 2 to 3 cm in length is made starting approximately 2 cm distal to the tibial plateau, midway between the tibial tubercle and the medial collateral ligament. Subcutaneous tissues and underlying muscle (insertions of sartorius and gracilis muscles) are separated with sharp and blunt dissection to reveal the proximal tibial metaphysis. The cross-sectional shape of the proximal tibia is triangular, with the base of the triangle located caudally. In light of this, the access hole in the metaphysis should be made at a caudomedial location as shown in Figure 54-4.



Figure 54-4. Caudomedial access hole in the proximal tibia.

Iliac Crest

A 4 to 8 cm long skin incision is made directly over the dorsal aspect of the iliac crest. Deep fascia is incised along the entire length of the incision. The middle gluteal muscle is sharply incised from its attachment to the dorsal aspect of the iliac crest and then is subperiosteally elevated from the wing of the ilium to reveal the bone. The dorsomedial aspect of the ilium is exposed by sharp incision of the insertion of the sacrospinalis muscle. Exposure is maintained with Gelpi retractors. An access hole can be made in the dorsal surface of the ilium, or an osteotome or saw can be used to remove a cap of bone from the craniodorsal aspect of the iliac crest as shown in Figure 54-5. If

a large quantity of bone graft is needed, this cap can be cut into multiple pieces with a pair of rongeurs to serve as a cancellous bone extender. The corticocancellous bone chips are then mixed with cancellous bone and applied to the recipient site. The iliac crest may be preferable to the previously mentioned longbone metaphyseal donor sites in young animals with open growth plates because there is less risk of clinically significant growth disturbance as a complication of graft procurement.



Figure 54-5. Lateral aspect of the left ilium with an osteotomy of the craniodorsal portion of the iliac wing.

Instrumentation and Graft Harvesting Procedure

Minimal instrumentation is required for harvesting cancellous bone grafts from the humerus, femur or tibia. Placement of a small Gelpi retractor is useful to maintain exposure at the donor site. A Steinmann pin or drill bit is used to penetrate the thin cortex of the metaphysis. The access hole should not be made through the thicker cortical bone of the diaphysis. In young patients with open physes, it is important to locate the access hole a safe distance away from the growth plate. Growth deformities have been reported secondary to graft harvest in these patients. In very small patients with open physes, cancellous bone graft harvest from the wing of the ilium is a safer procedure than graft procurement from a longbone donor site. An osteotome or a bone saw are helpful for removing the craniodorsal portion of the wing of the ilium for improved access to the cancellous bone available for harvest.

A bone curette is inserted through the access hole to remove cancellous bone. The size of the bone curette can be varied according to the size of the patient, but a 5 mm curette works well in most cases. A rotational scooping movement of the curette is effective for harvesting cancellous chips. It is important to avoid penetration of the far cortex during graft procurement. A large amount of cancellous bone can be harvested through a single access hole, although the volume available is frequently underestimated (See Figure 54-6). If a larger opening is needed, the hole should be lengthened along the longitudinal axis of the bone, keeping the corners rounded. Square corners and extension of the access hole perpendicular to the long axis of the bone cause significant mechanical weakening that may predispose inatrogenic fracture of the bone through the graft site.

Graft Application Techniques

Cancellous bone graft material should be protected from dehydration in order to achieve optimal effect. Individual chips

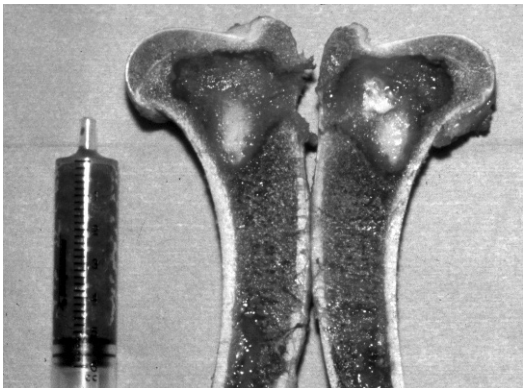


Figure 54-6. Split section of the humerus after collection of a cancellous bone graft from a junior surgery dog. The volume collected is contained within a 6 cc syringe. Note the large amount of cancellous bone that is still available distal to the graft collection site.

can be immersed in patient blood that has been aspirated from the access hole and placed in a small stainless steel cup. Alternatively, graft chips can be placed in a blood soaked sponge until they are applied to the recipient site. Graft chips should never be immersed in saline or disinfectant solutions.

Graft application should be the last thing done prior to soft tissue closure over the repair site. Adequate preparation of the recipient site is very important. The orthopedic repair and all debridement and lavage should be completed prior to graft harvesting and placement. Adequate nutrition to sustain the cancellous graft chips until they are revascularized is most likely to occur when they are applied to viable bone surfaces and immediately covered with viable soft tissues during surgical closure of the wound. When severe soft tissue trauma is present (i.e. shearing wounds), it may be prudent to delay cancellous bone grafting until sufficient wound healing has occurred to provide a supportive environment for the graft.

Graft chips that are about the size of a match head (2 to 3 mm in diameter) provide an ideal surface to volume ratio, thus facilitating nutrition of the graft by diffusion until revascularization takes place. Cancellous bone chips should not be densely packed into a defect as this may impair diffusion. Appropriately applied cancellous autograft chips have been shown to be extensively revascularized by 1 week after implantation.

"Closed" application of cancellous bone graft may be useful when highly comminuted shaft fractures are treated using a non-invasive repair technique such as closed application of an external skeletal fixator. "Closed" cancellous bone grafting involves making a 1 cm long access incision over the middle portion of the fracture region. This will accommodate a modified 3 cc syringe which is used to inject the bone graft material over the area of comminution. The tip of the syringe is cut off, the plunger is pulled back, and chips of cancellous bone graft are loaded into the empty cylinder. The loaded syringe is then inserted through the access incision down to the level of the fracture and graft material is injected. This process can be repeated at different angles to deposit 3 cc aliquots of cancellous bone throughout the area of comminution.

Avoiding Possible Complications of Cancellous Bone Grafting

Complications following cancellous bone grafting in dogs and cats are uncommon. Formation of a seroma or hematoma at the donor site is perhaps the most frequently encountered problem. Both of these events are easily preventable. If persistent hemorrhage is encountered from the access hole, it can be plugged with a piece of absorbable gelatin sponge (Gelfoam). Careful closure of overlying soft tissue layers (especially the deepest layer immediately over the access hole) to obliterate dead space, and proper attention to hemostasis will prevent postoperative seroma formation.

Iatrogenic fracture through the access hole has been reported after cancellous bone graft harvest from the proximal humerus and proximal tibia. Guidelines for avoiding this complication are as follows: 1) Make sure to locate the access hole in the metaphysis rather than in the diaphysis; 2) Make sure to direct the drill bit perpendicular to the cortex rather than obliquely when drilling, so that the access hole will be circular; and 3) If the access hole needs to be enlarged, an increase in its length is less detrimental to bone strength than an increase in width.

Premature closure of open physes and resultant growth deformities have been reported secondary to the harvesting of cancellous bone graft material from longbone metaphyses. In skeletally immature animals (< 13 months old), cancellous bone should be obtained from the wing of the ilium (instead of from the humerus, tibia, or femur) because there is little chance that disturbed growth will result in a major clinical problem at this site.

Infection at the donor site is a potential complication when the surgeon is confronted with an open, contaminated or infected fracture. In this situation, a separate set of sterile, uncontaminated instruments and a new pair of surgical gloves must be used for harvesting the cancellous bone graft. The surgeon must not go back and forth between the donor site and the repair site. The graft material is stored in a cup filled with blood obtained from the access hole or in a blood soaked sponge while the surgeon closes soft tissues over the donor site. The graft is then applied to the fracture region and the repair site is closed.

With proper attention to detail, all of the complications of cancellous bone grafting previously discussed are easily avoidable. In any case in which the use of a cancellous bone graft is anticipated, the surgeon must remember to clip and prepare an appropriate donor site to enable the use of this simple and an extremely valuable technique when needed.

Suggested Readings

Ferguson JF: Fracture of the humerus after cancellous bone graft harvesting in a dog. *J Sm Anim Pract* 37:232, 1996.

Johnson KA: Cancellous bone graft collection from the tibia in dogs. *Vet Surg* 15:334, 1986.

McLaughlin RM, Roush JK: Autogenous cancellous and cortico-cancellous bone grafting. *Vet Medicine* 93:1071, 1998.

Palmisano MP, Schrader SC: Premature closure of the proximal physis of the humerus in a dog as a result of harvesting a cancellous bone graft. *J Am Vet Med Assoc* 215:1460, 1999.

Penwick RC, Mosier DA, Clark DM: Healing of canine autogenous cancellous bone graft donor sites. *Vet Surg* 20:229, 1991.

Slocum B, Slocum TD: Bone graft harvest: Distal femoral condyles. *In Bojrab MJ, ed: Current Techniques in Small Animal Surgery, 4th ed.* Philadelphia: Lippincott Williams & Wilkins, 1998, p. 909.

Stallings JT, Parker RB, Lewis DD, *et al:* A comparison of autogenous cortico-cancellous bone graft obtained from the wing of the ilium with an acetabular reamer to autogenous cancellous bone graft obtained from the proximal humerus in dogs. *Vet Comp Orthop Traumatol* 10:79, 1997.

Trevor PB, *et al:* Evaluation of the proximal portion of the femur as an autogenous cancellous bone donor site in dogs. *Am J Vet Res* 53:1599, 1992.

Wilson JW, Rhinelander FW, Stewart CL: Vascularization of cancellous bone chip grafts. *Am J Vet Res* 46:1691, 1985.

Corticocancellous Bone Graft Harvested from the Wing of the Ilium with an Acetabular Reamer

Colin W. Sereda and Daniel D. Lewis

Introduction

A large volume of corticocancellous bone graft may be readily obtained from the wing of the ilium using a powered acetabular reamer. Although graft incorporation is slower and less uniform when compared to similar volumes of cancellous bone graft, the corticocancellous bone grafting technique is advantageous because it yields a greater volume of graft, offers a more proximate location of the harvest site when performing procedures involving the hind limb, and produces graft with a consistency that is favorable for packing into bone defects, resulting in an intimate association with the recipient bed.

Surgical Procedure

The patient is placed in lateral recumbency. An area extending approximately 5 cm cranial to the wing of the ilium to 3 cm caudal to the greater trochanter, and from dorsal to the wing of the contralateral ilium to 5 cm ventral to the ilial body is clipped, aseptically prepared and draped for surgery.

The skin incision begins craniodorsal to the iliac spine and is continued caudally, paramidline to the level of the middle of the body of the ilium. Subcutaneous tissues and the deep gluteal fascia are incised along the same line as the skin incision, exposing the tuber sacrale. The origin of the middle gluteal muscle on the dorsal ilium is incised, allowing subperiosteal elevation of the middle gluteal muscle. Elevation is continued caudally to the level of the caudal dorsal iliac spine, but should not be continued beyond this point in order to preserve the cranial gluteal vein, artery, and nerve. Elevating the middle gluteal muscle off of the cranial aspect of the wing of the ilium improves exposure. Exposure is maintained by placing one or two Hohmann retractors from dorsal

to ventral to expose the wing of the ilium. Gelpi retractors can also be placed to facilitate esposure.

An acetabular reamer (20 or 23 mm for small dogs, 26 or 29 mm for medium-sized dogs, and 29 or 32 mm for large dogs) attached to a low speed, high torque drill is used for harvesting the graft. Reaming is initiated on the lateral ilium immediately caudal to the iliac crest. It is continued caudally, removing the lateral cortex and cancellous bone while leaving the medial cortex and dorsal edge of the ilium intact. Reaming is carried as far caudally as is feasible, creating an oval-shaped defect (Figure 54-7). When the cup of the reamer is full, it is detached from the extension and the graft is removed to be stored in a sterile receptacle until required. Switching to a smaller diameter reamer generally allows the surgeon to extend reaming down the body of the ilium. Care must be taken to avoid penetrating the medial cortex of the ilium with the reamer. When the reaming is completed, additional exposed cancellous bone along the periphery of the defect can be harvested with a bone curette.

The donor site is thoroughly lavaged with sterile saline. A splash block of local anesthetic may be administered prior to closure to decrease postoperative discomfort. Closure is performed in multiple layers to decrease the risk of postoperative seroma formation. The superficial fascia of the middle gluteal muscle is apposed to its periosteal insertion or to the superficial fasia of the sacrospinalis muscle with a series of horizontal mattress sutures. The gluteal fascia, subcutaneous tissues, and skin are closed routinely.

The harvested graft has a paste-like consistency, which facilitates packing the graft into bone defects and results in intimate contact with the recipient bed.

Postoperative Considerations

The cortiocancellous graft appears more radiodense than a cancellous graft on immediate postoperative radiographs because of the graft's cortical component. Morbidity associated with ilial corticocancellous graft harvest is minimal; however, transient, self-limiting hind limb lameness and seroma formation may occur. Restricted postoperative activity is therefore recommended.

Suggested Readings

Culvenor JA, Parker RB: Collection of cortico-cancellous bone graft from the ilium of the dog using an acteabular reamer. J Small Anim Pract 37:513, 1996.

Piermattei DL, Johnson KA: An atlas of surgical approaches to the bones and joints of the dog and cat, 4th ed. Philadelphia: W.B. Saunders, 2004, 278.

Stallings JT, Parker RB, Lewis DD, et al.: A comparison of autogenous cortico-cancellous bone graft obtained from the wing of the ilium with an acetabular reamer to autogenous cancellous bone graft obtained from the proximal humerus in dogs. Vet Comp Orthop Traumatol 10:79, 1997.

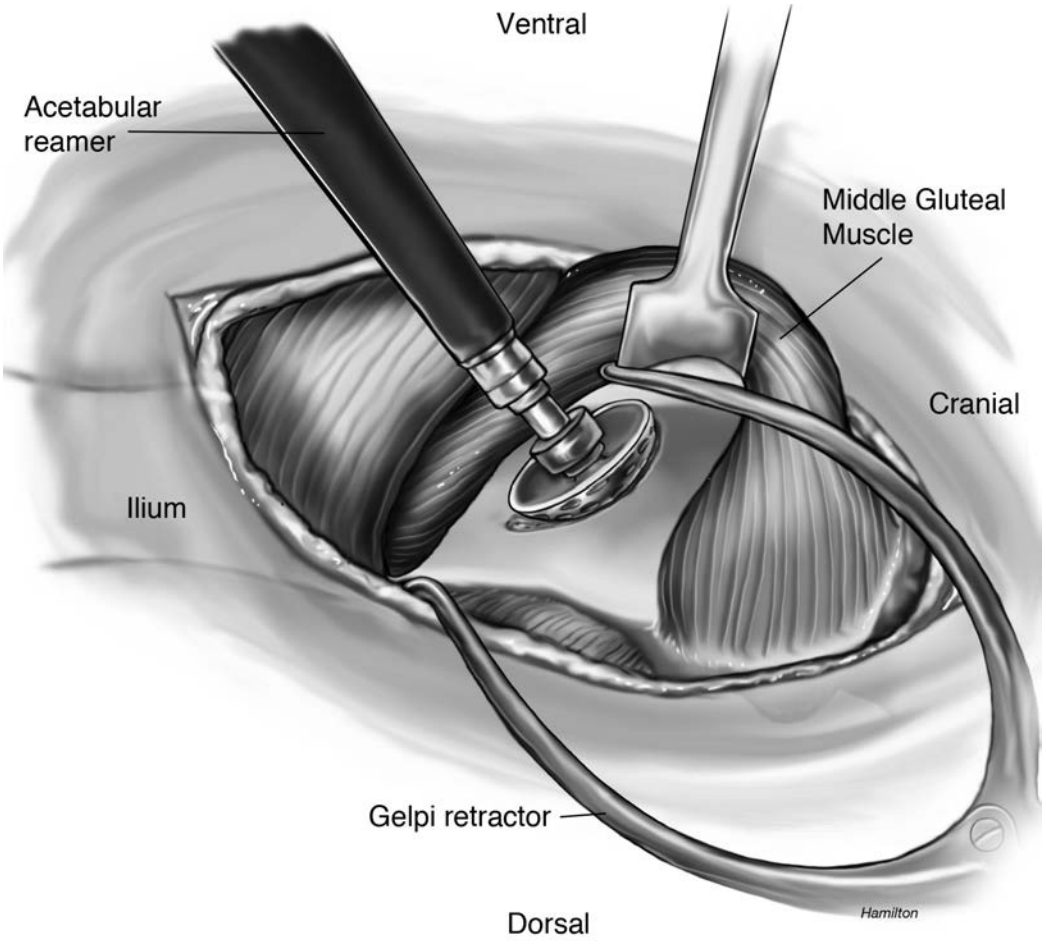


Figure 54-7. Self-retaining retractors are used to increase exposure of the lateral aspect of the wing of the ilium. Reaming begins immediately caudal to the iliac crest and is continued caudally as far as is reasonably possible. The lateral cortical and inner cancellous bone is removed.

Harvesting, Storage and Application of Cortical Allografts

Kenneth R. Sinibaldi

Introduction

Cortical allografts have been used to enhance repair of long bone fractures in veterinary surgery for several decades.[1-4] An allograft is bone transferred from one individual to another individual of the same species. This type of graft elicits an immune response because of foreign cellular antigens of the allograft and the reaction of the host immune system. Fresh-frozen processed cortical allografts are the most commonly used cortical grafts in veterinary orthopedic surgery. Allografts are also considered alloimplants because they are a nonviable material (dead bone), and by definition, the term implant refers to any nonviable material placed in the body.

An autogenous allograft (autograft) is bone transferred from a donor site to a recipient site in the same individual. There are definite disadvantages to this type of graft. Sufficient bone is often not available, morbidity at the donor site is a concern, increased anesthetic and surgery time, and increased risk of infection. Fresh frozen allograft is preferred for convenience of storage, and reduction of disease and immunogenicity.[5-9]

Frozen allografts provide structural (mechanical), osteoconductive, and osteoinductive support to fracture repair.[10] Other methods of processing bone allografts include cryopreservation, freeze-drying (lypholized) and demineralized preparation. The processing of bone grafts by these methods is more involved technically and are not practical for the veterinary surgeon in practice. Inconvience of allograft harvesting, processing, storage, and quality assurance have limited their use.[11]

Harvesting of Allografts

Harvesting of allografts is practical for the veterinary surgeon and requires adherence to strict asepsis, preparation and time. The procurement of cortical allografts begins with proper donor selection. Donors should be mature, healthy animals, preferably between the 1.5 to 8 years of age, with no preexisting neoplastic, metabolic, bacterial, or viral diseases. A complete physical examination and review of history are essential. Current vaccinations and blood screening for transmissible diseases should be performed. Immature donors have bones that may be brittle and less developed than older donors, and this factor may cause problems during implantation with stability (screw purchase).

Allografts can be harvested from dead donors and then sterilized with ethylene oxide. Although ethylene oxide is considered a superior sterilizing agent for surface contamination, but low residual levels may be toxic to recipient tissue and could interfere with healing. It may also affect the mechanical strength and incorporation of cortical allografts.[12,13] Freshly harvested cortical allografts are preferred.

Absolute aseptic surgical technique is required. All donors should be prepared as for any standard surgical orthopedic procedure, with proper aseptic scrubbing and draping. Donors are placed under general anesthesia, and standard approaches to the long bones are used. The bone should be exposed from metaphysis to metaphysis by removing as much soft tissues (muscle and periosteum) as possible. An oscillating bone saw is used to cut the bone. This saw should be cooled with liquid during cutting. After the bone is removed, it is placed in a solution of lactated Ringer's or saline. This is temporary before final preparation of the graft. Once all the donor graft has been harvested, euthanasia is performed on the donor.

The grafts are then stripped of all remaining soft tissue attachments, and the medullary contents are removed. A sharp periosteal elevator or scalpel blade works best for stripping, whereas a bone curette works best for removal of medullary contents. The medullary cavity should be flushed out with sterile lactated Ringer's or saline solution. Once the graft is clean, it can be cut into proximal, middle, and distal thirds, halved or maintained in its full length. The graft's medullary cavity is cultured for aerobic and anaerobic organisms. The graft is placed in a suitable glass jar that has been previously autoclaved. Each jar with the graft should be marked, indicating left or right, with the name of the bone, segment of bone, date of harvesting, and donor identification. The jar and graft are then immediately placed in a household freezer at a temperature of -20° C. Any temperature warmer than this leads to improper freezing and possible autolysis. The American Association of Tissue Banks allows 6 months storage at -20° C and recommends -40° C for longer-term storage (up to 5 years); -70° C is preferred.[11] The colder temperatures inhibit molecular translations that result in degradation. The author has not had any problems safely storing bone grafts at -20° C for 1 year. Only grafts that culture negative are placed in the bone bank.

The most common indication for use of cortical allografts is replacement of bone in patients with highly comminuted fractures. Other indications are correction of nonunions, delayed unions, and mal-unions with or without bone loss, bone lengthening, limb-sparing procedures for bone tumors, and, in selected cases, osteomyelitis with bone loss due to sequestrum formation.[14] This last indication should be considered a salvage procedure if amputation is not an option. In preparation for surgical implantation of an allograft, radiographs of the opposite limb should be made, and bone length measured. An estimate of the graft length needed is made by comparing the intact cortical segments on the lateral projection of the affected limb and subtracting this from the total length of the normal bone. (Figure 54-8). A graft is then selected based on this estimate as well as by visually comparing the width of the host and graft bone. Usually, the femur is used to replace a segment of femur, however the use of other long bones should not be discouraged because the width of other bones may be adequate if a near perfect match cannot be made with similar bones.

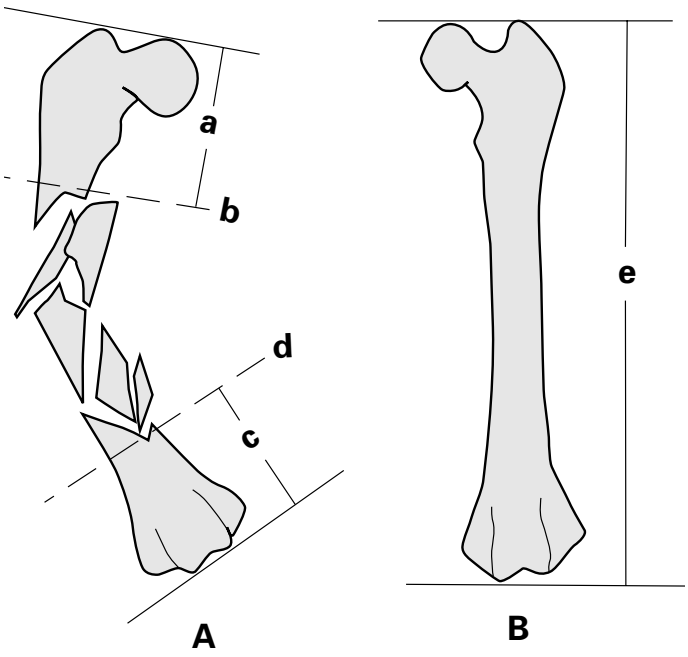


Figure 54-8. Estimate of allograft length is made by measuring the proximal bone segment *(a)* with the planned osteotomy cut *(b)* and the distal bone segment *(c)* with the planned osteotomy cut *(d)* and subtracting the total of these from the length of the normal opposite femur *(e)*. Fractured femur **A.** Opposite normal femur **B.**

Surgical Application

Prior to surgery a proper allograft is selected based on previous radiographic planning, visual observation and comparison of available allografts. It is prudent to select an allograft that is slightly longer then is required should adjustment be needed during surgery. Most importantly, the diameter of the allograft bone should be as close as possible to the host bone. Prophylactic antibiotics are administered at the time of anesthesia, during the operation and postoperatively. An appropriate cancellous bone graft site is prepared. The addition of cancellous bone at the host-graft site increases the success of the procedure.[7] Before the surgical procedure, the cortical allograft is allowed to thaw in a sterile bowl of lactated Ringer's solution or normal saline solution. The patient is aseptically prepped, draped and strict surgical technique followed. If a large number of bone segments are to be removed, the surgeon must have a point of reference proximally and distally to maintain proper alignment with respect to rotation, varus and valgus. This is best done with small Kirshner wires placed parallel to each other, one in the proximal fracture segment and one in the distal segment. The fracture is exposed, and the comminuted fragments are removed. The fractured bone ends, proximally and distally are cut with a bone saw perpendicular to the long axis of the bone in preparation for the cortical allograft. The allograft is cut to the proper size; the surgeon must ensure that it is perpendicular to the long axis of the graft. This cut should allow 360° of cortical contact ideally, and not less than 50% contact at the host-graft interface. In some cases of delayed union, malunion, and nonunion, the callous formation may be larger than the allograft or cut surface. This is not of concern and can serve as a ridge for autogenous cancellous bone to be placed on to augment grafting. A dynamic compression plate is selected to allow for a minimum of five cortices (three screws) above and below the allograft. Standard ASIF plating technique is used. The plate is contoured to both the host bone and allograft. An alternate technique is to contour the plate preoperatively from the radiograph of the normal intact bone and make adjustments at the time of surgery. The plate is first applied to the allograft with a minimum of two screws (four cortices) in a neutral position. The allograft is aligned to the host bone to ensure as close to 360° of cortical contact as possible. This is not always possible, but the closer to 360° the better the stability. Care should be taken to test the reduction at both ends of the allograft before completing screw fixation of the plate. Alignment should be observed and rotation, varus and valgus corrected. The preplaced Kirschner wires and temporary cerclage wires or bone clamps aid in proper positioning. If any correction is needed the plate can be removed and the allograft cut for correction. If the correction causes the total bone length to be shorter, a new allograft should be used. Depending on the bone, most patients can tolerate shortening of 2 to 3 cm in the limb without an impact on function. The screw holes above and below the allograft are placed in the loaded position. This maneuver results in compression at the host-graft interfaces. The remaining screws are placed in a neutral position. The entire surgical site is flushed with lactated Ringer's solution before placing an autogenous cancellous bone graft around the host-graft interfaces. Commercially prepared cancellous bone chips or cancellous bone chips and demineralized powder can also be used (Veterinary Transplant Services, Seattle, WA). The surgical site is cultured for aerobic and anaerobic organisms before routine closure.

Postoperative Care

Postoperative care consists of an appropriate coaptation with a modified Robert Jones dressing or padded bandage, depending on the long bone repaired, for 2 to 3 weeks. Activity should be restricted to leash only walks and cage or kennel confinement during this time period. Antibiotics are administered for 2 weeks postoperatively and are adjusted or discontinued based on the culture results. Radiographs are taken at 3 to 4 week intervals, to follow healing and implant stability for the first 3 months followed by radiographic exam every 6 to 12 months thereafter. Plate removal should only be considered in young patients or in those patients with allografts less than 3cm and only after 2 years post surgery. Plate removal is "staged" with 3 to 6 months between surgeries.

Bone Healing

Cortical allografts heal by proceeding through phases of inflammation, revascularization, osteoinduction, osteoconduction and remodeling. This process takes much longer due to the dense structure of cortical bone.[15] Cortical allograft incorporation differs from autogenous cancellous bone in that initial repair is due to osteoclastic rather than osteoblastic activity.[16] Resorption occurs rapidly shortly after transplantation and gradually declines to normal levels within a year.[16] Resorption of the graft and replacement by host bone begin at the host-graft interface and move toward the center of the graft, with marked proliferation of periosteal and endosteal bone covering

the graft surfaces.[7] This process can take years depending on the length of the graft. Biopsy specimens taken at various levels of long allografts at 45.5 months[7] and 92 months[14] after implantation showed graft bone still present. As this process continues, mechanical strength is added to the graft. Predominately at the center portion of the allograft with live bone present in the external and internal circumferential lamella.14 The presence of dead bone matrix from the graft interspersed with interstitial lamellar and host osteons affords strength to the bone.[16]

Cortical allografts provide osteoconductive, osteoinductive and mechanical support in the repair of long bone fractures. Success has been reported to be over 80%.[7] Outcome is dependent on case selection, degree of trauma, soft tissue damage, coexisting injuries and adherence to strict surgical asepsis and technique. Decreased surgical time, stability of the fracture repair, and rapid return to function are definite benefits. Harvesting of bone, aseptic technique, and bone plating principles may be a limitation, depending on training and surgical experience. The added cost of proper surgical equipment and time spent setting up the bone bank are also possible limitations. As a general rule, infected or open fractures and metaphyseal fractures that do not allow proper screw purchase are not indications for cortical allografts.

References

1. Fox S: Cancellous bone grafting in the dog: An overview. *J Am Anim Hosp Assoc* 20:840, 1984.

2. Hulse D: Pathophysiology of autogenous cancellous bone grafts. *Compendium Continuing Education Pract Vet* 2(2): 136, 1980.

3. Johnson A: Principles of bone grafting. *Seminars Vet Med Surg* (Small Animal) 6(1): 90, 1991.

4. Olds R, Sinibaldi K, DeAngelis M, et al: Autogenous cancellous bone grafting in small animals. JAAHA 9:454, 1973.

5. Johnson AL: Principles and practical applications of cortical bone grafting techniques. Compendium Contin. Educ Pract Vet 10(8): 906,1988.

6. Schena C, McCurnin D: The use of fresh cortical and cancellous allografts in the repair of a fractured femur in a dog: A case report. *J Am Anim Hosp Assoc* 19:352,1983.

7. Sinibaldi K: Evaluation of full cortical allografts in 25 dogs. *J Am Vet Med Assoc* 194(11):1570, 1989.

8. Henry W, Wadsworth P: Diaphyseal allografts in the repair of long bone fractures. *J Am Anim Hosp Assoc* 17:535, 1981.

9. Aaron A, Wiedel J: Allograft use in orthopedic surgery. *Orthopedics* 17(1):41, 1994.

10. Burchardt H: The biology of bone graft repair. *Clinical Orthopedics* 174:28,1983.

11. Fitch R, Kerwin S, Newman-Gage H, Sinibaldi K: Bone autografts and allografts in dogs. *Compendium Continu Educ Pract Vet* 19(5)558,1997.

12. Arizono T, Iwanoto Y, Okuyama K, Sugioka Y: Ethylene oxide sterilization of bone grafts: Residual gas concentration and fibroblast toxicity. *Acta Orthop Scand* 65(6):640,1994.

13. Wagner S, Manley P, et al: Failure of ethylene oxide-sterilized cortical allografts in two dogs. *J Am Anim Hosp Assoc* 30:181, 1994.

14. Sinibaldi KR, unpublished data.

15. Burchardt H, Enneking WF: Transplantation of bone. *Surg Clin North Am.* 58:403, 1978.

16. Enneking WF, et al. Physical and biological aspects of repair in dog cortical bone transplants. *J Bone Joint Surg* (Am) 57:237, 1975.

Distraction Osteogenesis as an Alternative to Bone Grafting

Nicole Ehrhart

Introduction

Distraction osteogenesis is a technique capable of generating large amounts of bone by gradual distraction of osteotomized bone ends. This method is now widely accepted for the treatment of shortened limbs, bony defects from tumor or trauma and angular limb deformity.[18] The technique is most commonly performed using circular external fixator systems and tensioned fine wires, a method introduced and refined by Ilizarov.[18]

Historical Perspectives

Gavril A. Ilizarov was a physician with no formal orthopedic training who practiced in a small industrial town in Western Siberia after World War II. Antibiotics were scarce and chronic osteomyelitis and non-unions were common post-war injuries among the population of patients he cared for. As a result, he found himself practicing orthopedics in his general practice in an isolated area of the world without access to any of the technological and medical advances that took place during the post-World War II era. He devised an innovative external fixator system comprised of modular rings and trans-osseous wires attached to the rings under tension to stabilize bone fragments. The phenomenon of distraction osteogenesis was discovered incidentally, when Ilizarov applied a fixator designed to create gradual compression of the fracture ends to a patient with an infected non-union. He instructed the patient to adjust specialized nuts on the frame several times daily in order to achieve compression at the fracture site. Instead, the patient mistakenly turned the nuts in the wrong direction, thereby lengthening the frame and creating distraction at the fracture site (Figure 54-9). Ilizarov observed significant new bone formation in the distraction gap and simultaneous resolution of the infection. He applied this technique successfully to some of the most challenging conditions in orthopedic surgery.[16,17] The reconstruction of bones affected by post-traumatic conditions, such as intercalary defects, shortening and deformity was the most common application of his method. In 1984, an Italian

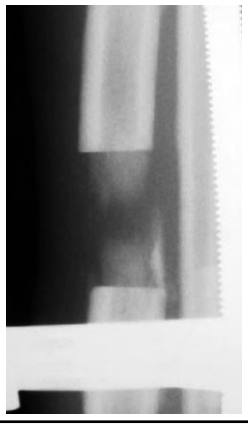


Figure 54-9. Distraction osteogenesis. Note the regenerate bone formation between the two osteotomized bone surfaces.

veterinarian by the name of Dr. Antionio Ferretti, began using the Ilizarov methods in veterinary patients. The use of circular fixation and distraction osteogenesis began to appear in North American veterinary literature in the early 1990s.[24] Currently, IMEX Veterinary (Longview, TX) manufactures a circular external fixator system that has lightweight design elements suitable for veterinary patients (Figure 54-10). Other circular external fixation systems are also available in North America and Europe.

Bone transport osteogenesis is a modification of the original distraction osteogenesis technique, involving the transport of a bone fragment across a bony defect with distraction osteogenesis occurring in the trailing pathway of movement (Figure 54-11). The bone fragment eventually contacts the opposite end of the defect, and is compressed to the adjacent bone in its new position, resulting in union between the bone fragment and the parent bone. The new bone that forms in the distraction pathway rapidly remodels into lamellar bone, thereby filling in the segmental defect. This method was used by Ilizarov to salvage many limbs that otherwise would have been amputated because of non-union, osteomyelitis or extensive segmental bone loss.[18] Bone transport osteogenesis is also used in veterinary patients for limb salvage following segmental bone loss due to trauma or tumor excision.[11,12]



Figure 54-10. Circular fixator on a canine patient.

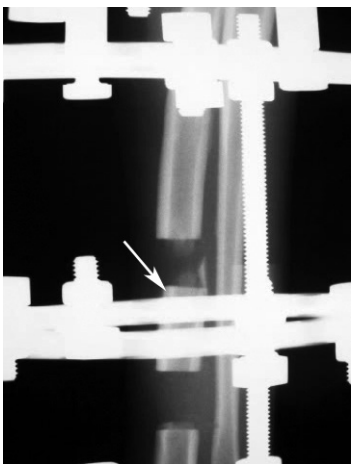


Figure 54-11. Bone transport osteogenesis 14 days following the start of distraction. Note the wisps of new bone forming between the transported bone segment *(arrow)* and the parent bone.

Histomorphology of Distraction Osteogenesis

Distraction osteogenesis requires prolonged and gradual distraction of two freshly osteotomized bone ends (See Figure 54-9). The new bone by distraction osteogenesis or bone transport osteogenesis is termed **regenerate bone**. The process of new bone formation is often called **osteoneogenesis**. The biology of distraction osteogenesis has been extensively studied.[1,4,6-8,10,21] The results of these investigations have greatly expanded the understanding of the histological, biochemical, vascular, radiographic, and mechanical properties of regenerate bone formation. Ilizarov mistakenly assumed that distraction osteogenesis recapitulated endochondral bone formation. This belief was generated by the radiographic observation that a radiolucent zone consistently occurred in the center of the regenerate bone **(radiolucent central zone)** until distraction was completed, similar to a growth plate which remains radiolucent until growth is completed. More recent studies have shown that bone formation during distraction osteogenesis results from both intramembranous and endochondral ossification, with intramembranous bone formation predominating at a ratio of 5:1.[14] The radiolucent central zone is comprised of Type I collagen columns adjacent to a zone of newly formed vessels. This vasculature delivers proliferating and differentiating osteoblasts which migrate along the collagen columns and deposit osteoid. These collagen columns are formed in parallel and along the lines of distraction tension. Each of these osteoid-covered, longitudinal columns of collagen begins to mineralize starting from either end of the gap and progressing toward the central radiolucent zone. The mineralizing new bone columns resemble stalagmites and stalactites projecting from each osteotomy surface on radiographs. Each bone column expands transversely as more collagen fibers are incorporated circumferentially and mineralized until they reach a maximum diameter of 150 to 200 microns. The space between the bone columns consists of large, thin-walled vessels.[2,3,9,10,14] Once distraction is completed, the bone columns begin to bridge the peripheral aspect of the radiolucent central zone. Columns of mineralizing new bone then rapidly bridge the entire central radiolucent zone and are eventually interconnected transversely by woven bone plates forming a honeycomb-like pattern. Once bridging occurs, rapid secondary remodeling of the cortices ensues and the Haversian system is re-established. This remodeling process occurs much more rapidly than with classical fracture healing; partly because the collagen fibers are more orderly and aligned at the start of mineralization and therefore tend to remodel in a manner parallel with the long axis of the bone. In addition, the mechanical strain environment created in the distraction gap seems to promote robust angiogenesis, massive osteoblast recruitment and rapid production of osteoid.[13,14]

Technique

Clinical Factors Influencing Distraction Osteogenesis

The environment created during distraction osteogenesis is not identical to the environment seen during fracture healing. The optimal mechanical environment in which bone formation occurs clinically has not been fully determined. Several unique factors are known to influence regenerate bone formation. These include: frame type, osteotomy technique, delay interval between surgery and distraction **(latency period)**, the total distance moved per day **(distraction rate)**, and the number of increments used to achieve the total distance moved per day (rhythm).

Frame Type

Although Ilizarov attributed special biological effects to the use of ring fixators, distraction osteogenesis can also be achieved using linear fixators or hybrid frames. The two major advantages of using circular external fixation systems are 1) the axial micromotion that occurs under compressive loads with fine wire fixation and 2) the versatility of fixator components and spatial configurations possible with circular frames that allow precise movement of bone fragments while not compromising overall frame stability. Fine wire fixation exhibits nonlinear biomechanical behavior. Specifically, controlled micromotion of the bone segments occurs during weight-bearing yet stiffness in bending and torsion similar is maintained in a manner similar or superior to conventional linear fixators. Controlled axial micromotion is thought to be beneficial to bone formation.[5,21,22]

Ring diameter, wire tension, bone position within the frame and number of rings and wires per bone segment affect overall frame stability. Clinicians should be familiar with the biomechanical characteristics of circular fixator frames and the principles of Ilizarov to achieve ideal stability when designing and positioning the frame for a particular patient.[19,20,23]

Osteotomy Technique

Ilizarov considered the preservation of the meduallary vascular system and periosteum to be essential for bone distraction osteogenesis. His original technique involved carefully cutting the cortex with an osteotome while preserving the periosteal sleeve, a procedure he termed ***corticotomy***.[18,23] Since that time however, results of animal studies have shown that the quality and quantity of bone formed during distraction osteogenesis following an osteotomy created with an oscillating saw, osteotome or corticotomy is similar.[15] No advantage has been seen with the corticotomy technique over the more standard osteotomy techniques. An important point to remember, however, is to avoid thermal damage to the bone. If an oscillating saw is used to create the osteotomy prior to distraction or bone transport osteogenesis, copious lavage with cool saline is required.

Latency Period

Latency refers to the amount of time between creation of the osteotomy and commencement of distraction. This period of time is important for the formation of a soft callous. Several factors influence the choice of latency period including the degree of trauma to the soft tissue envelope, age of the patient, location of the osteotomy (metaphyseal versus diaphyseal), and patient-related co-morbidity issues. In dogs, suggested latency periods range from 2 to 7 days.[23] In a healthy patient, the author typically uses a 3 day latency period unless there are significant co-morbidity factors. Co-morbidity factors include advanced patient age, soft tissue trauma or loss, or other conditions that would delay healing such as concurrent use of chemotherapy or diabetes, etc. When these conditions are present, the latency period may be lengthened. Too long a latency period will result in premature healing requiring re-fracture.

Distraction Rate

A rate of 1mm of distraction per day is the most common distraction rate used in veterinary medicine for linear distraction. Choice of distraction rate depends upon many of the same factors that influence latency period. Distraction can be performed more rapidly in young animals, sometimes up to 4 mm per day. In dogs, mineralized bone is usually visible within the distraction gap on radiographs by day 14 to 21 of distraction. It is important to monitor the appearance of the regenerate bone on radiographs during distraction because the distraction rate may need to be adjusted during distraction. Radiographic evaluation of the regenerate bone is recommended every 7 to 10 days. If the regenerate bone begins to take on a thinning, ductile shape resembling an hourglass or the radiolucent central zone begins to progressively widen, the distraction rate may need to be decreased. Alternatively, if the wires nearest the distraction gap begin to bend toward the distraction gap and the central radiolucent zone begins to disappear, the distraction rate may need to be increased to avoid premature consolidation.[11]

Distraction Rhythm

The rhythm of distraction refers to the number of incremental lengthenings performed per 24 hour period to achieve the desired rate of distraction. The recommended rhythm for dogs ranges from 2 to 4. This means that the total amount of distraction achieved during any given 24 hour time period should be divided into 2 to 4 increments. The author recommends a distraction rhythm of 4.[11] This is easy for clients to do because the nuts used to perform distraction on the IMEX veterinary circular fixator system have four faces. The owner can be instructed to turn the nuts one face four times daily. The pitch of the all-thread rods used in the same fixator system is 1 mm. Therefore, one complete revolution of the distraction nuts will move the distraction wires 1 mm. Studies performed in goats have shown that increasing the number of increments up to 270 per day using an automated distractor system did not seem to have an advantage.[21] In the author's experience, diminishing the distraction rhythm to less than 3 or 4 tends to be associated with more soft tissue complications such as inflammation and tendon contracture. It is likely that the ideal distraction rhythm varies from patient to patient and is probably influenced by similar factors as rate and latency.

Consolidation Period

Once distraction is discontinued, the consolidation period begins. Consolidation involves rapid mineralization of the radiolucent central zone and remodeling of the regenerate bone. The new cortices become organized and marrow elements begin to reform. Consolidation will be delayed if the patient is not weight-bearing. There are likely many other factors that influence consolidation such as biomechanical properties of the fixator, anatomic location etc., but these factors are less well understood. Clinicians must use radiographic evaluation to decide when to remove the fixator. If mineralization and cross-sectional area of the regenerate are similar to the parent bone, it is typically safe to remove the fixator. Certain frame designs allow for progressive destabilization which may allow for a more rapid gain in stiffness. There is no exact formula for deciding when the fixator should be removed, but the more bone created by distraction osteogenesis, the longer consolidation will take to complete. A very rough rule of thumb is that the fixator should remain in place for 50% to 100% of the time needed to achieve the desired amount of new bone.

Regenerate Bone as a Bone Graft Alternative

The use of regenerate bone as a bone grafting alternative is less familiar to many surgeons and initially more technically complex. Distraction osteogenesis may not be the first option of choice in patients where standard autogeneous or allogeneic graft material is suitable. However, there are unique advantages to regenerate bone as a means to fill a defect or create a bony union, particularly in situations where infection is established or likely. Because regenerate is autogenous and its formation is associated with an immediate, robust blood supply, it can be used in situations when cortical allograft would be contraindicated. In human trauma, distraction osteogenesis is most commonly used for severe soft tissue and bone loss following extremity shear injuries, such as those sustained in motorcycle accidents. Because this method of reconstruction does not require internal fixation, such as with cortical allografts, surgeons can begin bony repair prior to establishment of a healthy soft tissue envelope. Other unique uses include chronic osteomyelitic non-unions. In these patients, distraction osteogenesis is used to achieve union, but also as a means to resolve the infection and replace resorbed bone. Ilizarov was the first to note the remarkable ability of distraction osteogenesis to treat osteomylelitis without the aid of antibiotics in his patients. His phrase for this observation was that distraction osteogenesis "burned the infection in the flame of the regenerate", referring to the effect of angiogenesis and subsequent arrival of immune cells that successfully eradicated infection.

Theoretically, distraction osteogenesis can create limitless quantities of bone. This is in contrast to large-segment cadaveric bone allografts, where supply is often limited and procurement and storage is expensive; and to cortical autograft, where donor site morbidity limits the anatomic location and amount of bone available. In addition, the use of autogeneous tissue eliminates the risk of disease transmission from donor to recipient, a significant concern in human medicine.

Future Directions

To date, the major limitations to the use of distraction osteogenesis as an alternative to bone grafting in veterinary medicine have been the relatively lengthy period of time required to reconstruct large defects and the small number of veterinary surgeons comfortable with the technique. Circular and hybrid fixators have recently become more "main stream" as veterinarians become familiar with their versatility. Research is ongoing to understand more about the biology of osteogenesis, thereby allowing clinicians to manipulate the distraction osteogenesis process using novel growth factors and gene therapies to create bone more rapidly. Double level distraction osteogenesis has been described in veterinary patients to diminish the time needed to reconstruct large diaphyseal defects. Newer hybrid fixator designs and components allow distraction in more than one anatomic plane at a time and, as clinical experience accumulates, surgeons will become more comfortable with case selection and management. Clinical applications for distraction osteogenesis are likely to expand, but will probably be used as a solution in the more challenging orthopedic situations, rather than in cases where simple grafting is routinely successful.

References

1. Aronson, J. Experimental and clinical experience with distraction osteogenesis. Cleft Palate Craniofac. J. 31: 473-481, 1994.
2. Aronson, J. Temporal and spatial increases in blood flow during distraction osteogenesis. Clin. Orthop. Relat Res. 124-131, 1994.
3. Aronson, J., Good, B., Stewart, C., Harrison, B., Harp, J. Preliminary studies of mineralization during distraction osteogenesis. Clin. Orthop. Relat Res. 43-49, 1990.
4. Aronson, J., Harp, J. H. Mechanical forces as predictors of healing during tibial lengthening by distraction osteogenesis. Clin. Orthop. Relat Res. 73-79, 1994.
5. Aronson, J., Harp, J. H., Jr. Factors influencing the choice of external fixation for distraction osteogenesis. Instr. Course Lect. 39: 175-183, 1990.
6. Aronson, J., Harrison, B. H., Stewart, C. L., Harp, J. H., Jr. The histology of distraction osteogenesis using different external fixators. Clin. Orthop. Relat Res. 106-116, 1989.
7. Aronson, J., Johnson, E., Harp, J. H. Local bone transportation for treatment of intercalary defects by the Ilizarov technique. Biomechanical and clinical considerations. Clin. Orthop. Relat Res. 71-79, 1989.
8. Aronson, J., Shen, X. Experimental healing of distraction osteogenesis comparing metaphyseal with diaphyseal sites. Clin. Orthop. Relat Res. 25-30, 1994.
9. Aronson, J., Shen, X. C., Gao, G. G. et al. Sustained proliferation accompanies distraction osteogenesis in the rat. J. Orthop. Res. 15: 563-569, 1997.
10. Aronson, J., Shen, X. C., Skinner, R. A., Hogue, W. R., Badger, T. M., Lumpkin, C. K., Jr. Rat model of distraction osteogenesis. J. Orthop. Res. 15: 221-226, 1997.
11. Ehrhart, N. Longitudinal bone transport for treatment of primary bone tumors in dogs: technique description and outcome in 9 dogs. Vet. Surg. 34: 24-34, 2005.
12. Ehrhart, N., Eurell, J. A., Tommasini, M., Constable, P. D., Johnson, A. L., Feretti, A. Effect of cisplatin on bone transport osteogenesis in dogs. Am. J. Vet. Res. 63: 703-711, 2002.
13. Fink, B., Krieger, M., Strauss, J. M. et al. Osteoneogenesis and its influencing factors during treatment with the Ilizarov method. Clin. Orthop. Relat Res. 261-272, 1996.

14. Fink, B., Pollnau, C., Vogel, M., Skripitz, R., Enderle, A. Histomorphometry of distraction osteogenesis during experimental tibial lengthening. J. Orthop. Trauma 17: 113-118, 2003.
15. Frierson, M., Ibrahim, K., Boles, M., Bote, H., Ganey, T. Distraction osteogenesis. A comparison of corticotomy techniques. Clin. Orthop. Relat Res. 19-24, 1994.
16. Ilizarov, G. A. The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. Clin. Orthop. 249-281, 1989.
17. Ilizarov, G. A. The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. Clin. Orthop. 263-285, 1989.
18. Ilizarov, G. A. The principles of the Ilizarov method. 1988. Bull. Hosp. Jt. Dis. 56: 49-53, 1997.
19. Lewis, D. D., Bronson, D. G., Cross, A. R., Welch, R. D., Kubilis, P. S. Axial characteristics of circular external skeletal fixator single ring constructs. Vet. Surg. 30: 386-394, 2001.
20. Lewis, D. D., Cross, A. R., Carmichael, S., Anderson, M. A. Recent advances in external skeletal fixation. J. Small Anim Pract. 42: 103-112, 2001.
21. Welch, R. D., Birch, J. G., Makarov, M. R., Samchukov, M. L. Histomorphometry of distraction osteogenesis in a caprine tibial lengthening model. J. Bone Miner. Res. 13: 1-9, 1998.
22. Welch, R. D., Lewis, D. D. Distraction osteogenesis. Vet. Clin. North Am. Small Anim Pract. 29: 1187-viii, 1999.
23. Welch, R. D., Lewis, D. D. Distraction osteogenesis. Vet. Clin. North Am. Small Anim Pract. 29: 1187-viii, 1999.
24. Yanoff, S. R., Hulse, D. A., Palmer, R. H., Herron, M. R. Distraction osteogenesis using modified external fixation devices in five dogs. Vet. Surg. 21: 480-487, 1992.

Section M

Appendicular Skeleton – Thoracic Limb

Chapter 55

Scapula and Shoulder Joint

Repair of Scapular Fractures

Randy Willer and Jennifer Fick

The scapula is a large, flat bone of the shoulder which serves as support for the thoracic limb and is attached to the trunk by several large muscle masses. The scapula is located adjacent to the chest wall with extensive muscle mass surrounding it, a configuration that helps to prevent the occurrence of fractures. In one study, the incidence of scapular fractures was reported to be 2.4% of fracture cases treated, with most resulting from vehicular trauma.[1] A retrospective study in 105 cases revealed most scapular fractures occur in young (<4 years of age), male, medium-large (>10kg) dogs.[2] Because of the increased forces necessary to create such a fracture in this location, a thorough physical, neurologic, and orthopedic exam is necessary to detect other possible concurrent problems such as spinal, skull, brachial plexus injuries, and other musculoskeletal injuries which may influence prognosis. In patients with scapular fractures, approximately two-thirds have concurrent thoracic cavity lesions which include pneumothorax, pneumomediastinum, pulmonary contusions, cardiac arrhythmias, and fractured ribs.[1] Prognosis and treatment options depend on the anatomic location of the fracture which are classified as the body, spine, acromion, neck, supraglenoid tubercle and glenoid of the scapula.[1,3]

Diagnosis and Clinical History

Clinical signs on presentation of a scapular fracture vary depending on the location and the severity of the fracture. Signs range from a mild weight bearing lameness to a severely dysfunctional non-weight bearing lameness of the limb. The latter is usually associated with intra-articular fractures of the glenoid and neck fractures that cause the animal to carry the injured leg lower than the opposite limb, with the carpus held in a flexed position or the paw dragging.[4] Localized pain, swelling, and crepitus on palpation may be present. Comparing findings of palpation of the opposite normal limb with those of the injured limb is valuable when attempting to localize the source of the problem. A thorough history, physical exam, and radiographs are necessary to make a diagnosis.

Radiographs are necessary to confirm the anatomic location and extent of the fracture. Heavy sedation or general anesthesia may be required to position the scapula accurately while also maintaining comfort for the animal. Four views may be necessary to maximize visualization of the entire scapula. Caudocranial views are taken with the animal positioned in dorsal recumbency and the affected limb drawn forward but with the sagittal plane of the thorax rotated 30° away from the affected limb to prevent superimposition of bony densities[5] (Figure 55-1). The mediolateral view is taken with the animal in lateral recumbency, the affected limb against the film and extended approximately 45° craniad with the opposite limb pulled caudad. The positioning prevents superimposition of the ribs and sternum.[5] The scapular neck, glenoid, and supraglenoid tubercle are best visualized radiographically with this position but to view the body of the scapula with the mediolateral view, the affected limb should be superimposed over the cranial thorax with the opposite limb pulled craniad instead of caudad.[5-7] The distoproximal (axial) radiographic view may be helpful in visualizing and diagnosing scapular fractures when other views do not. The dog is placed in dorsal recumbency with the elbows extended and the limb pulled caudad and parallel to the table surface. The humerus is at a 90o angle to the scapular spine and the scapula is perpendicular to the table top. The thickness of the tissues is measured at the level of the greater tubercle of the humerus and the beam is centered over the shoulder joint.[8]

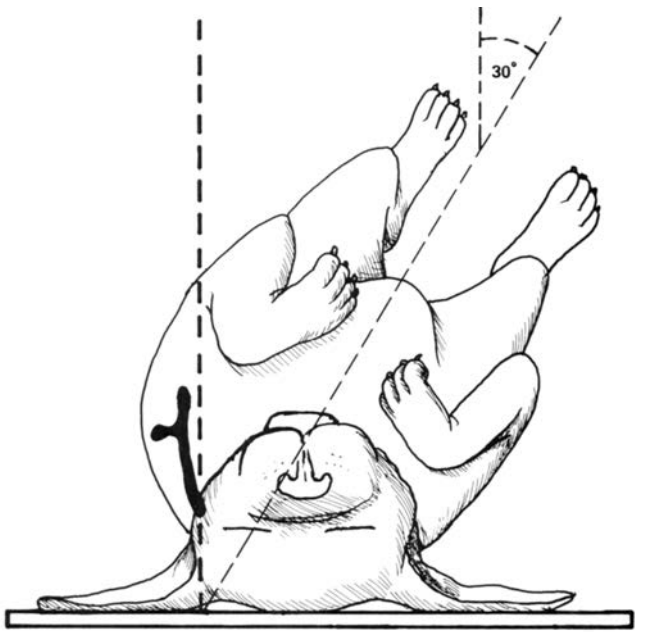


Figure 55-1. A caudocranial radiograph of the scapula is taken with the sagittal plane rotated 30° away from the affected side.

Treatment Options

Recommended treatment options have not changed significantly over the past 25 years. The healing potential of the scapula is excellent because of the abundance of cancellous bone, the intrinsic support from the musculature, and the abundant contribution of blood supply from the musculature and surrounding soft tissues.[9] Fractures of the scapula can be managed either conservatively or with internal fixation. The method chosen depends on the anatomic location and type of fracture. In general, fractures

of the scapula can be managed conservatively except when they involve the articular surface (glenoid), when the fracture results in a distinct change in the angulation of the shoulder joint articulation (displaced scapular neck and body fractures), and when the injury is an avulsion fracture of the acromion and supraglenoid tubercle. Conservatively managed fractures require only limited activity for 3-4 weeks, whereas others may benefit from a modified Velpeau sling or spica splint.[3] Support bandages add to the comfort of the animal during the healing period.

Surgical Techniques

Approaches to the scapula, which vary and depend on the anatomic location of the fracture, have been well described and illustrated.[10] Approaches to the scapular neck, glenoid, and supraglenoid tubercle are more difficult and require more advanced surgical skills than approaches to the scapular body. These approaches may include an osteotomy or a muscle separation technique.[11] Anatomically, the suprascapular nerve, artery and vein course across the lateral aspect of the scapular neck distal to the acromial process and should be avoided and protected. Damage to the nerve can lead to atrophy of the supraspinatus and infraspinatus muscles.

Scapular Body and Spine Fractures

Fractures that involve the body and spine of the scapula are most often managed conservatively. Limited activity should be advised until a clinical union of the fracture is determined. Because of the abundance of cancellous bone and the inherent support of the fracture by the surrounding musculature along with the presence of an abundant blood supply, healing progresses rapidly, and many animals are clinically normal within 4 weeks, although others may require a longer period of healing.[1] Limitation in activity should be dictated by clinical progression of the animal. The fracture may not be completely healed when clinical function first appears normal; therefore, activity is limited for an additional few weeks. If a modified Velpeau sling is used for immobilization or to provide comfort for the animal, the bandage should be monitored closely and removed in 2-3 weeks to allow for return to normal shoulder joint function and to prevent unwanted contracture of soft tissues and limitations in joint motion.[4] Fractures that are severely displaced or comminuted or those that change the angle of the normal joint articulation should be repaired with internal fixation. Internal fixation improves the cosmetic result, especially in short-haired dogs, and provides the support necessary for early return to ambulation better function.

Internal fixation of scapular body and spine fractures consists primarily of the use of wires, plates, or a combination of both (Figure 55-2). When placing interfragmentary wires, predrilling the holes and preplacing wires (18, 20, 22 gauge wire) simplifies the procedure. The fractures are then reduced and the wires are tightened. If the spine of the scapula is fractured, tension band wiring may be used. The scapula lacks an abundance of harder cortical bone and care should be taken when tightening the wires so they do not cut through the bone. Minimal fixation can be combined with a Velpeau sling. Interfragmentary wires may be adequate for small dogs and cats, whereas a plate may be required in larger dogs or when angulation displacement is not controlled by wire alone. For plate fixation, the surgeon should place a plate in the angle formed between the junction of the body and the spine and place the screws at an angle for maximum screw purchase in the thickest portion of the bone (Figure 55-2B): Plate placement in the ventral half of the scapula should be along the cranial aspect of the scapular spine/body junction, with screws placed at a 45° angle to the spine. Conversely, a caudal approach should be considered when plating the dorsal half of the scapula.[12] Inverting a semitubular plate and placing it in this location may enhance the fit of the plate to the bone. Cerclage wires placed around the plate may be used in conjunction with the screws for added fixation support of the plate if the screws do not purchase the bone well. Plastic plates may also be placed on both sides of the spine and secured with nuts and screws to provide the support and fixation necessary for preventing angulation and overriding displacement of the fractures (Figure

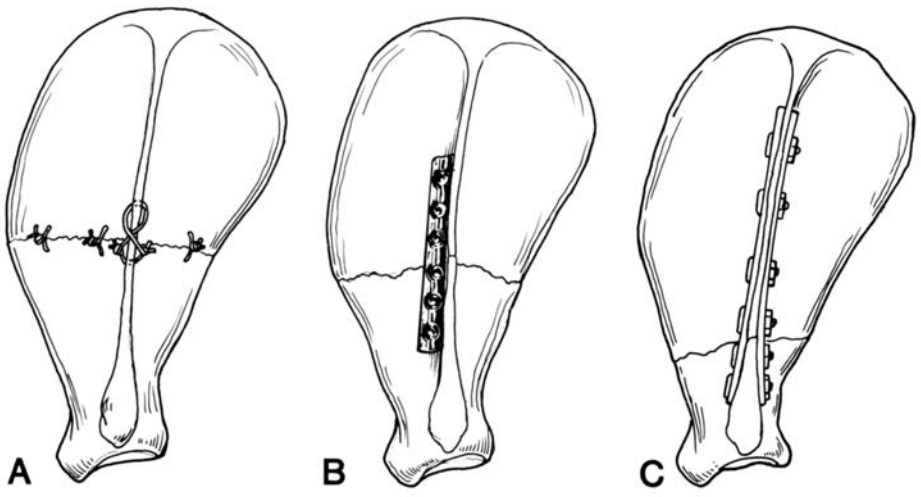


Figure 55-2. Repair of scapular body fractures. **A.** Interfragmentary wires with a tension band in the scapular spine. **B.** Inverted semitubular steel plate with screws directed at an angle into the thickest bone at the junction of the scapular spine and body. **C.** Plastic plate secured to the spine of the scapula with screws and nuts.

55-2C). In a mechanical study, when comparing single versus double semitubular plate fixation, single plate fixation of scapular body fractures may be sufficient. Any difference between single and double plating is likely not clinically relevant.[13] Locking plate technology has the potential to increase stability of the repair in light of the poor bone quality of the scapula.[5] However, in a scapular fracture model, locking SOP plates were not shown to have a different load to failure than an LC-DCP.[14] Locking plates have not yet been evaluated for scapular fractures in a clinical setting, or in a cyclic load model at the time of this manuscript preparation. Perfect fracture alignment and anatomic reconstruction may not be consistently achieved, but the goal of preventing overriding and angulation of the fracture segments with internal fixation methods is adequate to allow for good functional and cosmetic results.

Acromial Fractures

The bony prominence of the distal end of the spine of the scapula, the acromion, is the site at which the acromial head of the deltoid muscle arises and runs distally. The acromion is easily palpable under the skin and can be compared to the opposite limb for asymmetry and identification of a fracture. Fracture of the acromion results in distal displacement created from the pull of the acromial head of the deltoid muscle. The diagnosis can be made with palpation and radiographic findings. The animal typically has a weightbearing lameness and pain is elicited upon palpation. With constant pull from the acromial head of the deltoid, all forms of closed reduction and fixation are inadequate and internal fixation is required.[4] Typically, one of two methods is used to stabilize the fragment. Either two small pins and a tension band wire can be applied, or two twisted stainless steel interfragmentary wires are placed, depending on the size of the animal and the fragment (Figure 55-3). If the fixation is secure, no additional support is required, limited activity is advised for 6 to 8 weeks, and the prognosis for a complete recovery is good.

Scapular Neck Fractures

Animals with scapular neck fractures often present with severe lameness and dysfunction of the limb. If the fracture is not displaced, a spica splint may be applied for immobilization to prevent further displacement. The placement of a Velpeau sling may create stress on the fracture site by creating internal rotation and flexion of the shoulder.[4] The distal segment often displaces medially and proximally, and closed reduction is difficult. The risk of suprascapular nerve damage is present and the client should be warned of the possibility. As a result, the supraspinatus and infraspinatus muscles may atrophy, leaving a cosmetically altered appearance and impaired function. Internal fixation is recommended to achieve the best result. The suprascapular nerve should be retracted and protected during repair. Many combinations of methods can be used to repair fractures

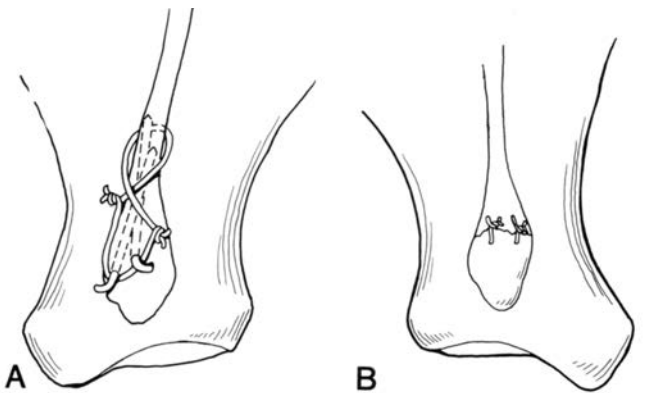


Figure 55-3. Acromial features repaired with Kirschner wires and a tension band **A.** or with wire sutures **B.**

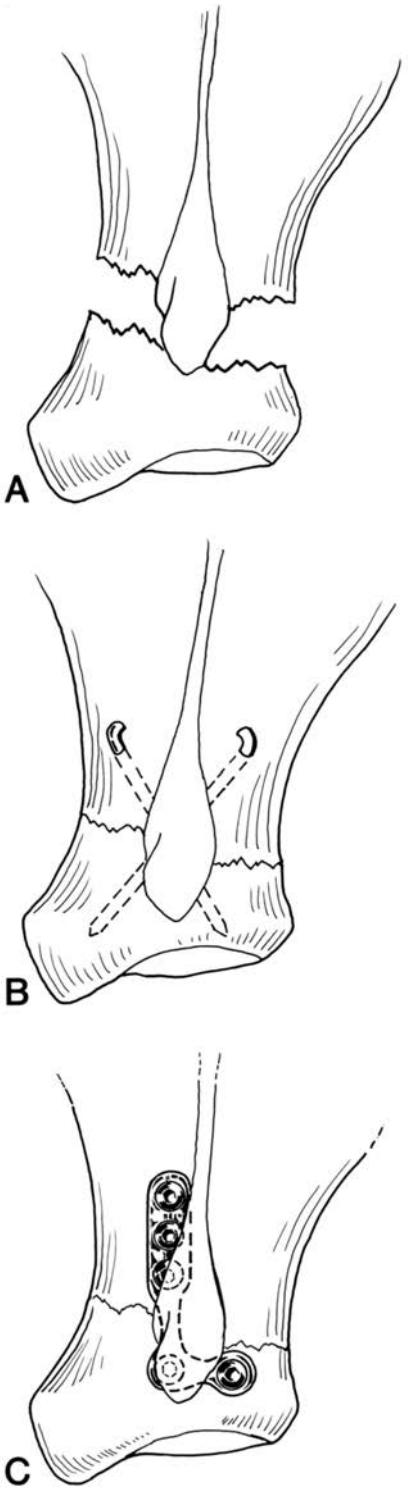


Figure 55-4. Scapular neck fracture **A.** repaired by cross-pinning with Kirschner wires introduced from the body into the neck **B.** or with an L-shaped bone plate in large dogs **C.**

of the neck. Cross-pinning the fracture with Steinman pins or Kirschner wires inserted from the body into the neck is often adequate stabilization for these fast healing fractures (Figure 55-4A and B). The cross pins alternatively can be placed from the supraglenoid tubercle across the neck fracture into the body and the other pin can be inserted from the caudal aspect of the glenoid across the fracture in a similar fashion. In larger breeds, the use of a screw placed in lag fashion or T or L plates can be used to provide more rigid fixation (Figure 55-4C). The technique depends on the size of the animal, nature of the fracture, and the level of exposure created by the surgeon who should be willing to expose as much as necessary to achieve adequate anatomic reduction and stable fixation. Because these methods of fixation are stable, further support is usually not necessary, and with adequate limitation of activity for 6 to 8 weeks, return to normal function is expected.

Glenoid Fractures

Fractures of the glenoid are intra-articular (Figure 55-5A). The animal will present with severe lameness and a dysfunctional limb. Palpation reveals an unstable shoulder with crepitus demonstrated when the joint is manipulated. Radiographs are necessary to assess the extent of the fracture. The fracture may involve the cranial half of the glenoid which is most common,[15] or the caudal half of the glenoid; alternatively, both portions may be fractured involving a neck fracture as well (T or Y fracture). (An ununited accessory caudal glenoid ossification center should not be confused with a glenoid fracture, although it may result in variable lameness.[16]) The degree of comminution may vary. This fracture requires great external forces, and the possibility of other injuries should be explored. Most patients have concurrent injury to another body region.[15] Brachial plexus injuries and thoracic trauma should be considered. Unless the fracture is so severely comminuted that it cannot be repaired, internal fixation is required. Closed methods of repair are not adequate and should only be considered if the goal is to allow the fractures to heal and later perform an arthrodesis or excision of the humeral head and glenoid as a salvage procedure. A spica splint should be placed with the leg in a more natural functional angle if this option is pursued. Partial scapulectomy is another salvage option, as it has been well described for tumor removal, and there is a single case report of its successful use in treatment of a glenoid fracture.[17] The goal of surgical repair is to expose the surgical site adequately and perfectly reconstruct the alignment of the articular surface of the glenoid to minimize secondary osteoarthritis as a result of incongruence of the articular surface. A combination of pins and screws are used to repair the glenoid first, and if the scapular neck is also fractured, it is repaired with one of the techniques described previously. Depending on the type and location of the fracture segments, various methods of cross pinning, lag screws, and plating may all be used to achieve a congruent and stable fracture repair (Figure 55-5). The prognosis for regaining function of the limb is good but an extended convalescent period can be expected, and most patients will have some degree of continued lameness following fracture repair.[15]

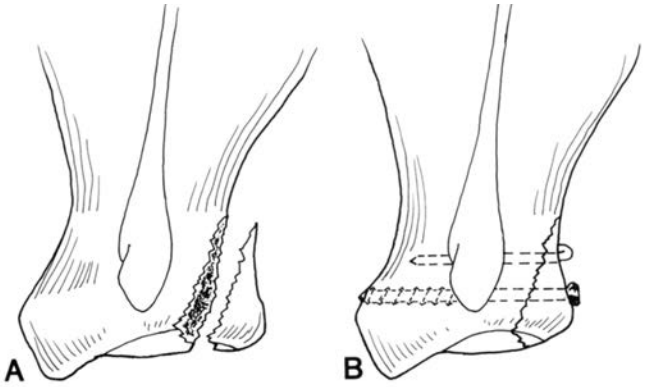


Figure 55-5. Glenoid fracture **A.** compressed with an interfragmentary lag screw and derotational Kirschner wire **B.** Anatomic alignment of the joint surface is important.

Supraglenoid Tubercle Fractures

The supraglenoid tubercle is the point of origin of the tendon of the biceps brachii muscle on the cranial portion of the glenoid. The supraglenoid tubercle develops as a separate center of ossification and through endochondral ossification, should fuse to the glenoid by 5 months of age.[18] In the skeletally immature dog, before endochondral ossification is complete, an avulsion fracture may develop through the growth plate and the pull of the biceps brachii muscle distracts the fragment. This type of fracture can occur in the mature animal as well. Utilizing principles of a pin and tension band technique or lag screw fixation can be used successfully to repair the fracture (Figure 55-6). The surgical exposure to accomplish this repair can be challenging. If the fragment is too small, removal may be necessary and the biceps tendon is secured to the proximal humerus creating a tenodesis or it may be released without securing the biceps tendon and allow it to retract without stabilization.

Conclusions

All animals identified as having scapular fractures should be examined carefully for concurrent body injuries, specifically cardiopulmonary, neurologic, and other musculoskeletal injuries. Scapular fractures tend to heal rapidly. In general, fractures of the body and spine of the scapula do not require repair if the displacement is minimal and the angulation of the shoulder articulation is not impaired, whereas intra-articular fractures must be properly aligned and stabilized to achieve good long term functional results. Velpeau slings or spica splints can be used to immobilize the fracture and provide comfort for the animal during the early healing period. Fractures of the glenoid, supraglenoid tubercle, acromion, and most neck fractures require internal fixation for best results. Inadequate anatomic reconstruction and instability can result in malalignment of the fractures, nonunion, secondary degenerative joint disease, unsatisfactory cosmetic appearance, and poor limb function. The suprascapular nerve should be retracted and protected during repair of scapular fractures to prevent iatrogenic injury resulting in muscle atrophy and impaired function. The surgeon should be familiar with the anatomy, different surgical approaches, and be willing to achieve the exposure necessary to reconstruct the fractures in a stable and anatomic fashion. Pins, wires, screws and plates provide adequate means for stabilizing scapular fractures.

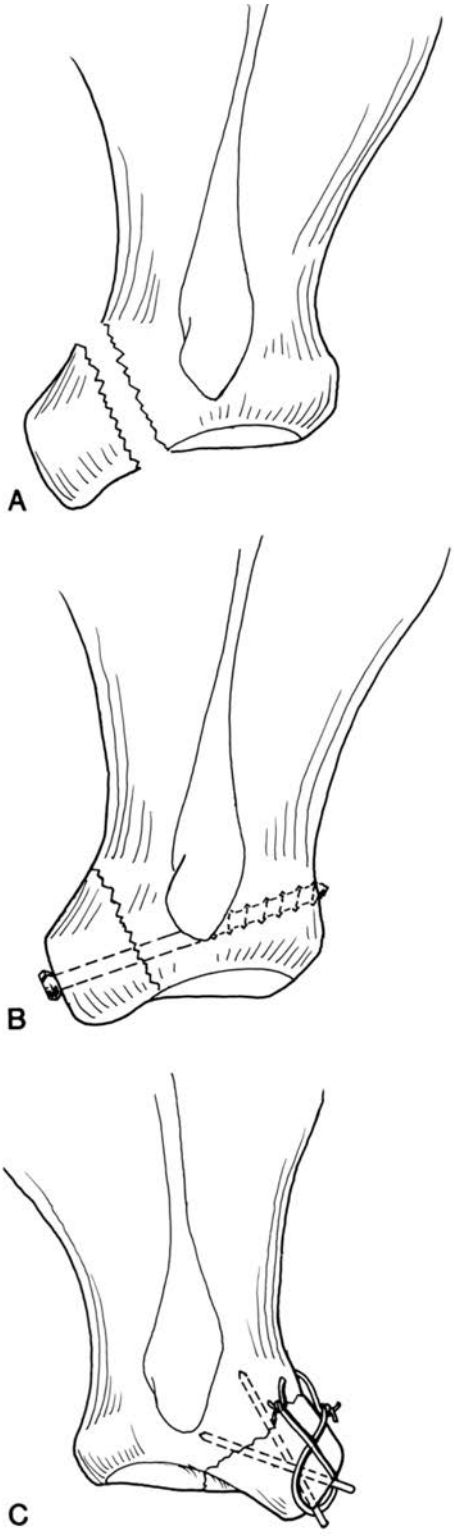


Figure 55-6. Supraglenoid tubercle fracture **A.** repaired with a lag screw **B.** or with Kirschner wires and a tension band **C.**

References

1. Harari, J, Dunning, D: Fractures of the Scapula in Dogs: A Retrospective Review of 12 Cases. Veterinary and Comparative Orthopaedics and Traumatology, 6:105-108, 1993.

2. Cook, JL, Cook CR, Thomlinson JL, et al: Scapular Fractures in Dogs: Epidemiology, classification, and concurrent injuries in 105 cases (1988-1994). J Am Anim Hosp Assoc 1997; 33:528-532.

3. Piermattei, DL, Flo, GL DeCamp, CE: Brinker Piermattei, and Flo's handbook of Small Animal Orthopedics and Fracture Repair, ed 4, St. Louis, Elsevier, 2006.

4. Newton, CD: Fractures of the Scapula. In Textbook of Small Animal Orthopedics. Edited by CD Newton and DM Nunamaker. Philadelphia, J.B. Lippincott, 1985.

5. Peck, J.: Musculoskeletal System - Scapula. In Veterinary Surgery: Small Animal. Edited by KM Tobias and SA Johnston, St. Louis, Elsevier, 2012.

6. Ticer, JW: Radiographic Technique in Veterinary Practice. Philadelphia, WB Saunders, 1984.

7. Straw, RC: Thoracic Limb - Repair of Scapular Fractures. In Current Techniques in Small Animal Surgery. Edited by MJ Bojrab, Philadelphia, Lea and Febiger, 1990.

8. Roush, JK, Lord, PF: Clinical Application of a Distoproximal (Axial) Radiographic View of the Scapula. J Am Anim Hosp Assoc, 1990; 26(2): 129-132.

9. Brinker, WO, Hohn, RB, and Prieur, WD (eds): Manual of Internal Fixation in Small Animals. New York, Springer-Verlag, 1984.

10. Piermattei, DL, Johnson, KA: An Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat, ed 4. Philadelphia, Saunders/Elsevier, 2004.

11. McCartney, WT, Garvan, CB: Muscle separation approach to scapular neck fractures in eight dogs. Veterinary and Comparative Orthopaedics and Traumatology, 5:471-473, 2008.

12. Ocal, MK, Toros, G: A morphometric study on the cross-sections of the scapular spine in dogs. Veterinary and Comparative Orthopaedics and Traumatology, 4:281-284, 2007.

13. Mair, JJ, Belkoff SM, Boudrieau RJ: An Ex Vivo Mechanical Evaluation of Single Versus Double Semitubular Plate Fixation of a Transverse Distal-Third Scapular Osteotomy in the Dog. Vet Surg 2003;32:580-584

14. Acquaviva, AE, Miller, EI, Eisenmann, DJ, Stone, RT, Kraus, KH: Biomechanical testing of locking and nonlocking plates in the canine scapula. J Am Anim Hosp Assoc, 2012; 48: 372-378.

15. Johnston, SA: Articular Fractures of the Scapula in the Dog: A Clinical Retrospective Study of 26 Cases. Journal of the American Animal Hospital Association, 1993; 29(2): 157-164.

16. Olivieri, M, Piras, A, Marcellin-Little, DJ et al: Accessory caudal glenoid ossification centre as possible cause of lameness in nine dogs. Veterinary and Comparative Orthopaedics and Traumatology, 3:131-135, 2004.

17. Plesman, RL, French, S, Nykamp, S, Ringwood, PB: Partial scapulectomy for treatment of an articular fracture of the scapula in a cat. Veterinary and Comparative Orthopaedics and Traumatology, 6:468-473, 2011.

18. Denny, HR: Pectoral Limb Fractures. In Canine Orthopedics. Edited by W.G. Whittick, Philadelphia, Lea and Febiger, 1990.

Surgical Treatment of Shoulder Luxation

Kent Talcott

Introduction

Scapulohumeral luxation is an uncommon problem in the dog and rarely occurs in the cat. Luxation is typically the result of traumatic injury or congenital glenoid abnormality. Lateral luxation most commonly occurs in large breed dogs with historical trauma. Medial luxation typically occurs in small dogs with congenital capsular laxity or glenoid dysplasia. Cranial and caudal luxations are documented but occur less frequently than lateral or medial luxation.

Anatomical Considerations and Surgical Approach

It is important to establish a thorough knowledge of anatomy and understanding of anatomical function prior to performing surgical correction for scapulohumeral luxation. Errors in surgical technique are not well tolerated and may contribute to persistent lameness or disability. The following is a brief review of anatomy and surgical approach. A more detailed review of this information is highly recommended for individuals with limited experience in shoulder surgery.

Scapulohumeral stability is the combination of articular stability and soft tissue restraints. The primary soft tissue restraints include the joint capsule and its associated glenohumeral ligaments, and "rotator cuff" tendons. Glenohumeral ligaments are described as thickened regions of the joint capsule and are not grossly apparent from external evaluation (Figure 55-7). However, they are distinct structures when viewed arthroscopically. The medial glenohumeral ligament is "Y" shaped with a cranial and caudal component while the lateral glenohumeral ligament is a wide solitary band that tapers near its insertion. Luxation is not possible without disruption of the joint capsule and its associated glenohumeral ligament. The four "cuff tendons" provide dynamic support with minimal contribution during static conditions. The "cuff tendons" include the supraspinatus cranially, subscapular medially, infraspinatus laterally, and teres minor caudolaterally. Collectively, soft tissue structures are important restraints to joint motion and contribute to joint stability. Identifying injury to such structures is important when selecting methods of stabilization.

A craniomedial approach is most often used for surgical treatment of medial and lateral luxation while a craniolateral approach is performed for cranial luxation. The following craniomedial approach provides general access to the shoulder. Once the shoulder is approached, further dissection varies dependent upon technique and is further described within the relevant section of this chapter. With the patient in dorsal recumbency, a parahumeral incision originating from the medial or cranial aspect of the scapular neck is extended distally to the medial aspect of the humeral mid-diaphysis. Subcutaneous fat is incised exposing the brachiocephalicus muscle. A fascial incision is created the entire length of the lateral border of the brachiocephalicus muscle which requires ligation and division of the omobrachial vein. The brachiocephalicus is elevated and retracted caudomedially while the humerus is externally rotated. The insertion of the superficial pectoral is incised from the humerus along its proximal border to the omobrachial vein.

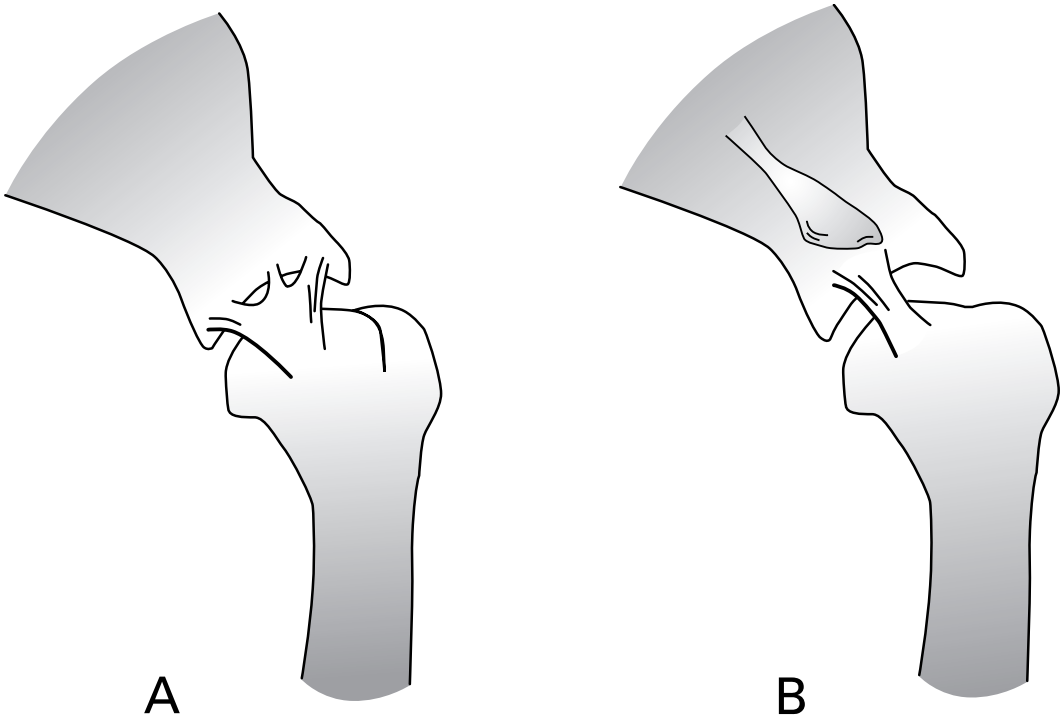


Figure 55-7. Medial view illustrating both bands of the medial glenohumeral ligament **A.** The lateral glenohumeral ligament is a solitary band of connective tissue within the joint capsule **B.** (From Talcott KW, Vasseur PB: Luxation of the Scapulohumeral joint. In Slatter D (ed): Textbook of Small Animal Surgery, 3rd ed. Saunders, Philadelphia, 2003, p 1898.).

Similarly, the deep pectoral muscle is freed from its insertion but requires separation from the overlapping supraspinatus muscle proximally. Both pectoral muscles are retracted medially and the supraspinatus caudolaterally.

Lateral Scapulohumeral Luxation

Lateral luxation commonly presents in large breed dogs with historical trauma. The mechanism is not well defined but is presumably caused by extreme adduction of the limb. Lateral humeral luxation requires tearing of the lateral aspect of the joint capsule, its associated glenohumeral ligament, and infraspinatus tendon.

Diagnosis

Patients present with the forelimb held in flexion and concurrent internal rotation of the foot. The greater tubercle is prominent and displaced laterally. Joint manipulation is painful with overt crepitus. A neurologic examination is indicated to identify

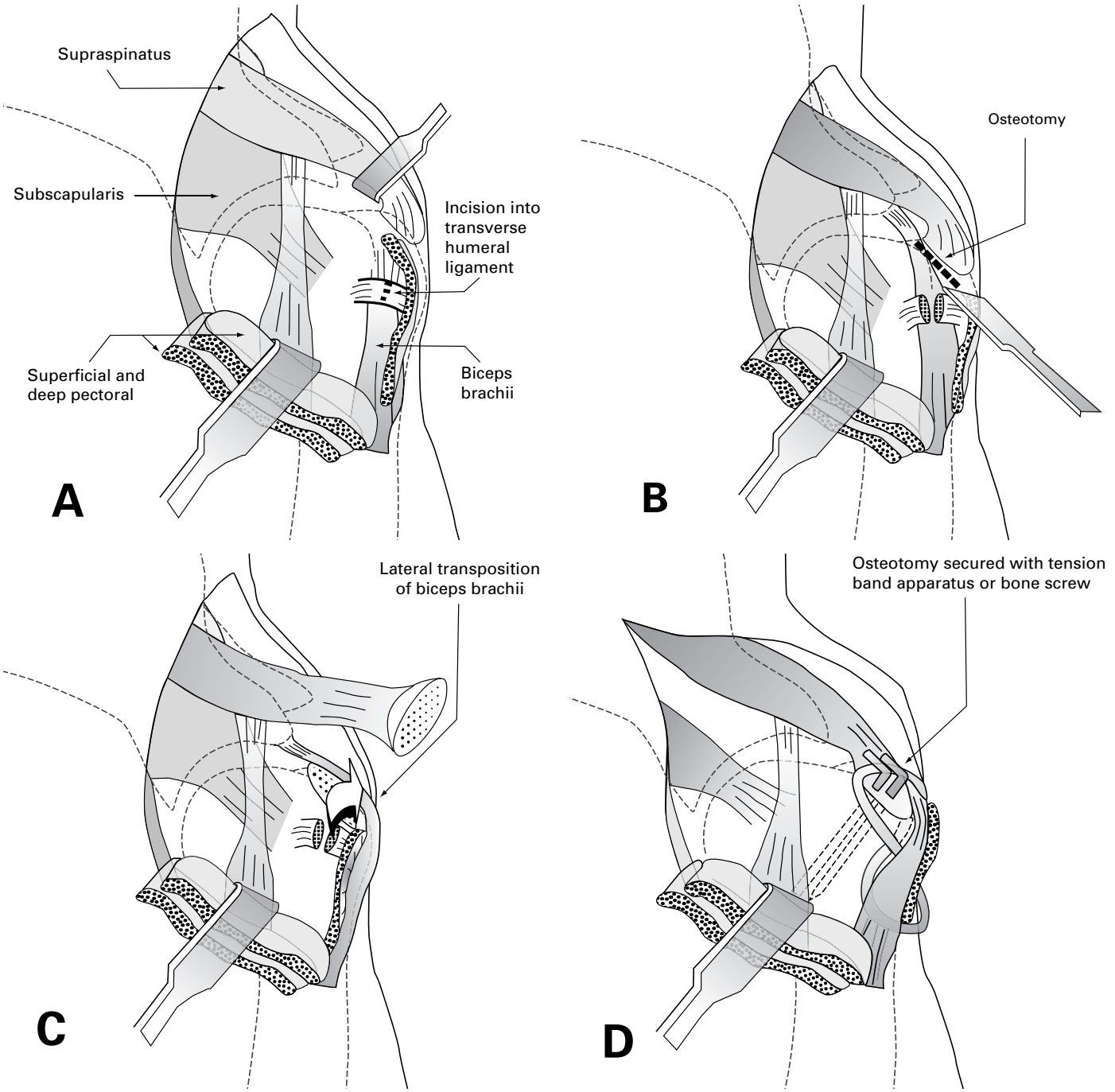


Figure 55-8. Craniomedial approach to the shoulder. The pectoral muscles are retracted ventrally and the supraspinatus proximally. The transverse humeral ligament is incised to free the biceps tendon **A.** Osteotomy is required to free the supraspinatus muscle **B.** The biceps brachii tendon is transferred laterally over the cut surface of the greater tubercle **C.** The greater tubercle is stabilized with a pin and tension band apparatus, maintaining the biceps brachii in a lateral position **D.** (From Talcott KW, Vasseur PB: Luxation of the Scapulohumeral joint. In Slatter D (ed): Textbook of Small Animal Surgery, 3rd ed. Saunders, Philadelphia, 2003, p 1899).

concurrent brachial plexus injury. Survey radiographs are performed to confirm the diagnosis and identify concurrent fractures or glenoid rim erosion. Stress radiography may be useful to identify dynamic luxation or subluxation.

Treatment

Closed reduction and splintage is considered in patients with acute injury and mild to moderate joint instability. Under general anesthesia the limb is extended and medial pressure is applied to the humeral head while counter pressure is applied to the scapular neck. Range of motion and joint stability are assessed after reduction and either a spica splint or non-weight bearing carpal sling is maintained for 10 to 14 days. A Velpeau sling is contraindicated for lateral luxation as it applies lateral translation to the humeral head. Results of nonsurgical treatment for lateral luxation are variable and are contingent upon the magnitude of soft tissue disruption, success of splintage, and patient/owner compliance regarding activity restriction. Surgical stabilization should be considered when reluxation is easily elicited.

Surgical intervention is performed for patients with acute unstable injury, concurrent fracture, or chronic luxation. Numerous procedures are described including prosthetic ligament reconstruction, biceps tendon transposition, transarticular pinning, glenoid excisional arthroplasty, and arthrodesis. The method of repair is based upon etiology of luxation, concurrent fracture, or the ability to restore glenoid integrity if a fracture is present. The advantages and disadvantages of each technique should be considered in relationship to patient signalment, health status, and patient compliance.

Lateral transposition of the biceps tendon is the most documented technique in the literature and is the preferred method of repair when patient variables are appropriate (Figure 55-8). A craniomedial approach is used for biceps transposition. Once the pectoral muscles are retracted medially and the supraspinatus caudolaterally, the transverse humeral ligament is incised and the biceps tendon is freed from regional fascial and capsular tissue. The greater tubercle is osteotomized to allow lateral transfer of the biceps tendon over the cut surface of the greater tubercle. The tubercle is reattached with a screw or pin and tension band apparatus. The joint capsule is closed with absorbable suture and the pectoral muscles are apposed to deltoid fascia. Remaining fascia, subcutaneous fat and skin are routinely closed. Seroma formation is common in this area and may be avoided with careful implant technique, tissue apposition, and postoperative recovery. Strict activity restriction and confinement are required for 2 to 3 weeks. Passive range of motion may be performed in the initial recovery period. Short controlled leash walks begin 2 weeks postoperatively followed by a gradual return to full function over an additional 6 to 12 weeks.

Prognosis and Complications

Normal return to function and full range of motion has been reported with long-term evaluation of this technique. Mild distortion of joint congruity is common at the time of repair but resolves as weightbearing forces cause stretching and relaxation of the tendon. Progression of osteoarthrosis is expected and the biceps tendon is at risk for midsubstance tearing in the future. In spite of such adverse effects, the technique is still recommended as excellent clinical function is the most commonly reported outcome. This technique is less successful in patients with chronic luxation or glenoid dysplasia; in which case arthrodesis or glenoid excisional arthroplasty should be considered.

Medial Scapulohumeral Luxation

Medial luxation is more common than lateral and is reported in small and large breed dogs. Medial luxation in large breed dogs is typically associated with trauma while congenital luxation is more common in small breed dogs. Congenital luxation may be bilateral and is associated with developmental laxity or glenoid dysplasia which is difficult and potentially impossible to correct.

Diagnosis

The historical presentation and physical examination findings vary depending upon the etiology for luxation. Traumatically induced medial luxation presents with an acute persistent lameness with the affected limb held in flexion with external rotation of the foot. Joint manipulation is typically painful during extension and medial displacement of the greater tubercle.

In contrast, congenital luxation may present with intermittent to continuous lameness and joint manipulation is often well tolerated. Mild to moderately dysplastic luxations are often easily reduced and reluxated. More severely dysplastic luxations are commonly non-weightbearing, pain is variable, and joint reduction is difficult.

Radiographic evaluation of traumatically induced medial luxation is scrutinized for concurrent glenoid fracture. Congenital luxation is carefully evaluated for hypoplastic glenoid development and erosion of the medial glenoid rim. Stress radiography should be considered to document luxation in patients with intermittent lameness.

Treatment

Conservative management for medial luxation is contraindicated when glenoid dysplasia is present. However, conservative management is considered for traumatically induced medial luxation when reasonable joint stability is achieved following closed reduction. Closed reduction is performed under general anesthesia with the patient in lateral recumbency and the limb in a neutral standing position. Traction and slight adduction are initiated while lateral pressure is applied to the proximal medial humerus and counter pressure is applied to the scapular neck. A Velpeau sling is ideal stabilization for medial luxation as it eliminates weightbearing and compresses the humeral head laterally. The Velpeau sling is maintained for 2 weeks followed by careful gradual return to function over 4 to 8 weeks.

Surgical techniques reported for medial luxation include prosthetic collateral suture, supraspinatus transposition, transarticular pinning, medial biceps transposition, arthrodesis, excisional arthroplasty, and amputation. Choosing a method of repair is based upon glenoid conformation, concurrent injury, patient size and chronicity of luxation.

In patients with acute traumatic luxation without glenoid dysplasia; medial transposition of the biceps tendon is the preferred technique (Figure 55-9). A craniomedial approach is performed and once the pectoral muscles are reflected, the leg is externally rotated to access the subscapularis muscle. The insertion of the subscapularis is incised allowing caudal retraction of the subscapularis and coracobrachialis while the biceps tendon is freed by incising the transverse humeral ligament and regional capsular attachments. At the lesser tubercle, a craniodorsal hinged flap of bone is created with a crescent-shaped osteotomy. Cancellous bone is removed beneath the flap to accommodate transposition of the biceps tendon. Once the luxation is reduced, the biceps tendon is transferred and secured into the preformed groove by reattaching the bone flap with Kirschner wires. Medial capsular imbrication is performed with absorbable suture and the subscapularis is advanced and attached to the insertion of the deep pectoral muscle. The pectoral muscles are secured to the deltoid and deep brachial fascia. The brachiocephalic muscle is sutured to brachial fascia. The remaining fascial, subcutaneous and skin layers are closed separately. The repair is supported with a Velpeau sling for 7 to 10 days followed by gradual return to function over 4 weeks.

An alternative to biceps transposition is prosthetic collateral repair. It is less time consuming, less invasive, and simpler to perform. The technique is not appropriate for large dogs but should be considered for acute traumatic luxation in small dogs without glenoid dysplasia. The technique is performed using a standard craniolateral approach with tenotomy of the infraspinatus tendon. A curved incision starts at the distal third of the scapular spine extending distally across the joint craniolaterally to the mid-diaphysis of the humerus. Subcutaneous fat and fascia are dissected and the deep brachial fascia is incised from the cranial aspect of the acromion process extending distally along the cranial border of the acromial part of the deltoid muscle. The deltoid is retracted caudally allowing transaction of the infraspinatus tendon which is reflected dorsally. The joint capsule is incised transversely and intra-articular structures are inspected. The joint capsule is closed and a hole is drilled from lateral to medial through the center of the humeral neck. A similar hole is drilled in the center of the scapular neck paying careful attention to protect the suprascapular nerve. Suture is passed from lateral to medial through the scapular bone tunnel and medial to lateral in the humeral tunnel (Figure 55-10). External rotation of the limb and retraction of the brachiocephalic and pectoral muscles medially is required to expose the medial aspects of the humerus and scapular neck for suture advancement. The joint is reduced, suture is tied in moderate tension, and joint mobility and stability are assessed. This technique reported using double strands of 0 or number 1 monofilament polybutester for its elastic properties. The infraspinatus tendon is reattached and routine closure is performed. The repair is supported with a Velpeau sling for 14 to 21 days followed by 4 weeks of passive range of motion and gradual rehabilitation.

If the biceps tendon is damaged or if previous repair is unsuccessful, partial supraspinatus transposition may be considered (Figure 55-11). The approach is identical to the biceps transposition technique, however, the biceps tendon and transverse humeral ligament are repaired and medial capsular imbrication

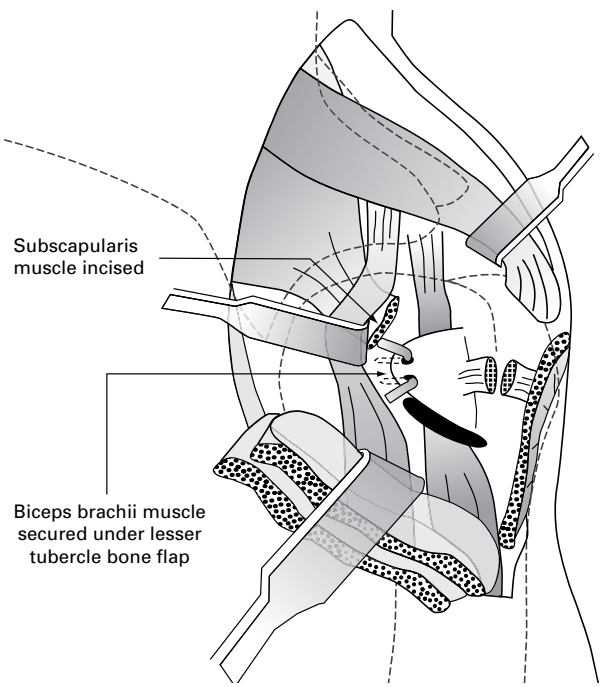


Figure 55-9. The biceps brachii muscle is released and is secured into a tunnel, covered by a bone flap that is secured with Kirschner pins. (From Talcott KW, Vasseur PB: Luxation of the Scapulohumeral joint. In Slatter D (ed): Textbook of Small Animal Surgery, 3rd ed. Saunders, Philadelphia, 2003, p 1900).

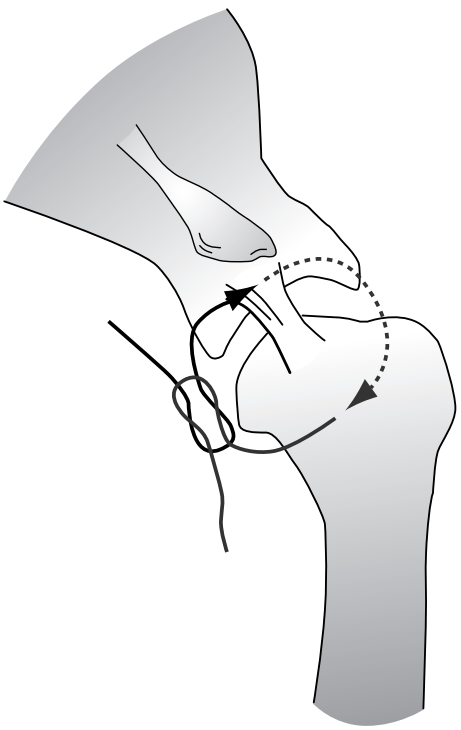


Figure 55-10. Heavy nonabsorbale suture is passed from lateral to medial in the scapular neck and from medial to lateral through the neck of the humerus. Careful dissection and placement of bone tunnels are required to avoid injury to the suprascapular nerve located distal to the acromion process. (From Talcott KW, Vasseur PB: Luxation of the Scapulohumeral joint. In Slatter D (ed): Textbook of Small Animal Surgery, 3rd ed. Saunders, Philadelphia, 2003, p 1901).

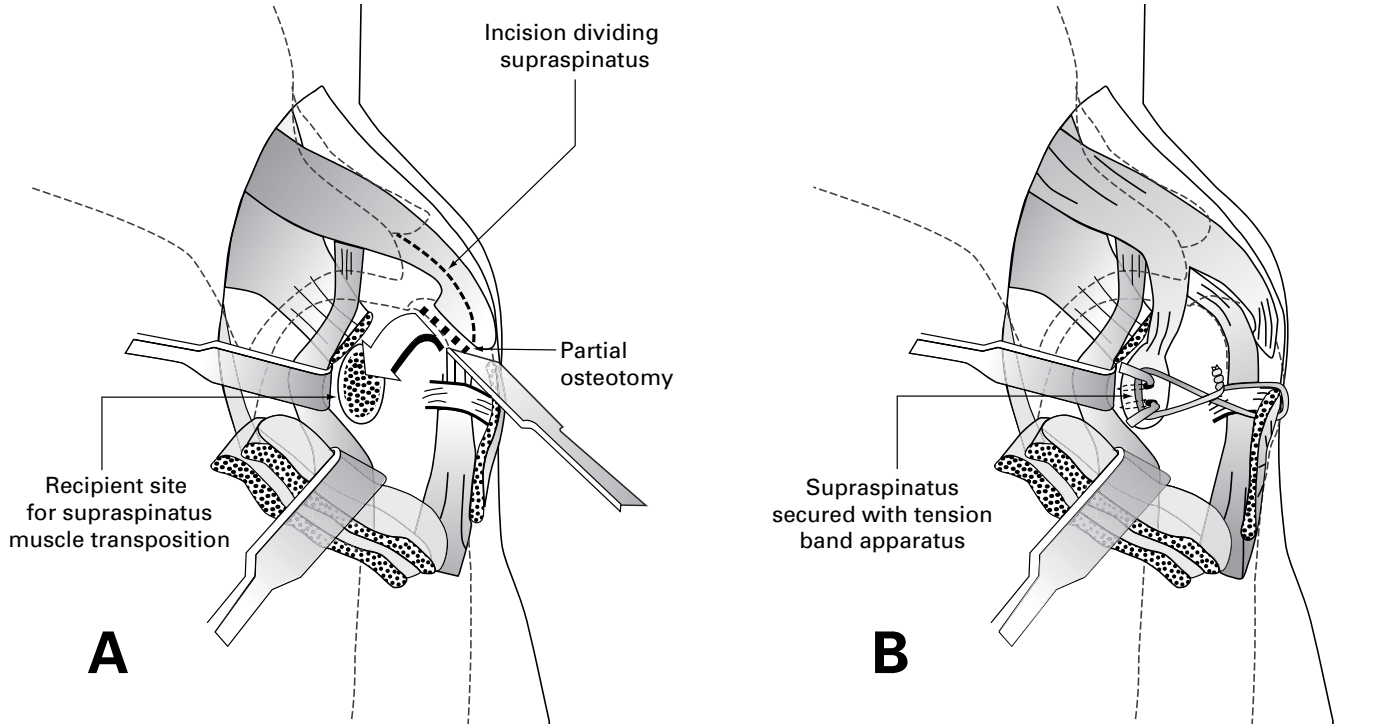


Figure 55-11. A portion of the supraspinatus muscle is mobilized by performing a partial osteotomy of the greater tubercle. A recipient site is created medially by removing cortical bone to facilitate bone union **A.** The bone fragment is secured to the recipient site with pins and tension band **B.** (From Talcott KW, Vasseur PB: Luxation of the Scapulohumeral joint. In Slatter D (ed): Textbook of Small Animal Surgery, 3rd ed. Saunders, Philadelphia, 2003, p 1901).

is performed. The greater tubercle is osteotomized such that the superficial one-half of the supraspinatus tendon is released. The insertion of the subscapularis muscle is incised and a recipient site of exposed cancellous bone is created at the lesser tubercle with a burr, rasp, or osteotome. The supraspinatus is divided only to the extent that the oseotomized tubercle may reach the recipient site with moderate tension. Recurrence of luxation is contingent upon proper tension in the transferred component of the supraspinatus tendon. The transferred tubercle is stabilized with multiple Kirschner pins or pin and tension band. The subscapularis is advanced to the pectoral insertion and pectoral muscles are attached as far cranial as possible to augment medial support of the shoulder. Remaining layers are closed separately. A Velpeau sling is maintained for 7 to 10 days followed by gradual return to function.

Arthrodesis is indicated for patients following failed attempts at surgical repair or in patients with significant glenoid dysplasia or degenerative joint disease. Standard principles of arthrodesis apply to the shoulder. In small dogs, a single screw through the scapular neck and into the humerus combined with a spica splint may be adequate for stabilization. Large dogs typically require bone plate application along the scapular spine and proximal humerus. More detailed information is covered in the arthrodesis section of this chapter.

Excisional glenoid arthroplasty has been described as an alternative to arthrodesis. Excisional arthroplasty may achieve pain-free movement with limited compromise of limb length and joint motion. More detailed information is covered in the excisional glenoid arthroplasty section of this chapter.

Amputation is reserved as a salvage procedure for patients with multiple failed surgical correction, severe glenoid dysplasia, or severe degenerative joint disease. Amputation may not be appropriate for giant breed dogs. Candidates for amputation should be carefully assessed for congenital or traumatic contralateral limb abnormalities.

Prognosis and Complications

Prognosis after medial biceps transposition is variable. The majority of dogs are expected to achieve satisfactory limb function; however, intermittent to persistent lameness occurs is approximately 50% of cases. Similar to lateral biceps tendon transfer, transient joint incongruity, osteoarthrosis, and midsubstance biceps tendon tearing have been reported for medial transfer of the biceps tendon. In general, experience with this technique is favorable.

Full return of limb function was reported in dogs 2 to 3 months following collateral prosthetic ligament reconstruction with polybutester suture. This is the authors preferred technique provided case selection is limited to small dogs without preexisting joint abnormalities. There are no reports of this technique in cats, however; intuitively, this technique may provide similar favorable results.

Prognosis of partial supraspinatus tendon transfer is limited to a single case report describing normal function and full range of motion 2 months following surgery. Adverse effects of joint incongruity and tendon tearing are less apt to occur but further study has not been performed.

Reports of shoulder arthrodesis are generally favorable due to mobility of the scapula. Best results are seen in small dogs, whereas, large dogs have a varied outcome and more apparent gait abnormality.

Excisional glenoid arthroplasty was reported to achieve good to excellent results in one study. This technique is limited to patients with severe glenoid dysplasia or degenerative joint disease. Clients should be informed that mild reduction in joint mobility, muscle atrophy, and limb shortening are expected.

Cranial and Caudal Luxation

Cranial and caudal scapulohumeral luxation are rare. Reports in the veterinary literature are limited to a few case reports. Etiology of cranial and caudal luxation appears to be associated with trauma. The only described technique for cranial luxation is transfer of the biceps tendon cranially into a groove within the greater tubercle (Figure 55-12). A craniolateral approach is performed and the greater tubercle is osteotomized. A groove is made into the cut surface of the osteotomy. The transverse humeral ligament is incised and the biceps tendon is mobilized into the preformed groove. The capsular tissue is imbricated and the greater tubercle is reattached with pins and tension band apparatus. Standard closure is performed and a spica splint is maintained for 10 days.

Caudal luxation has been treated with caudal and lateral imbrication in combination with a non-weightbearing sling for 10 days.

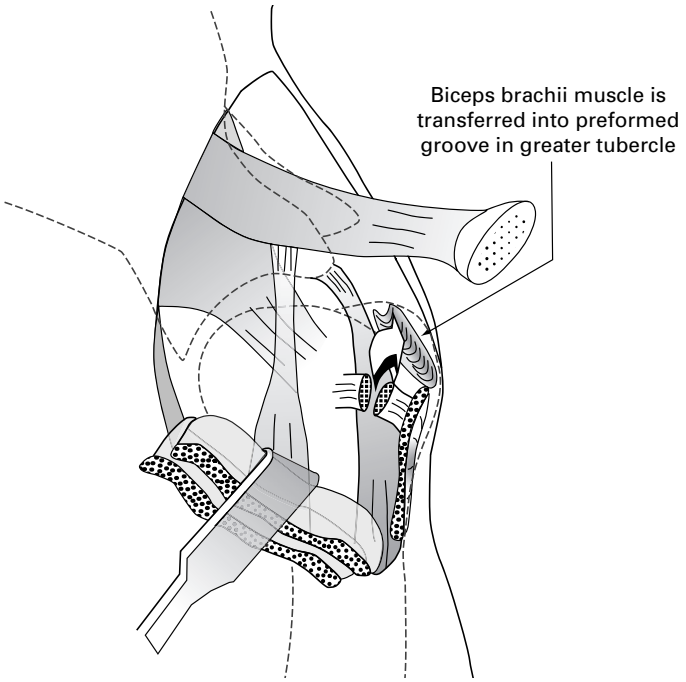


Figure 55-12. The biceps brachii tendon is transferred into a bone tunnel created at the osteotomy site of the supraspinatus muscle insertion. The biceps is secured in the groove by attaching the greater tubercle to its insertion site with a tension band apparatus. (From Talcott KW, Vasseur PB: Luxation of the Scapulohumeral joint. In Slatter D (ed): Textbook of Small Animal Surgery, 3rd ed. Saunders, Philadelphia, 2003, p 1902).

Prognosis is difficult to predict as no long-term studies have evaluated cranial or caudal luxation repair. Limb function is presumed to be satisfactory but further study is needed.

Suggested Readings

Ball DC: A case of medial luxation of the canine shoulder joint and its surgical correction. *Vet Rec* 83:195, 1968.

Bardet JF: Lesions of the biceps tendon diagnosis and classification. *Vet Comp Orthop Traumatol* 13:188, 1999.

Craig E, et al: Surgical stabilization of traumatic medial shoulder dislocation. *J Am Anim Hosp Assoc* 16:93, 1980.

Craig E, et al: Treatment of shoulder joint luxations. *In* Bojrab MJ (ed): *Current Techniques in Small Animal Surgery, 3rd ed.* Lea & Febiger, Philadelphia, 1990, p 740.

DeAngelis MP: Luxations of the shoulder. *In* Bojrab MJ (ed): *Current Techniques in Small Animal Surgery,* Lea & Febiger, Philadelphia, 1975, p 499.

DeAngelis MP, Schwartz A: Surgical correction of the cranial dislocation of the scapulohumeral joint in the dog. *J Am Vet Med Assoc* 156:435, 1970.

Evans HE, Christensen GC: *Miller's Anatomy of the Dog, 2nd ed.* WB Saunders, Philadelphia, 1979, p 240.

Fowler D, et al: Scapulohumeral arthrodesis: Results in seven dogs. *J Am Anim Hosp Assoc* 24:667, 1988.

Franczuski D, Parks LJ: Glenoid excision as a treatment in chronic shoulder disabilities: Surgical technique and clinical results. *J Am Anim Hosp Assoc* 24:637, 1988.

Herron MR: Scapulohumeral arthrodesis: An evaluation of two techniques in 33 cases [abstract] *Vet Surg* 18:78, 1989.

Piermattei DL, Blass CE: Resection of the glenoid rim and humeral head. *In* Bojrab MJ (ed): *Current Techniques in Small Animal Surgery. 3rd ed.* Lea & Febiger, Philadelphia, 1990, p 748.

Piermattei DL, Greeley RG: *An Atlas of Surgical Approaches to the Bones of the Dog and Cat, 2nd ed.* WB Saunders, Philadelphia, 1979, p 72.

Prostredny JM, et al: Use of polybutester suture to repair medial scapulohumeral luxation in the dog: Three cases. *J Am Anim Hosp Assoc* 29:180, 1993.

Vasseur PB: Clinical results of surgical correction of shoulder luxation in dogs. *J Am Vet Med Assoc* 182:503, 1983.

Vasseur PB: Effects of tendon transfer on the scapulohumeral joint. *Am J Vet Res* 44:811, 1983.

Vasseur PB, et al: Stability of the canine shoulder joint: An in vitro analysis. *Am J Vet Res* 43:352, 1982.

Caudal Approach to the Shoulder Joint for Treatment of Osteochondritis Dissecans

Dean R. Gahring

Introduction

Treatment of osteochondritis dissecans (OCD) of the shoulder joint involves removal of all loose and damaged fragments of cartilage and bone from all aspects of the joint. OCD lesions in the shoulder almost always occur on the caudal aspect of the humeral head. Loose fragments of cartilage can migrate into the caudal cul-de-sac of the joint and/or into the cranial bicipital tendon sheath. There is no effective surgical approach to both areas, so dealing with each area requires two separate approaches. Consequently, I usually recommend doing an arthrogram prior to surgery to determine whether or not the bicipital tendon sheath needs to be explored. Arthroscopy can also be used.

Surgical management of OCD of the caudal humeral head involves removal of all loose cartilage with a sharp curette so that no cartilage remains elevated and unattached to underlying bone. The removal and curettage of damaged bone and cartilage will decrease pain and inflammation resulting from irritation and impingement of the joint capsule and other joint elements. Exposed subchondral bone is curetted to bleeding surfaces so that the resultant defect can be resurfaced with new fibrocartilage. If any cartilage is left unattached to subchondral bone, it may fragment and produce loose bodies in the joint. Loose cartilage is unlikely to re-attach to the underlying bone.

This caudal approach to the shoulder joint allows excellent visualization of, and access to, the caudal humeral head and both the medial and lateral aspects of the caudal joint cul-de-sac. It is primarily a muscle-separating approach. No tendons are incised, so recovery is rapid with minimal post-operative complications.

Surgical Technique

The patient is placed in lateral recumbency with the affected leg in an upward position and hung so it can be completely draped and be free for extensive manipulation during surgery. The location of the skin incision is identified by connecting the midpoint of the scapular spine with the midpoint of the humerus (Figure 55-13). The skin, subcutaneous tissue, and superficial fascia are retracted to expose a whitish linear fascial raphe between the spinous (or scapular) head of the deltoid muscle and the long head of the triceps muscles (Figures 55-14 and 55-15). This fibrous raphe is incised either bluntly or sharply. Blunt dissection between these two muscles is continued until the caudal shoulder joint capsule is identified (Figures 55-16 and 55-17). It is easier to start the blunt separation digitally between the spinous (scapular) head of the deltoid muscle and the long head of the triceps muscle slightly above the level of the caudal shoulder joint and proceed in a cranioventral direction than to begin the blunt dissection from

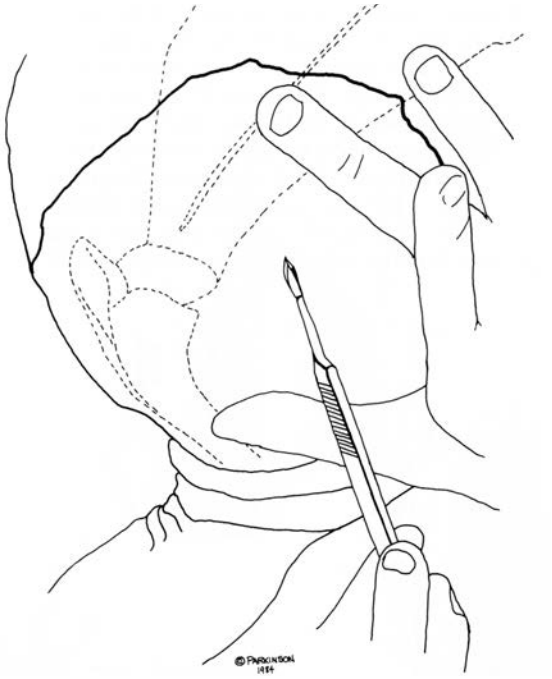


Figure 55-13. The skin incision is made from the midpoint of the scapular spine to the midpoint of the humerus. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

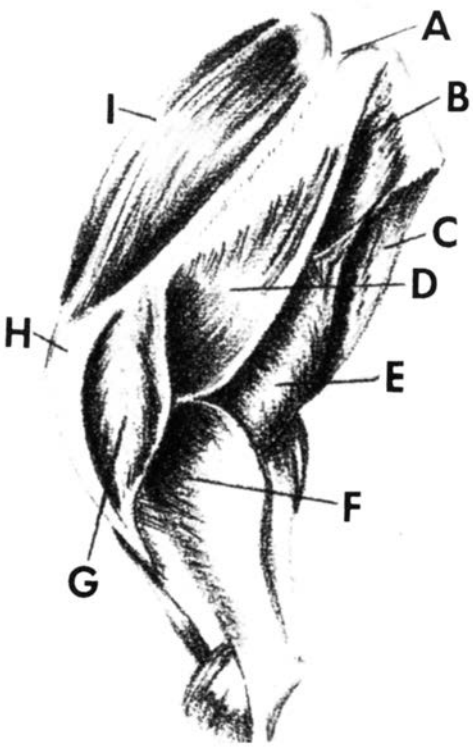


Figure 55-14. The landmark to look for is the fascial raphe between the spinous (or scapular) head of the deltoid and the long head of the triceps muscles: *A,* spine of scapula; *B,* infraspinatus muscle; *C,* teres major muscle; *D,* spinous (or scapular) head of the deltoid muscle; *E,* long head of the triceps muscle; *F,* lateral head of the triceps muscle; *G,* acromial head of the triceps muscle; *H,* greater tubercle of the humerus; *I,* supraspinatus muscle. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

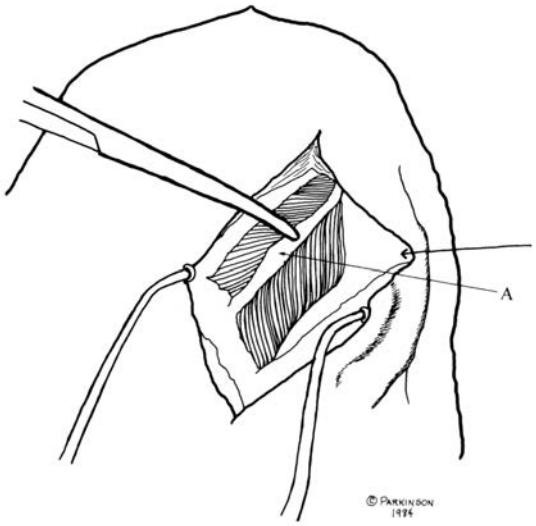


Figure 55-15. Using the landmarks in Figure 55-13, the fascial raphe between the spinous (or scapular) head of the deltoid and the long head of the triceps muscles *(A)* should be immediately beneath the skin and subcutaneous tissue incision. The large arrow depicts retraction of subcutaneous areolar tissue. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

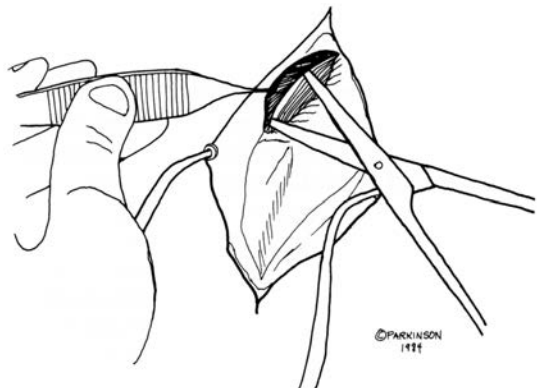


Figure 55-16. Blunt or sharp separation of the fascial raphe between the spinous (or scapular) head of the deltoid and the long head of the triceps muscles is performed. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

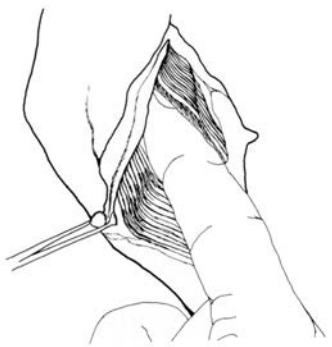


Figure 55-17. Digital blunt dissection between the spinous (or scapular) head of the deltoid and long head of the triceps muscles is carried out to the caudal shoulder joint capsule. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

below the caudal shoulder joint and proceed in a craniodorsal direction. Thus the surgeon does not have to deal with the lateral head of the triceps muscle (See Figure 55-14). The few small muscular branch vessels encountered are either retracted or ligated. A self-retaining retractor is used to maintain separation of the spinous (scapular) head of the deltoid and the long head of the triceps muscles (Figure 55-18). The teres minor is seen crossing the dorsal aspect of the caudal joint capsule (Figures 55-19 and 55-20). The axillary nerve is identified as it crosses the ventral aspect of the caudal joint capsule (Figures 55-21 and 55-22). An incision into the joint capsule is made transversely (perpendicular to the long axis of the humerus) between and parallel to, the teres minor muscle and the axillary nerve (Figure 55-23). This incision

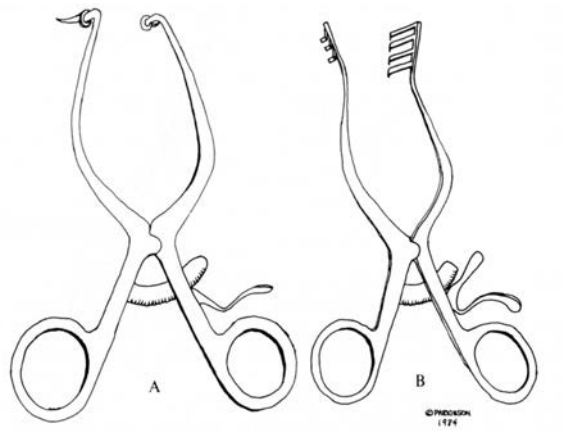


Figure 55-18. Self-retaining Gelpi **A.** or Weitlaner **B.** retractors aid the exposure. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

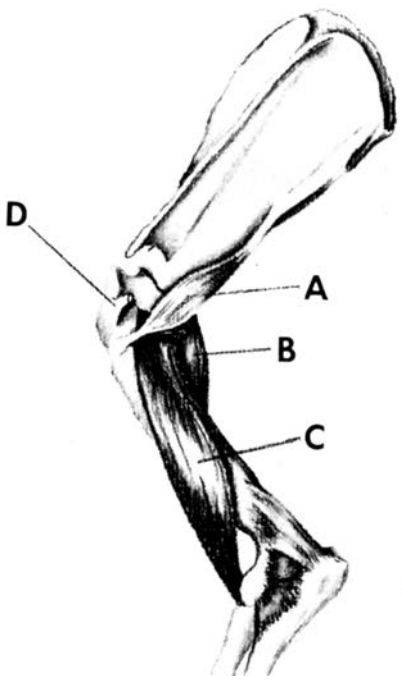


Figure 55-19. The caudal shoulder joint capsule exposed by the muscle separation described in Figures 55-14 and 55-17 lies caudoventrally to the teres minor muscle belly *(A). (B)* coracobrachialis muscle; *(C)* brachialis muscle; *(D)* tendon of insertion of the infraspinatus muscle. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

exposes the caudal glenoid, caudal humeral head, and caudal joint cul-de-sac (Figure 55-24). Another self-retaining retractor may be used here to retract the cut edges of the joint capsule if desired (See Figure 55-18).

A lesion of osteochondritis dissecans can be identified and treated (Figure 55-25). Manipulation of the leg by an assistant aids in identifying the full extent of the lesion (Figure 55-26). The caudal cul-de-sac can be examined and flushed (Figure 55-27).

The caudal shoulder joint capsular incision is closed with a horizontal mattress absorbable suture (Figure 55-28). The fasciae of the spinous (or scapular) head of the deltoid and the long head of the triceps muscles are reapposed with simple continuous absorbable suture (Figure 55-29). The subcutaneous and skin closures are routine (Figure 55-30). Restricted activity is allowed for the first two weeks postoperatively. Slings and splints are not necessary nor are they advised.

Summary and Results

This surgical approach to the caudal shoulder joint offers a number of advantages to other surgical approaches. It is primarily a muscle-separating approach where no tendons or ligaments are incised. It offers excellent visualization of the caudal humeral head and caudal joint cul-de-sac. The skin and the joint capsule are the only tissues sharply incised. This approach offers a less traumatic, less time consuming, and more effective way to manage shoulder OCD. There is no resultant loss of range of motion of the shoulder joint with this procedure. It offers good visualization of the joint (albeit not as exquisite as can be seen with arthroscopy) and recovery is remarkably comfortable and rapid in most patients. The caudomedial joint can be explored via this approach, an area unavailable via a caudolateral approach. In addition, the vascular and neural plexuses are easier to retract and avoid in the caudal approach than in the caudolateral approaches.

Complications are minimal. Seroma formation is extremely rare. Some manipulation of the leg is necessary to fully identify the full extent of some lesions of OCD on the caudal humeral head, but this has not ever precluded visualization of the entire extent of the lesion at surgery. The facts that the surgery can be performed quickly and relatively comfortably makes this approach an excellent alternative to the more time-intensive use of arthroscopy. Closure is quick and simple and patients usually return to near normal activity within days after surgery.

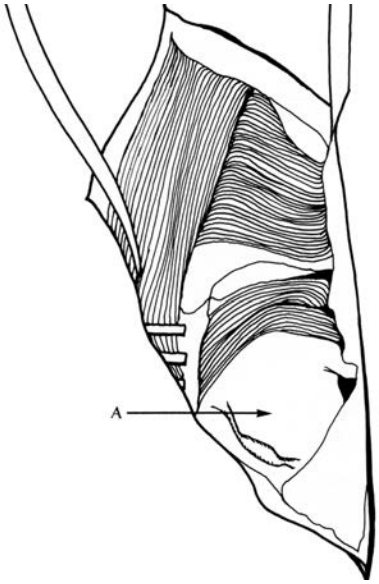


Figure 55-20. Using self-retaining retractors described in Figure 55-18, the caudal shoulder joint capsule is identified easily *(A)*. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

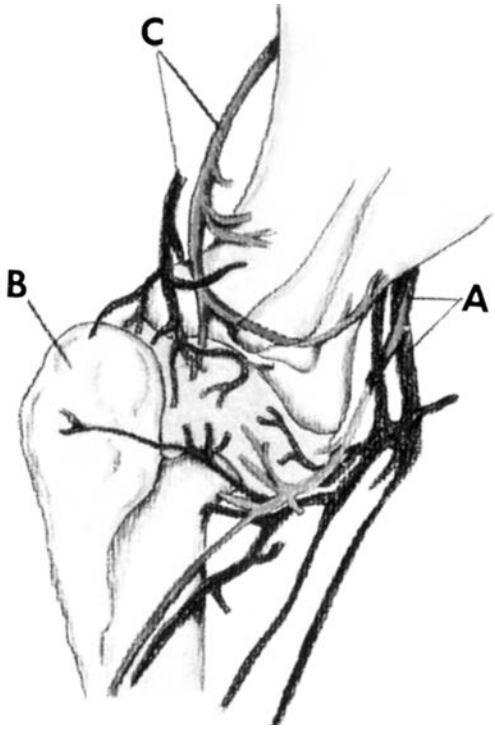


Figure 55-21. The axillary nerve *(A)* exposed in this approach to the shoulder joint runs horizontally across the ventral border of the caudal shoulder joint capsule. *(B)* greater tubercle of the humerus; *(C)* suprascapular artery and nerve. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

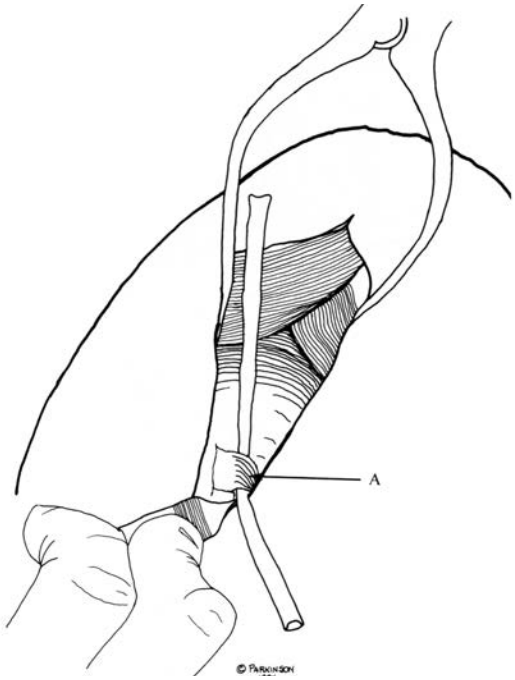


Figure 55-22. The axillary nerve *(A)* is retracted with a soft rubber seton. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

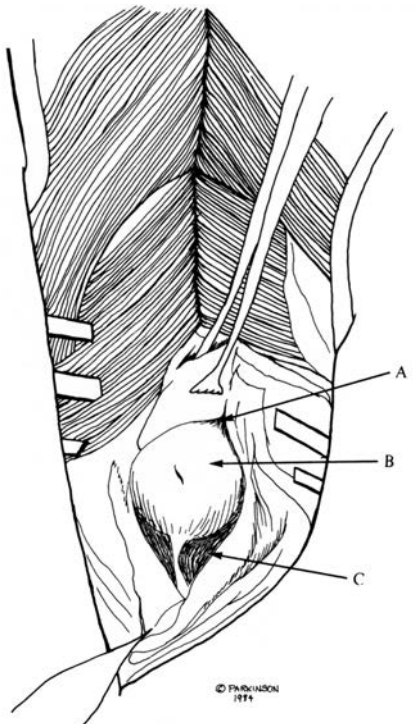


Figure 55-24. Joint capsular incision exposes the caudal glenoid *(A)*, the caudal humeral head *(B)*, and the caudal joint capsule cul-de-sac *(C)*. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

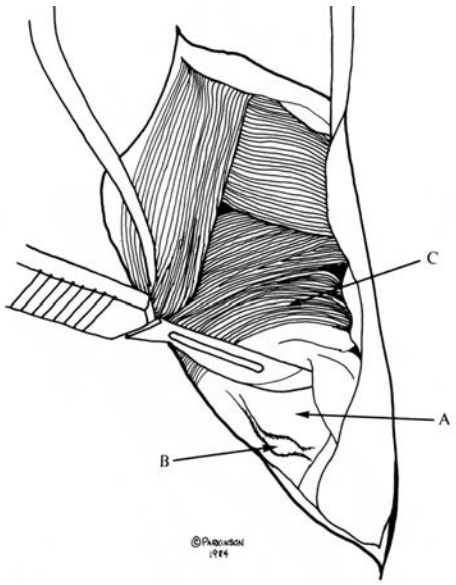


Figure 55-23. The caudal shoulder joint capsule *(A)* is incised longitudinally parallel to, and between, the axillary nerve *(B)* ventrally, and the teres minor muscle dorsally *(C)*. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

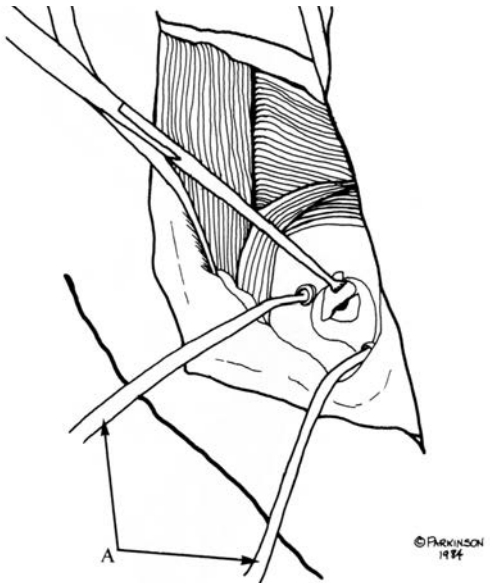


Figure 55-25. Improved exposure for joint inspection is allowed by using a self-retaining retractor *(A)* to retract the incised edges of the joint capsule. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

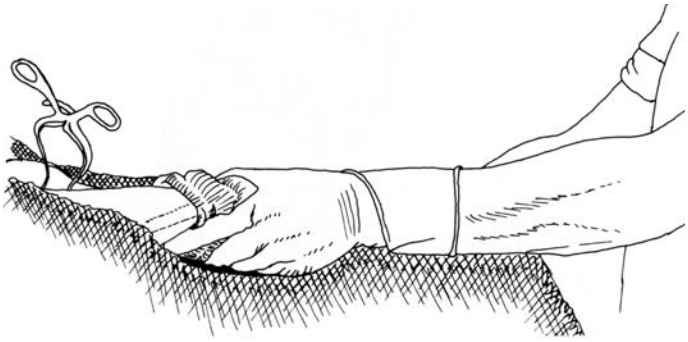


Figure 55-26. An assistant usually is needed to manipulate the patient's leg to allow the surgeon full inspection of an osteochondritis dissecans lesion of the caudal humeral head. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

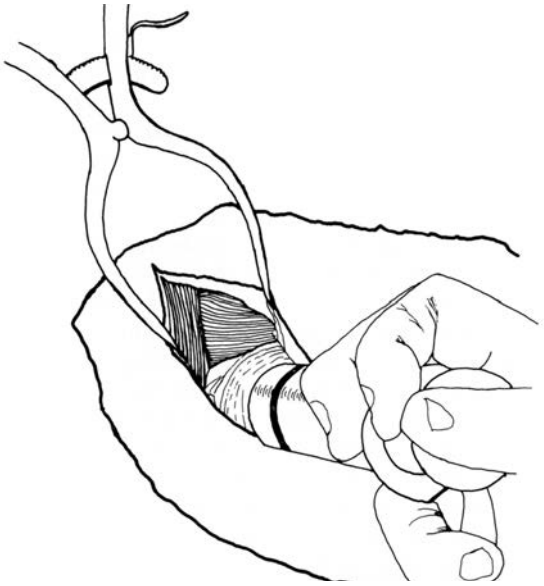


Figure 55-27. The caudal shoulder joint is flushed to remove debris. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

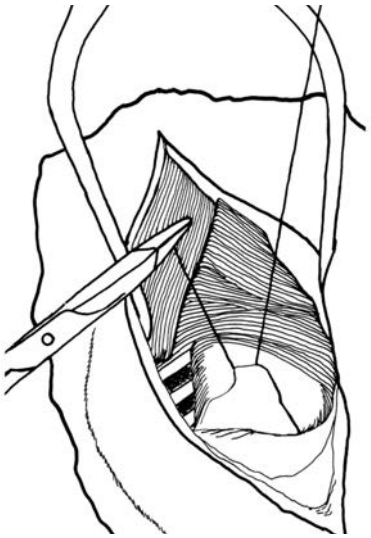


Figure 55-28. An absorbable mattress suture is placed to close the caudal shoulder joint capsular incision. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

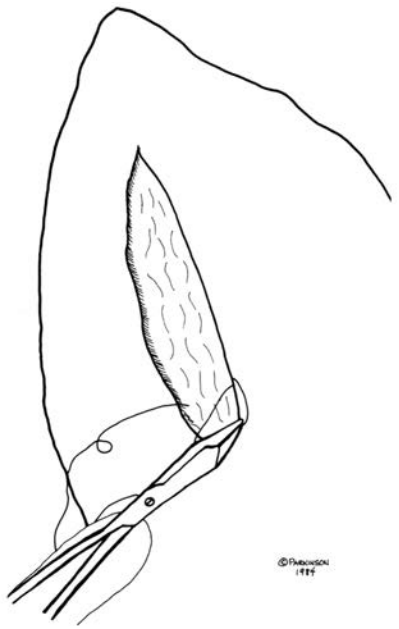


Figure 55-29. A continuous absorbable suture is placed to reappose the spinous (or scapular) head of the deltoid and the long head of the triceps muscles. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

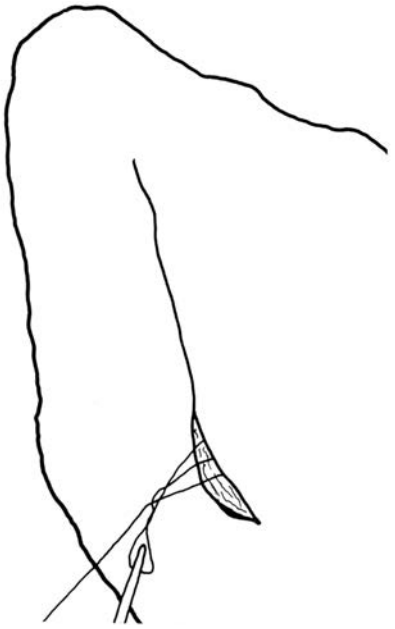


Figure 55-30. Subcutaneous and skin closures are routine. (From Gahring, DR. A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc. 1985:21:613).

Suggested Readings

Gahring, DR: A modified caudal approach to the canine shoulder joint. J Am Anim Hosp Assoc 21:613, 1985.

Gahring, DR: Surgical Treatment of Osteochondritis Dissecans of the Shoulder. In: Bojrab, MJ, ed.: Current Techniques in Small Animal Surgery, 4th Ed. Baltimore: Williams & Wilkins 1998, p 1069.

Surgical Treatment of Biceps Brachii Tendon Injury

James L. Cook

This topic is written based on the available literature through 2010 and does not cover the most current literature on this topic.

Background

Injury or insult to the biceps tendon has been reported as a frequent cause of forelimb lameness in dogs that typically requires treatment.[1-9] Reported pathologic conditions of the biceps tendon include tenosynovitis, partial or complete rupture, avulsion, tendinitis, tendinosis, displacement, and bipartite tendon. The pathology, epidemiology, and diagnostics associated with these conditions have been described.[1-9] Biceps tendon injuries occur most commonly in middle-aged medium and large breed dogs that participate in athletic activities. There is no documented gender predisposition to the author's knowledge. Apart from rupture or avulsion, dogs with biceps tendon pathology are presented for a unilateral forelimb lameness of insidious onset. Dogs are typically weightbearing on the affected limb. Rupture or avulsion may result in a lameness that is acute and more severe.

Diagnostics

Physical examination findings in dogs with biceps tendon pathology are very similar regardless of the specific cause. The most consistent findings include mild to moderate atrophy of the affected spinatus muscles, pain on shoulder flexion (especially with the elbow extended), and pain on direct palpation of the biceps tendon and/or manual tensioning of the biceps muscle.[1-6,23]

Definitive diagnosis and characterization of the type of pathology of the biceps tendon typically require more advanced imaging modalities such as contrast arthrography, ultrasonographic evaluation and/or arthroscopic visualization. Plain radiographic views of the affected shoulder joint provide relevant information regarding secondary bone and soft tissue changes and should be included in the diagnostic database. "Skyline" radiographic views may aid in evaluating the biceps groove.[3,7] In cases of bicipital tenosynovitis, radiographs may show evidence of osteophytosis and enthesiophytosis associated with the biceps tendon and groove (Figure 55-31). Contrast arthrography provides additional information regarding the anatomy and integrity of the biceps tendon. Contrast arthrography is reported to be sensitive for identifying biceps tenosynovitis,[7] but generally does not delineate type or extent of the pathology or give information regarding changes within the tendon tissue.[1-3,7-9] Ultrasonography of the biceps tendon, performed by an experienced individual, provides for assessment of intratendinous pathology, associated effusion, and pathologic changes of the biceps groove (Figure 55-32).[5,7,21] Ultrasonography is helpful for determining the type and severity of the pathology in the majority of cases. Arthroscopic evaluation of the shoulder joint allows for visualization and assessment of all intra-articular structures providing definitive evidence of visible biceps pathology as well as involvement of other tissues (Figure 55-33). Techniques for exploratory arthroscopy of the

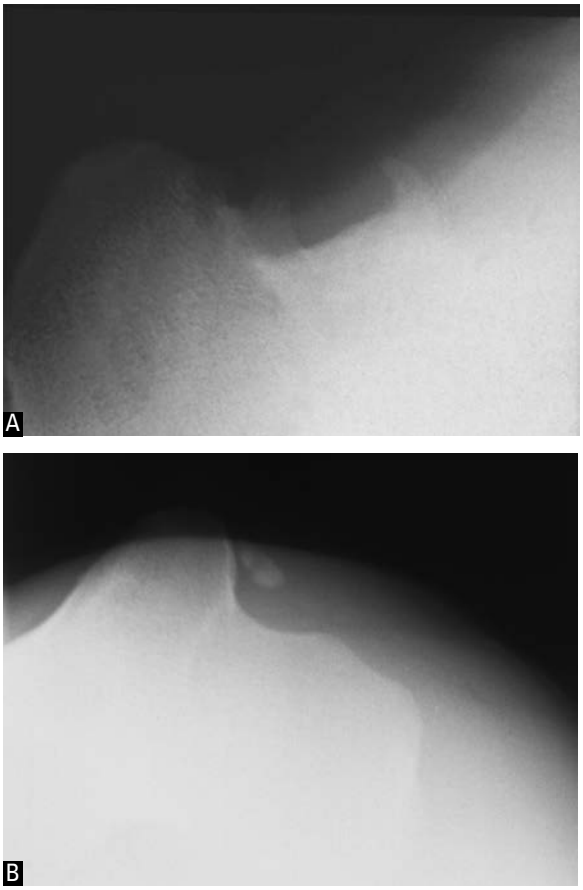


Figure 55-31. "Skyline" radiographic views showing osteophytosis and enthesiophytosis associated with the biceps groove **A.** and tendon **B.**

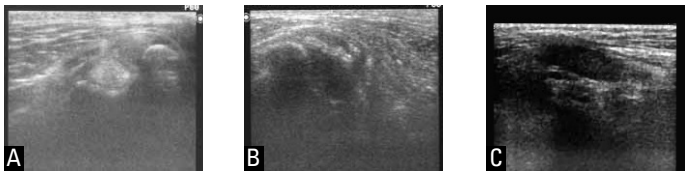


Figure 55-32. Ultrasonographic images showing a transverse view of a normal **A.** biceps tendon and transverse **B.** and longitudinal **C.** views of a biceps tendon with disruption of normal tendon architecture and associated effusion indicating biceps tenosynovitis from a partial tear.

shoulder joint of dogs have been previously described.[4,5,10,21,22,23] Arthroscopic evaluation of the shoulder joint is recommended as the diagnostic modality of choice as it allows for visualization, "palpation", biopsy, and when necessary, treatment, of pathology. More advanced imaging techniques such as computed tomography and magnetic resonance imaging are currently being investigated for their usefulness for diagnosis of shoulder joint pathology in dogs.[19,26,28]

It is critical to perform a comprehensive diagnostic evaluation of dogs suspected, or even confirmed, to have biceps tendon pathology. Biceps tendon pathology can be a secondary or incidental finding. Many dogs with biceps tendon problems will also have elbow pathology, neurologic dysfunction, or neoplasia. In addition, the biceps tendons of insertion may be a primary or additional source of pain in these cases.[24,28] It is vital to look for other pathology in every dog diagnosed with biceps tendon disorders as these other problems are often more clini-



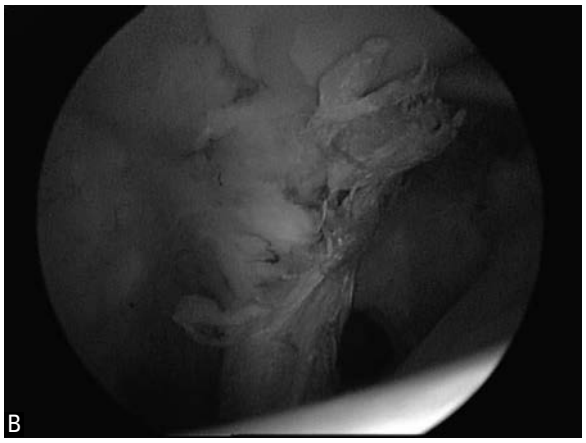


Figure 55-33. Arthroscopic views of a normal biceps tendon **A.** a biceps tendon with severe partial tearing **B.** and a biceps tendon with tenosynovitis and partial avulsion.

cally important and will greatly affect treatment and prognosis. Complete neurologic examination and radiographs of the elbows are recommended in all cases.

Surgical Treatment

When biceps tendon pathology is determined to be a significant cause of pain, lameness, and/or dysfunction in dogs, treatment is indicated. Non-surgical management of biceps tendon pathology consisting of activity modification, non-steroidal anti-inflammatory drugs, analgesics, and/or intra-articular injections may be effective in many cases.[1-3,8,22] However, surgical management often becomes necessary in a significant number of these patients.[1-5,8] The reported surgical treatment options for biceps tendon disease include tenodesis, tenotomy, primary repair, debridement, transposition, and lavage.[1-5,8] Primary repair, debridement, and transposition are rarely indicated for primary lesions of the biceps tendon and will not be addressed further in this chapter. Based on the published veterinary literature, biceps tenodesis via an open approach and open or arthroscopic biceps tendon release (tenotomy) are the most common surgical procedures used to treat biceps tendon problems in dogs.[1-4,8,20] Arthroscopic tenodesis has also been reported to be a successful means of treatment for biceps disorders in dogs.[5]

Tenotomy

Open tenotomy is performed through a modified cranial approach to the shoulder joint.[11] After incision of the skin over the cranial aspect of the distal scapula and medial aspect of the greater tubercle, the supraglenoid tubercle can be palpated proximal to the pectoral muscles. The fascia and joint capsule over the supraglenoid tubercle can be incised taking care to avoid the suprascapular nerve and associated vessels proximally. The biceps tendon can then be visualized and tenotomized at its origin using a scalpel blade, scissors, or other appropriate cutting device. Routine closure of the joint capsule, fascia, subcutaneous tissues, and skin is performed.

For arthroscopic tenotomy,[4] a caudolateral camera portal and craniolateral instrument portal are used.[10] Complete arthroscopic assessment of the joint is performed, and the biceps tendon is identified and assessed. The biceps tendon is tenotomized at its origin using a scalpel blade (beaver blade or #11 blade), arthroscopic scissors or basket forceps, a motorized shaver, radiofrequency, or electrosurgical device placed through the instrument portal (Figure 55-34). The skin incisions are closed routinely.

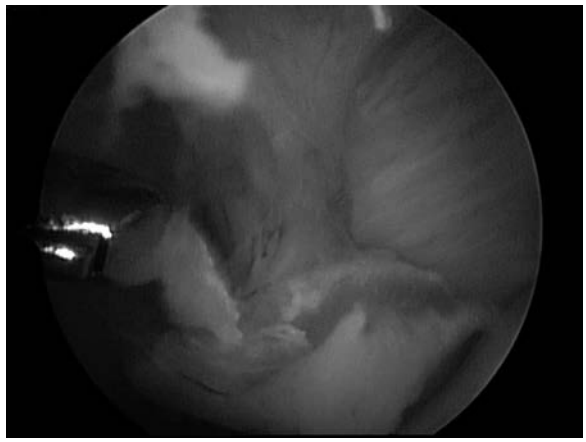


Figure 55-34. Arthroscopic view of a biceps tendon after tenotomy performed using basket forceps shown.

Tenodesis[3]

After performing a cranial approach to the shoulder,[11] the biceps tendon is visualized and detached from its origin on the supraglenoid tubercle. The tendon is then transposed laterally and fixed to the proximal humerus in one of three ways: 1) the tendon can be passed from medial to lateral through a hole drilled through the greater tubercle that is large enough to accommodate the diameter of the tendon and then sutured to the periosteum laterally and medially; 2) the greater tubercle can be osteotomized, the tendon placed at the site of osteotomy and the tubercle reattached over the tendon using a tension band wire technique; or 3) a longitudinal incision is made in the biceps tendon, a cancellous bone screw with spiked washer is placed through the incision and into the bone to attach the tendon at its transposed location. The elbow is held in extension and adequate length of tendon ensured prior to fixation. Routine closure of the joint capsule, muscle and fascia, subcutaneous tissues, and skin is performed. Postoperative radiographs should be obtained in all cases.

Arthroscopic Tenodesis[5]

The technique is performed using a caudolateral camera portal and two instrument portals (i.e., craniolateral and cranial) (Figure 55-35). The arthroscope is inserted and the joint thoroughly evaluated for pathology of all relevant structures. The biceps tendon is identified and a 16-gauge spinal needle, or other

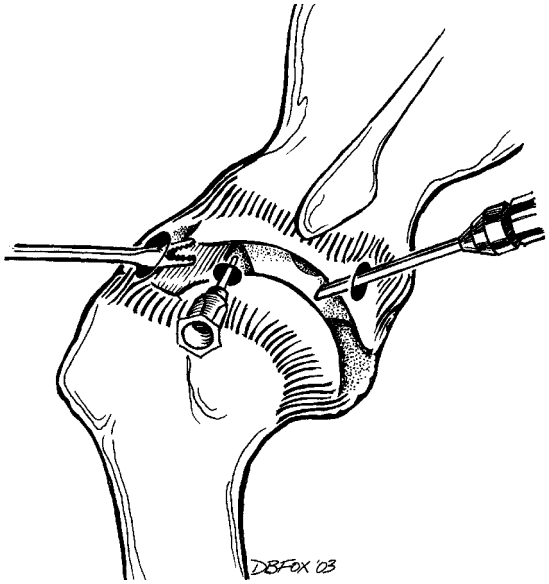


Figure 55-35. Illustration showing the anatomical locations of the three arthroscopic portals used for arthroscopic assisted tenodesis (reprinted from Cook JL, et al. J Am Anim Hosp Assoc 2005; 41:121-127 with permission).

suture-passing device, inserted through the craniolateral portal and through the biceps tendon at its proximal aspect. Suture (#2 braided polyblend suture (FiberWire suture, Arthrex, Naples, FL 34104) or 0 polypropylene suture (0 Prolene, Ethicon, Somerville, NJ 08876) with the needle removed) is passed through the tendon. The suture-passing device is removed, and both ends of the suture are grasped through the cranial portal and pulled through the skin using arthroscopic grasping forceps. The suture ends are clamped with a mosquito forceps. The biceps tendon is then released at its attachment of origin on the supraglenoid tubercle using a basket forceps, scalpel blade, motorized shaver, or other cutting device (Figure 55-36). An intramedullary pin is then inserted through the cranial portal to locate the point of drilling for tendon fixation insertion. The point of fixation placement should be the most distal point in the biceps groove that is visible arthroscopically with the shoulder held at a weight bearing angle (approximately 110 to 130°). The appropriate drill sleeve for the intended fixation device is then inserted over the pin. The pin is removed and the appropriate drill bit inserted through the drill sleeve and used to drill a hole through the cis cortex of the proximal humerus. The drill bit and sleeve are removed and the fixation device is inserted and tightened to fix the tendon to the proximal humerus (Figure 55-37). It is imperative that the elbow be held in extension and that adequate tendon length is verified prior to insertion of the fixation device. At least two different devices can be used for fixation. When using the Arthrex® Biceps Tenodesis 5.5 mm non-absorbable cannulated interference screw system (Bio-Tenodesis System, Arthrex, Naples, FL 34104), the suture in the tendon is pulled through the cannulated screw using the driver. The screw is inserted into the hole pulling the tendon with it, and the screw is tightened until it is flush with the bone (Figure 55-38). A 3.0 mm cannulated screw (3.0 mm cannulated screw, Synthes, Monument, CO 80132) and tissue washer (spiked washer, Synthes, Monument, CO 80132) can also be employed effectively (Figure 55-39). When using the cannulated screw and washer, the cannulation wire is placed

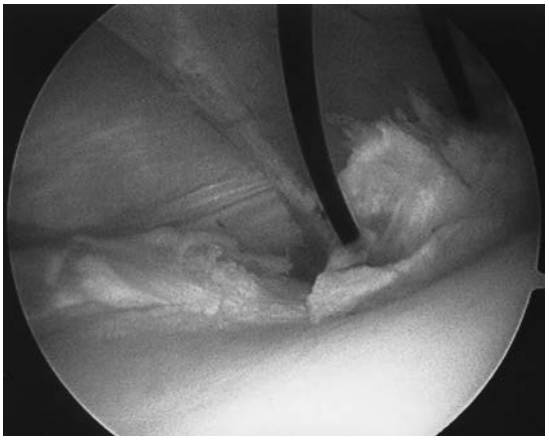


Figure 55-36. Arthroscopic view of a biceps tendon during tenodesis procedure. A suture has been placed through the tendon prior to tenotomy. (reprinted from Cook JL, et al. J Am Anim Hosp Assoc 2005; 41:121-127 with permission).

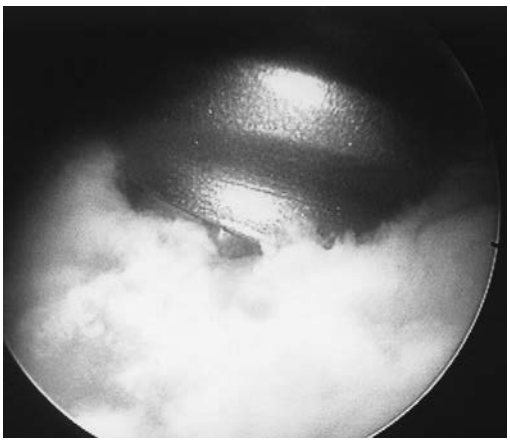


Figure 55-37. Arthroscopic view of an Arthrex biceps tenodesis cannulated interference screw being placed in the biceps groove of the humerus to accomplish fixation of the biceps tendon during tenodesis (reprinted from Cook JL, et al. J Am Anim Hosp Assoc 2005; 41:121-127 with permission).

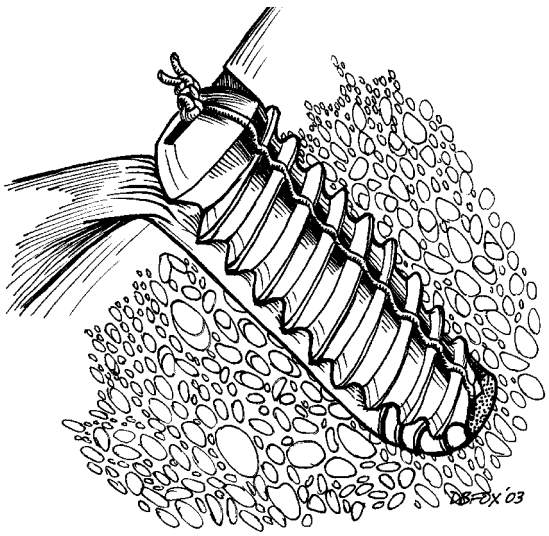


Figure 55-38. Illustration showing the method of fixation of the biceps tendon when using the Arthrex biceps tenodesis cannulated interference screw with suture for arthroscopic biceps tenodesis (reprinted from Cook JL, et al. J Am Anim Hosp Assoc 2005; 41:121-127 with permission).

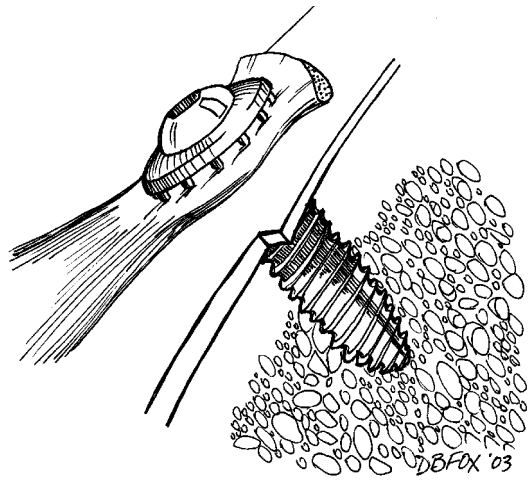


Figure 55-39. Illustration showing the method of fixation of the biceps tendon when using the screw and tissue washer method for arthroscopic biceps tenodesis (reprinted from Cook JL, et al. J Am Anim Hosp Assoc 2005; 41:121-127 with permission).

through the tendon at the level of the suture. The drill bit is then inserted over the wire and the hole is drilled. The cannulated screw with washer is then driven through the tendon into the hole and tightened until the washer firmly engages the tendon and contacts the underlying bone. Again, the elbow should be held in extension during final screw insertion. The skin incisions are closed routinely and postoperative radiographs are taken.

Postoperative Care

For open tenodesis cases, home care instructions included 10 to 15 minute walks 3 to 4 times a day, and ice packing the surgery site for 5 to 10 minutes twice daily. Jumping, running, or off leash activity were prohibited for 2 weeks. The use of a Velpeau sling for 10 days and restriction of exercise to on-leash activities for 6 to 8 weeks following open tenodesis has been recommended.[3]

For arthroscopic tenodesis cases, clients are instructed to allow short leash walks only, and to restrict the dog to a cage, crate, or kennel when unobserved. These restrictions apply to the first 6 weeks after surgery. If the dog can bear weight on the operated limb with no evidence of pain or displacement of the biceps muscle, and no evidence of implant failure is present at the 6 week recheck, a progressive return to full activity is encouraged over the subsequent 6 weeks. Range-of-motion exercises and non-concussive activities such as swimming and leash walking are encouraged during the second 6 week period. Full, unrestricted activity is allowed after 12 weeks of rehabilitation. Additional restrictions and rehabilitation modalities are tailored to each individual case.[4,25]

Complications

If osteoarthritis is present in the affected joint at the time of surgery, progression is likely regardless of the surgical technique employed. For arthroscopic tenotomy cases, reported complications include progression of radiographic pathology, continued pain and lameness and/or recurrence of pain and lameness.[4,20] Other complications that have been associated with open or arthroscopic tenotomy include seroma formation, change in appearance of the brachial musculature, and infection.

In cases of open tenodesis, delayed union of the tubercle osteotomy, implant migration, and seroma formation have been reported.[3] In the published report on arthroscopic tenodesis, seroma formation was the only reported complication.[5] No biceps muscle displacement or laxity was reported for any of the tenodesis cases following surgery.

Prognosis

For arthroscopic biceps tenotomy for treatment of bicipital tenosynovitis, good to excellent results were obtained in all five dogs in one series based on subjective measures over a 6 month follow-up period.[4] In another series of cases, excellent outcomes were reported for 22 of 25 shoulders assessed of a mean of 26 months postoperatively.[20]

Open tenodesis has been associated with good and excellent outcomes in more than 90% of dogs treated.[3,8] In the single published report on arthroscopic tenodesis, all 6 dogs treated were judged to have good or excellent outcomes according to the owners.[5] Owners reported that full return to function was typically evident by 12 to 18 weeks after surgery. Follow-up times range from 5 months to 18 months (mean = 11.7 months, median = 12.5 months). Return of spinatus and brachial muscle mass symmetry and resolution of lameness were evident in all cases based on subjective evaluation by the surgeon.

The published literature regarding surgical treatment of biceps tendon pathology suggests that weight management and physical rehabilitation are critical for a successful outcome when treating biceps tendon problems using any modality.[1-5,8] In addition, maximal function may not be reached until 6 months following surgery in the majority of cases.

Summary

Both tenotomy and tenodesis are used in people for treatment of biceps tendon pathology.[12-18] Indications and recommendations for tenotomy versus tenodesis vary among types of pathology; patient age; activity level and expectations; and surgeons' preferences.[12-18] Good and excellent results have been reported for both tenodesis and tenotomy in people, and many surgeons recommend achieving competence in both techniques to provide comprehensive treatment options and patient care.[14-18] Tenotomy has been reported to provide similar outcomes in terms of cosmetic appearance, anterior shoulder pain, and degree of muscle spasms in humans with chronic bicipital pain.[14] However, to the authors' knowledge, no studies have compared functional outcomes of arthroscopic biceps tenotomy versus tenodesis in terms of limb strength and activity levels in the human or veterinary literature. Tenodesis is typically recommended over tenotomy in athletic people, especially those who participate in overhead athletic activities.[16-18] Similarly, athletic dogs may benefit from tenodesis when compared to tenotomy. In addition, since dogs have the added function of weight bearing in the forelimb, tenodesis might be advantageous for dogs. This consideration was supported by the excellent long-term results of open biceps tenodesis reported by Stobie, et al.[3] The theoretical advantages of tenodesis may be further optimized by employing an all-arthroscopic technique in order to minimize soft tissue

disruption and the associated pain, morbidity, complications, and recovery time. While arthroscopic tenodesis is technically demanding, repetition and experience allow for more efficient and precise implementation of the procedure. The technical demands, surgical time, and costs associated with arthroscopic tenodesis far exceed those for tenotomy. However, the indications, as well as the long-term outcomes, of arthroscopic biceps tenotomy versus tenodesis have not been determined in dogs. Therefore, it is important to explore the feasibility and results of both techniques until definitive conclusions regarding their efficacy can be drawn from scientific data. Long-term studies are needed to determine the effects of arthroscopic tenotomy versus tenodesis on muscle, elbow, and limb function before definitive recommendations regarding indications, complications, and prognosis can be made.

References

1. Bardet JF. Shoulder diseases in dogs. *Vet Med* Dec: 909, 2002.

2. Bardet JF. Lesions of the biceps tendon – diagnosis and classification. *Vet Comp Orthop Traumatol* 12: 188, 1999.

3. Stobiie D, Wallace LJ, Lipowitz AJ, et al: Chronic bicipital tenosynovitis in dogs: 29 cases (1985 – 1992). *J Am Vet Med Assoc* 207: 201, 1995.

4. Wall CR, Taylor R: Arthroscopic biceps brachii tenotomy as a treatment for canine bicipital tenosynovitis. *J Am Anim Hosp Assoc* 38: 169, 2002.

5. Cook JL, Kenter K, Fox DB: Arthroscopic biceps tenodesis: Technique and results in six dogs. *J Am Anim Hosp Assoc* 41: 121, 2005.

6. Gilley RS, Wallace LJ, Hayden DW: Clinical and pathologic analyses of bicipital tenosynovitis in dogs. *Am J Vet Res* 63: 402, 2002.

7. Rivers B, Wallace L, Johnston GR: Biceps tenosynovitis in the dog: Radiographic and sonographic findings. *Vet Comp Orthop Traumatol* 5:51, 1992.

8. Lincoln JD, Potter K: Tenosynovitis of the biceps brachii tendon in dogs. *J Am Anim Hosp Assoc* 20: 385, 1984.

9. Davidson EB, Griffey SM, Vasseur PB, et al: Histopathologic, radiographic and arthrographic comparison of the biceps tendon in normal dogs and dogs with biceps tenosynovitis. *J Am Anim Hosp Assoc* 36 – 522, 2000.

10. Beale BS, Hulse DA, Schulz KS, Whitney WO: Small Animal arthroscopy. Philadelphia: Saunders, 2003.

11. Piermattei DL: An Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat. Philadelphia: Saunders, 1993.

12. Kleps S, Hazrati Y, Flatow E: Arthroscopic biceps tenodesis. *Arthroscopy* 18: 1040, 2002.

13. Boileau P, Krishnan SG, Costa JS, et al: Arthroscopic diceps tenodesis: A new technique using bioabsorbable interference screw fixation. *Artrhsocopy* 18: 1002, 2002.

14. Osbahr DC, Diamond AB, Speer KP: The cosmetic appearance of the biceps muscle after long-head tenotomy versus tenodesis. *Arthroscopy* 18:483, 2002.

15. Gill TJ, McIrvin E, Mair SD, et al. Results of biceps tenotomy for treatment of pathology of the long head of the biceps brachii. *J Shoulder Elbow Surg* 2001; 10: 247 – 249.

16. Berlemann U, Bayley I. Tendonitis of the long head of biceps brachii in the painful shoulder: improving results in the long term. *J Shoulder Elbow Surg* 1995; 4: 429 – 435.

17. Sethi N, Wright R, Yamaguchi K. Disorders of the long head of the biceps tendon. *J Shoulder Elbow Surg* 1999; 8: 644 – 654.

18. Patton WC, McCluskey GM. Biceps tendinitis and subluxation. *Clin Sports Med* 2001; 20: 505 -529.

19. Agnello KA, Puchalski SM, Wisner ER, Schulz KS Kapatkin AS. Effect of positioning, scan plane, and arthrography on visibility of periarticular canine shoulder soft tissue structures on magnetic resonance images. *Vet Radiol Ultrasound.* 2008 Nov – Dec; 49(6): 529 -539.

20. Bergenhuyzen AL, Vermote KA, van Bree H, Van Ryssen B. Long-term follow-up after arthroscopic tenotomy for partial rupture of the biceps brachii tendon. Vet Comp Orthop Traumatol. 2010; 23(1): 51 – 5.

21. Cogar SM, Cook CR, Curry SL, Grandis A, Cook JL. Prospective evaluation of techniques for differentiating shoulder pathology as a source of forelimb lameness in medium and large breed dogs. Vet Surg. 2008 Feb; 37(2): 132 – 141.

22. Cook JL, Cook CR. Bilateral shoulder and elbow arthroscopy in dogs with forelimb lameness: diagnostic findings and treatement outcomes. Vet Surg. 2009 Feb; 38(2): 224 – 232.

23. Devitt CM, Neely MR, Vanvetchten BJ. Relationship of physical examination test of shoulder instability to arthroscopic findings in dogs. Vet Surg. 2007 Oct; 36(7): 661 – 668.

24. Hulse D, Young B, Beale B, Kowaleski M, Vannini R. Relationship of the biceps-brachialis complex to the medial coronoid process of the canine ulna. Vet Comp Orthop Traumatol. 2010; 23(3): 173 – 176.

25. Marcellin-Little DJ, Levine D, Canapp SO Jr. The canine shoulder: selected disorders and their management with physical therapy. Clin Tech Small Anim Pract. 2007 Nov; 22(4): 171 – 182.

26. Murphy SE, Ballegeer EA, Forres LI, Schaefer SL. Magnetic resonance imaging findings in dogs with confirmed shoulder pathology. Vet Surg. 2008 Oct; 37(7): 631 – 638.

27. Schaaf OR, Eaton-Wells R, Mitchell RA. Biceps brachii and brachialis tendon of insertion injuries in eleven racing greyhounds. Vet Surg. 2009 Oct; 38(7): 825 – 833.

28. Schaefer SL, Baumel CA, Gerbig Jr, Forrest LI. Direct magnetic resonance arthrography of the canine shoulder. Vet Radiol Ultrasound. 2010 Jul-Aug: 51(4): 391 – 396.

Excision Arthroplasty of the Shoulder Joint

Donald L. Piermattei and Charles E. Blass

Introduction

Excision arthroplasty of the glenoid rim and humeral head provides a pseudoarthrosis based on fibrous tissue. It is an alternative to arthrodesis or amputation in conditions in which the shoulder joint cannot be adequately reconstructed. Indications for excision arthroplasty include chronic shoulder luxations in which the labrum of the glenoid cavity is excessively worn, severe degenerative joint disease, and irreparable intra-articular fractures, of which gunshot wounds are the most common example. The traditional method of treatment in these animals has been arthrodesis, which is technically demanding and requires bone-plating equipment in most cases.

While encouraging results have been obtained with this procedure, it has only been performed in a small number of patients. We recommend this procedure only as a salvage procedure with a fair to good prognosis for pain free normal, nonathletic function. As in the case of excision arthroplasty of the hip, more normal function can be anticipated in small breeds of dogs than in large breeds. The technique has been performed

bilaterally in a small-breed dog with good functional results by 4 months postoperatively.

Surgical Technique

The shoulder joint is exposed by a craniolateral approach with osteotomy of the acromion process. The tendons of insertion of the infraspinatus and teres minor muscles are transected and retracted caudally with stay sutures. The joint capsule is cut close to the glenoid rim and opened widely, and the tendon of origin of the biceps brachii muscle is transected near the supraglenoid tubercle (Figure 55-40). Ostectomies of the glenoid rim and humeral head (Figure 55-41) are made with and sharp osteotome, oscillating saw, or high-speed rotating burr. Care is taken to protect the suprascapular nerve and caudal circumflex humeral artery during the ostectomies. If the suprascapular nerve passes too closely to the ostectomy site, a notch may be cut in the base of the scapular spine to allow proximal displacement of the nerve. An alternative to ostectomy of the glenoid rim is removal of the articular cartilage of the glenoid to expose subchondral bone, thus opening vascular channels. This also obviates the necessity to detach the biceps tendon.

If the tendon of the biceps brachii was detached, it is reattached to the fascia of the supraspinatus muscle. The teres minor muscle is pulled between the cut surfaces of the scapula and humerus and sutured to the biceps tendon and medial joint capsule (Figure 55-42). The remaining jont capsule is pulled into the ostectomy site and sutured to the teres minor muscle and tendon. This interposition of soft tissues between the cut surfaces of the scapula and humerus is thought to hasten the formation of a fibrous false joint (pseudoarthrosis). The infraspinatus muscle is sutured to its insertion on the humerus. Finally, the acromion process is reattached to the spine of the scapula. It may be necessary to wire the acromion process more proximally than normal to remove laxity in the deltoideus muscle. Subcutaneous tissues and skin are closed routinely.

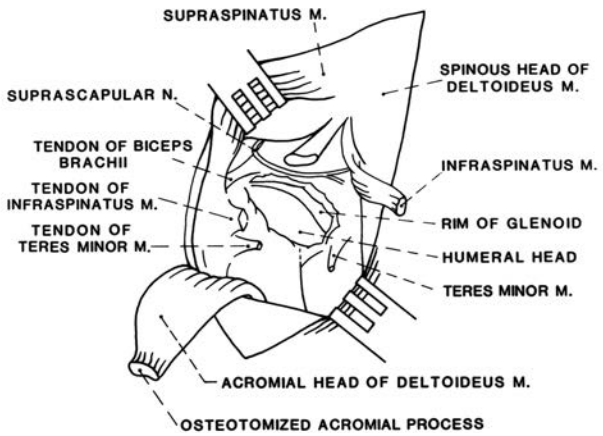


Figure 55-40. Following a craniolateral approach to the shoulder, tenotomies are performed on the biceps brachii, infraspinatus, and teres minor muscles. The joint capsule is cut close to the glenoid rim while preserving its attachment to the humeral head. (From Piermattei DL, Flo GL, DeCamp CE: Brinker, Piermattei, and Flo's Handbook of Small Animal Orthopedics and Fracture Repair, 4th ed. Philadelphia. W. B. Saunders, 2006).



Figure 55-41. Location of ostectomies in the glenoid rim andhumeral head. A small notch may be cut in the base of the scapular spine to allow the suprascapular nerve to be positioned more proximally ig it courses too near the ostectomy site(From Piermattei DL, Flo GL, DeCamp CE: Brinker, Piermattei, and Flo's Handbook of Small Animal Orthopedics and Fracture Repair, 4th ed. Philadelphia. W. B. Saunders, 2006).

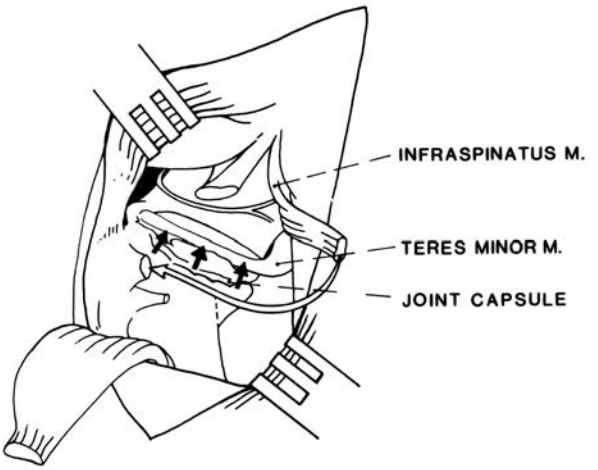


Figure 55-42. After ostectomies are completed, the teres minor muscle is pulled medially and sutured to the biceps tendon, which has previously been sutured to the fascia of the supraspinatus muscle. Joint capsule from the humeral head is sutured to the teres minor (arrows). The infraspinatus is reattached to its insertion, and the acromion process is wired to the spine more proximally than normal. (From Piermattei DL, Flo GL, DeCamp CE: Brinker, Piermattei, and Flo's Handbook of Small Animal Orthopedics and Fracture Repair, 4th ed. Philadelphia. W. B. Saunders, 2006).

Postoperative Care and Prognosis

Early use of the leg is encouraged by leash walking. Passive flexion and extension of the shoulder joint as well as analgesic therapy may be helpful in encouraging use of the leg. More vigorous activity is forced beginning 10 days postoperatively, and swimming is encouraged following suture removal. Early use of the leg stimulates the fibrosis necessary to create a functional pseudoarthrosis. Professional physical therapy starting at two weeks postoperatively will speed recovery.

Thirteen cases have been reported in two small series (Breucker and Piermattei 1988, and Franczuski and Parkes 1988). Good to excellent pain-free-function was obtained in each case. As previously noted, resection of the glenoid rim and humeral head must be considered a salvage procedure, and return to normal function of the limb cannot be expected. Pain-free use of the leg is usually achieved, although a mild gait abnormality and shoulder girdle muscle atrophy will be seen. Full recovery generally requires 3 to 6 months.

Suggested Readings

Breucker KA, Piermattei DL: Excision arthroplasty of the canine scapulo-humeral joint: Report of three cases. Vet Comp Orthop Trauma 3:134, 1988.

Franczuski D, Parkes LJ: Glenoid excision as a treatment in chronic shoulder disabilities: Surgical technique and clinical results. J Am Anim Hosp Assoc 14:637, 1988.

Piermattei DL, Flo GL, DeCamp CE: Brinker, Piermattei, and Flo's Handbook of Small Animal Orthopedics and Fracture Repair, 4th ed. Philadelphia. W. B. Saunders, 2006, p. 273.

Piermattei DL, Johnson KA: An Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat, 4th ed. Philadelphia. Saunders, 2004, p. 112.

Shoulder Arthrodesis

Arnold S. Lesser

Indications

Arthrodesis of the shoulder joint is not common but any condition resulting in intractable pain and dysfunction is an indication for arthrodesis. Malunion and highly comminuted articular fractures can lead to severe DJD. Untreated OCD and chronic luxation of the shoulder especially medial luxation in miniature breeds is another cause of DJD. It is unusual for the arthritis to be severely debilitating. But, when it is and conservative therapy is no longer controlling the pain arthrodesis becomes an option.

Surgical Approach

The approach to the shoulder is simplified by both an osteotomy of the acromial process of the scapula, and the greater tubercle of the humerus. The acromion process can then be retracted distally with the deltoid muscle. Osteotomy of the greater tubercle allows retraction of the supraspinatus muscle and also provides a smooth bed for the plate. The suprascapular nerve should be isolated and protected where it crosses the neck of the scapula. The biceps tendon can be transected from the supraglenoid tubercle if necessary (Figure 55-43).

Procedure

The cartilage is removed from both articular surfaces and a pin or K-wire is used to hold the joint in the proper position. This position is about 105 degrees and can be measured from the standing angle of the controlateral shoulder joint. Two flat congruent surfaces can be formed with an oscillating saw or osteotome. This will create a stable junction and also dictate the angle of the arthrodesis, an important consideration when making these cuts. Cancellous bone graft or substitute is placed between and around the fresh surfaces. Plates provide good long term, stable fixation and are the recommended implant. Compression should be used whenever possible. The scapula is a very thin bone and to get the best purchase for the screws the plate is placed along the cranial aspect of the spine and is twisted caudally to engage the bone where the spine arises from the body. Distally the plate is placed over the craniolateral aspect of the humerus. At least 4 to 5 screws should be placed in the humerus and in the scapula. The longer the plate the more the stresses are distributed and therefore not concentrated over the arthrodesis site. This is especially true of the scapular portion because of the thin bone

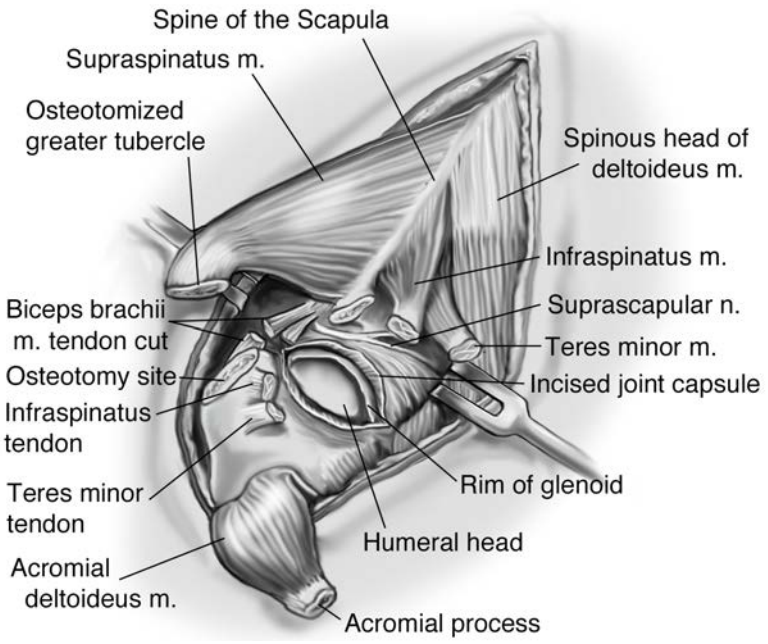


Figure 55-43. The approach to the shoulder joint is facilitated by osteotomy of the acromial process and greater tubercle. The suprascapular nerve should be isolated and protected.

and poor screw purchase. Care must be taken where the plate crosses the suprascapular nerve. The nerve can be placed under or over the plate depending on which places the least tension on the nerve itself. Part of the greater tubercle can be used for graft and the remainder can be attached to the humeral head. If the biceps tendon was transected it can be reattached to the humeral head with a screw and washer (Figure 55-44).

In small or miniature breed dogs combinations of compression screws and pins can also be used but with the availability of 1.5 mm and 2.0 mm plates I would still recommend plate fixation. After removing the cartilage, small pins or Kirschner wires can be passed from the glenoid or neck of the scapula into the humeral head and vise versa. A screw under compression can also be placed from the humeral head into the neck. The surfaces are prepared as described above. The problem with this fixation is that all the implants are concentrated right at the arthrodesis site where there are significant forces trying to create motion because of the long lever arm of the humerus. A secondary support such as a spica cast or splint extending over the shoulder and back will help distribute these forces and should be used with pin and screw fixation. The splint should be left on until signs of fusion are evident radiographically. Even with a plate fixation secondary coaptation is beneficial but does not need to be left on as long.

Even with a successful arthrodesis of the shoulder function may vary from patient to patient. However, there is still some motion preserved from the muscular sling that attaches the scapula to the body wall.

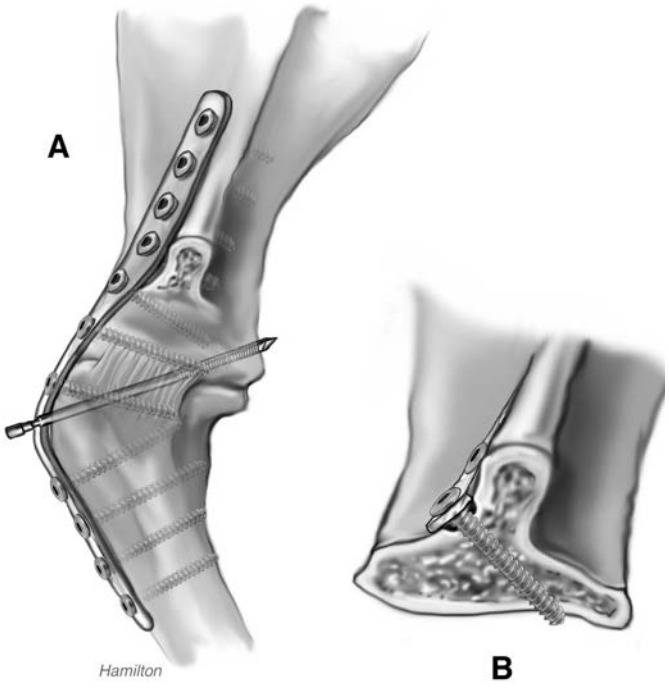


Figure 55-44. A longer plate angled to engage the base of the spine should be used because of the thin bone of the scapula. A pin should be paced across the joint to hold it in position prior to plate placement. The suprascapular nerve should be placed so there is no tension from the plate.

Suggested Readings

Piermattei DL, Flo GL: Brinker, Piermattei, and Flo's Handbook of Small Animal Orthopedics and Fracture Repair 3rd Edition. W.B. Saunders. Philadelphia. 1997.

Lesser: Arthrodesis. In Slatter: Textbook of Small Animal Surgery. Saunders. Philadelphia. 2003.

Chapter 56

Humerus and Elbow Joint

Repair of Fractures of the Humerus

Dennis A. Jackson

Editor's Note – The reader is encouraged to review other sections of this text regarding more recent options for the repair of humeral fractures: Chapter 50 – Interlocking Nailing; Chapter 51 – SOP Locking Plates; Chapter 52 – Plate-Rod Fixation; and Chapter 53 – Hybrid External Skeletal Fixation.

Proximal Fractures

Greater Tubercle

Fractures involving the greater tubercle of the humerus are rare. In young animals, these fractures are stabilized with two Kirschner wires or small Steinmann pins. In mature animals, a tension band wire technique is recommended. In both cases, open reduction is required through a craniolateral approach to the proximal humerus. External coaptation is not required, but restricted weightbearing is recommended until bone healing is confirmed by radiographic evaluation.

Humeral Head

Most fractures of the humeral head are caused by gunshot injuries and are highly comminuted. Reconstruction of the articular surface must be exact and is paramount to the successful return of joint function. Exposure of the articular surface of the humeral head can be difficult. A craniolateral approach to the shoulder joint is combined with an osteotomy of the acromion process and tenotomy of the infraspinatus and teres minor muscles as required to obtain surgical exposure. A supraspinatous tenotomy may be necessary to provide adequate visualization of the joint.

The fracture is reduced, and large articular fragments are compressed with lag screw fixation. Small fragments are reduced and are stabilized with multiple Kirschner wires or Stille nails placed at divergent angles. All pins and screws should be countersunk below the articular cartilage. Small Kirschner wires may be used to immobilize articular fragments temporarily while lag screws are placed. The Kirschner wires can be removed once lag screw fixation is completed. Autogenous cancellous bone grafts are used to fill large bone defects. After placement of each implant, the joint should be palpated in all planes to evaluate range of motion and crepitus. If crepitus is detected, the fixation is adjusted before the placement of the remaining implants. The fracture is stabilized, and the joint is lavaged thoroughly before joint capsule closure. Osteotomy of the acromion process is repaired with a tension band wire. The tenotomies and remaining soft tissues are sutured routinely.

For patients with fractures with severe comminution of the articular surface, surgical arthrodesis should be considered as a salvage procedure. Arthrodesis is especially indicated in medium to large breed dogs with severe joint comminution. For small dogs and cats with irreparable joint damage, the humeral head may be excised, or a Velpeau bandage or spica splint may provide adequate coaptation for functional healing. The goal of external coaptation or excision of the humeral head is to produce a functional, pain-free joint or pseudoarthrosis. Failure to obtain functional use of the limb or persistent pain in these patients is an indication for arthrodesis of the joint.

Growth Plate Injuries

Growth plate injuries, which occur in young animals with an open epiphyseal plate, are usually secondary to direct trauma or avulsion injuries. Physeal or epiphyseal plate injuries are classified by the Salter system. This clarifies the site of injury and is useful when selecting treatment and for predicting outcome. A Salter I fracture extends across the epiphyseal plate parallel to the joint surface. A Salter II fracture extends through the epiphyseal plate and includes a small portion of the metaphysis. These fractures are the most common growth plate injuries of the proximal humerus, and both carry a good prognosis if they are repaired early and accurately.

Most Salter I and II fractures require open reduction and internal fixation. The exception is selected Salter I fractures of less than 24 hours' duration in small dogs and cats. These fractures may be managed by closed reduction with the animal under general anesthesia. Manual traction of the distal limb is performed to fatigue the muscle contraction and to achieve reduction and alignment. The proximal physeal fragment is immobilized by grasping the acromion process of the scapula while the distal segment is gently reduced by abduction and adduction of the elbow. Care must be taken to avoid splitting the proximal physis at the thin junction between the humeral head and greater tubercle. Once reduction is achieved, closed normograde pinning using Kirschner wires or Steinmann pins is performed. The pins or wires are passed from the craniolateral aspect of the greater tubercle at a 20 to 30° angle to the long axis of the humeral shaft (Figure 56-1). Alignment and fixation are evaluated with anteroposterior and lateral postreduction radiographs.

Failure to obtain closed reduction or fracture duration of more than 24 to 36 hours is an indication for an open craniolateral approach to the proximal humerus. The fracture should be reduced carefully by gentle levering and distraction to ensure that soft tissues do not become interposed in the fracture site. A small Adson periosteal elevator or a Hohmann retractor facilitates levering and reduction of the fragment. Small Kirschner wires, Steinmann pins, or double Rush pins are the preferred methods for internal fixation. Tension band wires, screws, and bone plates are not used because they cross the epiphyseal plate, create compression, and may lead to premature physeal arrest and growth deformity. Double Rush pinning, with the pins placed craniomedially and craniolaterally through the greater tubercle, is the preferred method of repair. Prebending the pins and using a Rush awl to create guide holes facilitate their

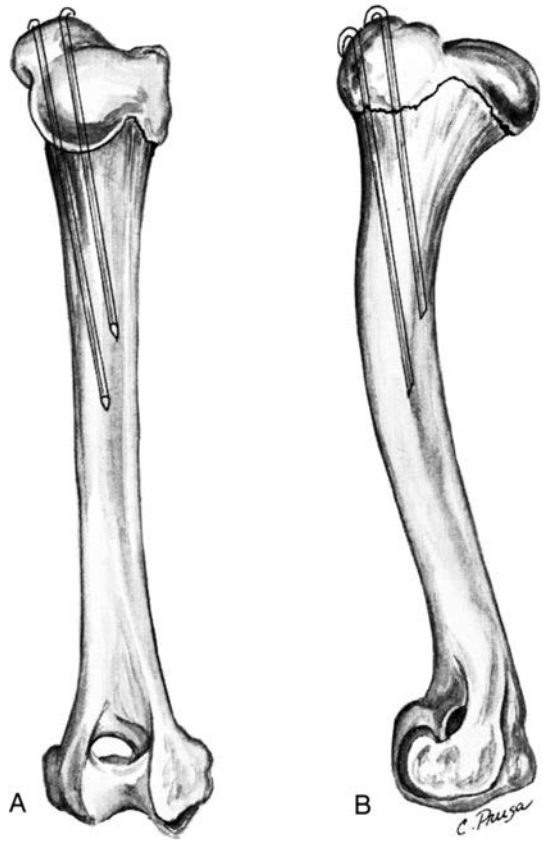


Figure 56-1. A Salter I proximal epiphyseal fracture repaired with two pins or Kirschner wires passed in a normograde fashion from the greater tubercle into the metaphysis after closed or open reduction. **A.** Caudocranial view. **B.** Lateral view.

insertion. Rush pins of appropriate size are driven in normograde fashion at an angle of approximately 20° to the long axis of the bone. While placing the pins, the lateral pin is directed toward the caudomedial cortex and the medial pin is directed toward the caudolateral cortex of the shaft (Figure 56-2). The pins should cross distal to the fracture site and should seat firmly against the cortex to provide rigid three-point fixation. For small dogs and cats, Kirschner wires can be substituted for Rush pins by a similar technique. No additional fixation is required, and early restricted weightbearing is encouraged postoperatively.

Infrequently, Salter injuries of the physis may occur simultaneously with fractures of the greater tubercle and humeral head. In young, growing animals, the repair involves pin fixation of the greater tubercle and humeral head through a craniolateral approach to the shoulder joint combined with tenotomy of the infra-spinatous and teres minor muscles. Pin fixation technique is selected in these animals to avoid interfering with future growth potential of the physis (Figure 56-3).

In mature animals, these fractures are repaired using tension band wire fixation of the greater tubercle combined with lag screw and Kirschner wire stabilization of the humeral head (Figure 56-4). Surgical exposure is through a craniolateral approach, with tenotomy of the infraspinatus and teres minor muscles, as described for a young, growing animal.

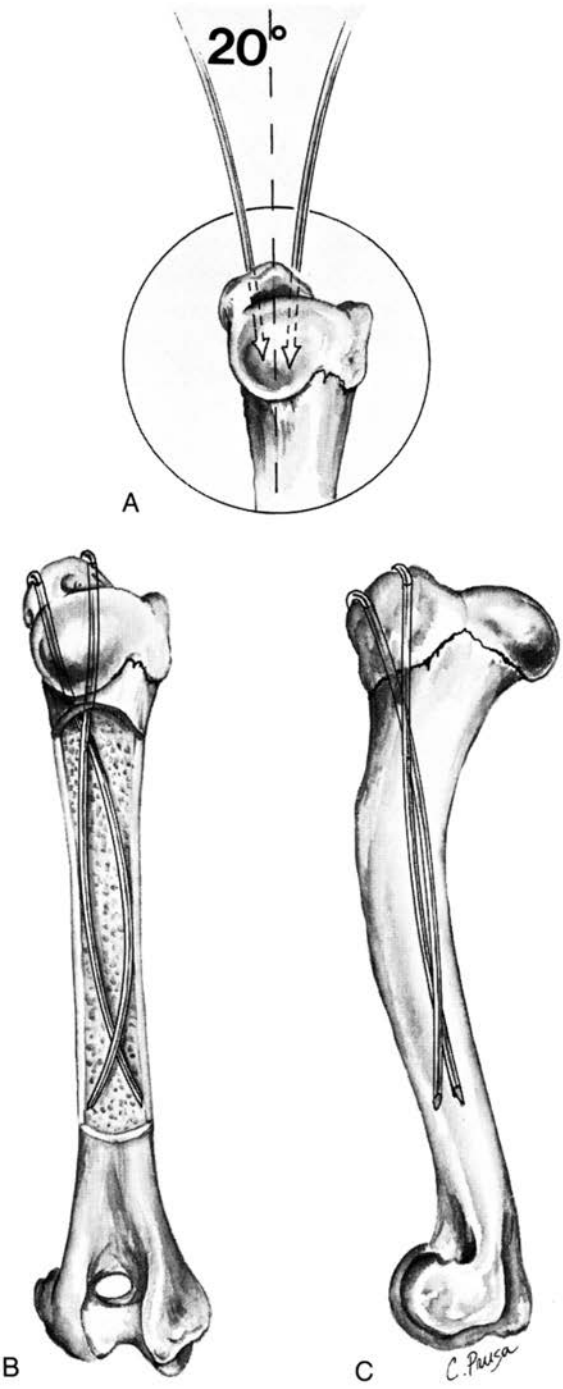


Figure 56-2. A Salter I proximal epiphyseal fracture stabilized with double Rush pins. Prebent pins are placed craniolaterally and craniomedially through the greater tubercle at an angle of approximately 20° to the long axis of the bone. **A** and **B.** Craniocaudal views. **C.** Lateral view.

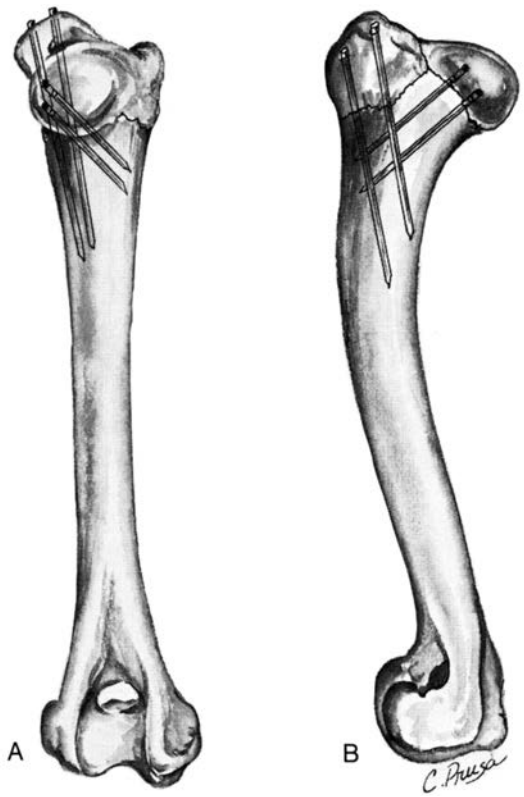


Figure 56-3. Capital and greater tubercle fractures in a young animal. The greater tubercle is repaired with Kirschner wires. The caput is stabilized with Kirschner wires or Stille nails driven through the lateral surface of the humeral head and countersunk below the article cartilage. **A.** Caudocranial view. **B.** Lateral view.

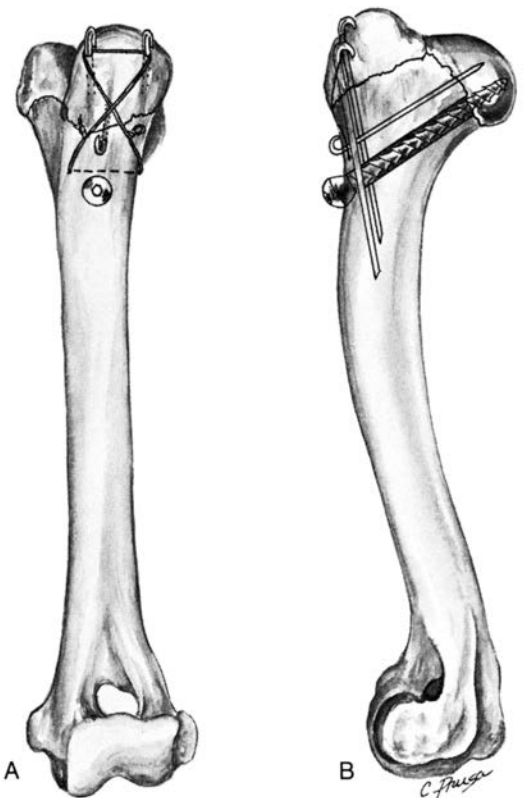


Figure 56-4. Capital and greater tubercle fractures in a mature animal. The greater tubercle is repaired with tension band wire. The capital fracture is stabilized with a Kirschner wire, and a cortical lag screw is placed in the neck of the humerus. **A.** Caudocranial view. **B.** Lateral view.

General Comments on Treating Proximal Fractures

For surgery, the animal is positioned in lateral recumbency, and the site is aseptically prepared from the proximal scapula to the level of the elbow. The limb is positioned through the body drape to facilitate surgical manipulation of the fragments. When exposing the proximal humerus by osteomy of the acromion process, the surgeon should be careful to preserve the suprascapular nerve, which courses deep to the infraspinatus muscle. The nerve lies lateral to the joint and medial and deep to the acromion process. In cats, a small metacromion protuberance is encountered just proximal to the acromion process. Its presence has no clinical significance and does not alter the surgical approach. The acromion process frequently is not ossified in young animals, and tenotomy of the acromion deltoid, rather than osteotomy, is recommended for exposure. For most proximal fractures, external support is usually not required, and an early return to weight-bearing is encouraged after surgery. The exception is a questionable repair of a comminuted articular fracture. Unstable articular repairs should be immobilized with a Velpeau bandage or a spica splint for 2 to 4 weeks postoperatively. Active physical therapy of the shoulder joint combined with swimming is recommended to obtain the best functional results. For patient comfort, appropriate analgesics should be used in the postoperative period to control pain and to facilitate physical therapy sessions. Early limb use is encouraged by slow, controlled leash walking. Activity during the third through eighth postoperative week should be confined to house and leash. For cases of articular fractures, the client should be advised of the possibility for developing secondary degenerative joint disease and the potential need for anti-inflammatory therapy.

Healing time with epiphyseal injuries can be as short as 3 to 4 weeks. Articular fractures may take several weeks to obtain clinical union. Depending on the age of the animal and the type of fracture, follow-up radiographs are scheduled for 3 to 6 weeks postoperatively. Serial radiographs are obtained at 3 to 4 months postoperatively to evaluate bone healing further. Unless contraindicated, all implants should be removed once radiographic union is complete.

Shaft Fractures

Proximal Metaphysis

The proximal metaphysis of the humerus is broad and strong relative to the rest of the bone. Proximal fractures may be described as transverse, short or long oblique, spiral, segmental, or comminuted. Fractures of this area are rare and usually result from a gunshot injury, vehicle injury, or other direct force or from a pathologic condition. Most cases occur in medium to large breed dogs. When animals are presented with pathologic fractures, nutritional, metabolic, or neoplastic causes should be considered and managed appropriately.

Simple transverse metaphyseal fractures of short duration in immature dogs and cats can be managed by closed reduction and normograde intramedullary pinning. A single intramedullary pin of appropriate size is placed normograde from the greater tubercle

and is passed toward the medial epicondyle and seated at that site. A smaller-diameter pin placed in similar fashion often exits through the medial epicondyle in close proximity to the ulnar nerve. Stack-pinning with two or more smaller pins may be used to increase resistance to rotational forces. Application of an external half- or full Kirschner splint in combination with intramedullary pinning may also be used to neutralize rotational forces.

Open reduction is required if the fracture is of long duration or if soft tissue swelling is significant. Fixation can be achieved with two Rush pins placed as described for repair of a proximal Salter epiphyseal fracture (See Figure 56-2). Alternatively, pins and tension band wire may be applied using appropriately sized Kirschner wires or Steinmann pins and orthopedic wire. With the tension band technique, pins are placed parallel and penetrate the midpoint of the greater tubercle. The wire is positioned in figure-of-eight fashion over the pins and is anchored in the distal fragment through a hole drilled in the bone (Figure 56-5).

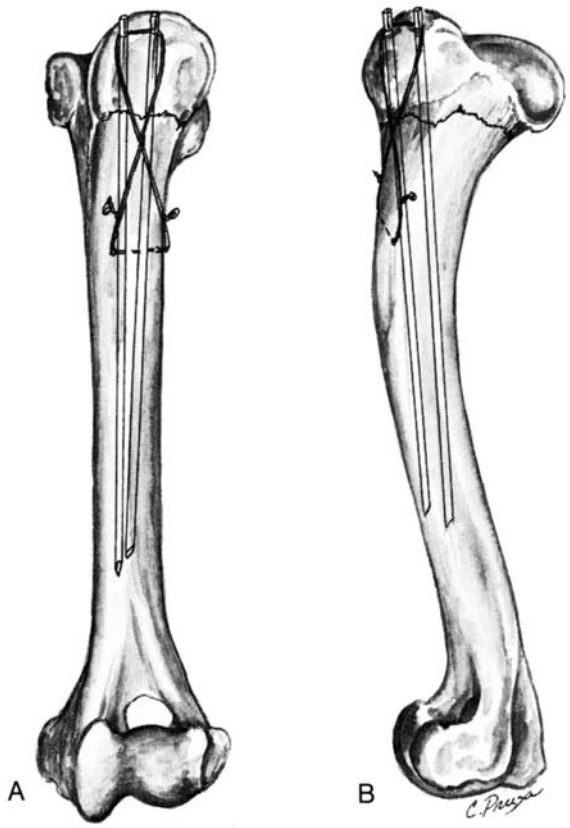


Figure 56-5. A proximal metaphyseal fracture stabilized with a tension band wire and two Kirschner wires or small Steinmann pins passed in normograde fashion from the greater tubercle into the shaft. **A.** Craniocaudal view. **B.** Lateral view.

Proximal Shaft

Proximal shaft fractures usually occur at or just distal to the deltoid tuberosity. Contraction of the deltoideus and latissimus dorsi muscles produces caudal displacement of the proximal fragment. Closed reduction with normograde intramedullary pinning or application of a Kirschner splint may be difficult because of fragment distraction and soft tissue swelling.

For oblique, segmental, and comminuted fractures of this area, open reduction is the preferred method of repair. A craniolateral approach to the proximal shaft with subperiosteal elevation of the deltoideus muscle is used to gain exposure. Several options are available for fixation, including single intramedullary pinning, stack-pins, Rush pinning, pin and tension band wire, hemicerclage wire, half- or full Kirschner splint, and bone plating.

Intramedullary pinning combined with half- or full Kirschner splinting usually provides good fixation for transverse fractures. Shear forces that occur with oblique fractures may be neutralized by the addition of full-cerclage or hemicerclage wire, Kirschner pins, or interfragmentary screws. Secure placement of cerclage wires is enhanced by creating grooves in the cortex or by placing transverse Kirschner pins to prevent the wires from migrating distal on the shaft and becoming loose. The use of single cerclage wires is avoided because it may create a fulcrum effect.

In large to giant breed dogs, or in animals with segmental and comminuted fractures of the proximal shaft, bone plating is the preferred method of repair. Evaluation of preoperative radiographs should ensure that sufficient bone is present to allow placement of two and preferably three bone screws on either side of the fracture site. Subperiosteal elevation of the insertion of the deltoid muscle is performed to provide exposure for reduction of the fracture, and the limb is held in external rotation to facilitate application of the bone plate. The bone plate is conformed to the cranial aspect of the proximal shaft and is applied to the bone.

Comminuted proximal fractures with loss of bone, as occurs with gunshot injuries, result in an unstable fracture and slow bone healing. These fractures are subjected to considerable rotational, compression, and bending forces and are susceptible to infection. Such fractures require rigid internal bone plate fixation combined with an autogenous cancellous bone graft. Alternatively, intramedullary pinning (single or stack) combined with autogenous cancellous bone grafting and Kirschner splint may be used. With open fractures of this type, Penrose drains should be placed at the surgical site. The Penrose drains are removed 3 to 5 days postoperatively.

Middle and Distal Shaft

Most humeral fractures involve the middle or distal diaphyseal regions of the bone. They present as transverse, oblique, spiral, comminuted, or multiple fractures. Overriding of bone fragments is common with midshaft to distal shaft fractures, and most cases require open reduction for repair. Select transverse midshaft fractures can be managed by closed reduction and intramedullary pinning.

Open intramedullary pinning is most applicable to transverse and short oblique shaft fractures in cats and small to medium breed dogs. This type of fixation can also be used for long oblique, spiral, comminuted, or multiple fractures in combination with cerclage wires, stack-pins, and Kirschner splints. Kirschner splints alone are most frequently used to stabilize open or closed, multiple, or comminuted shaft fractures. Bone plates are used most commonly for midshaft to distal shaft fractures in large and giant breed dogs.

Intramedullary Pin Fixation

Closed Reduction and Pinning

Closed reduction may be possible in small breed dogs and cats with recent transverse or short oblique midshaft to distal shaft fractures; closed reduction may be possible if the fracture site can be readily palpated. In medium to large breed dogs, closed reduction can be difficult because of the large muscle mass, soft tissue swelling, and fragment distraction. Open reduction is usually required for repair of shaft fractures in these breeds of dogs. When closed reduction is possible, an intramedullary pin is placed by inserting the pin in normograde fashion from the midpoint of the greater tubercle into the shaft. An intramedullary pin is selected that fills 70 to 75% of the medullary cavity at the fracture site. The size of the medullary cavity can be readily estimated and used to select the pin size based on the preoperative craniocaudal radiograph.

The pin is passed down the medullary cavity to a point just distal to the fracture site. The fracture is reduced by toggling the distal fragment onto the exposed pin. The pin is advanced to the distal fragment and is seated at a point just proximal to the supratrochlear foramen. Care is taken at this point to avoid penetrating the olecranon fossa (Figure 56-6). The joint should be palpated to ensure a full range of crepitus-free motion after pin placement. For closed intramedullary pinning of fractures at the junction of the middle and distal third of the shaft, a smaller pin is selected to allow for placement into the medial epicondyle. The pin should be of sufficient size to fill the medial epicondyle, based on the preoperative craniocaudal radiograph. The pin is inserted at the midpoint of the greater tubercle, is passed in normograde fashion down the medullary cavity, and is seated in the medial epicondyle. The pin is advanced until the tip is felt to penetrate the distal surface of the medial epicondyle. To ensure that the pin does not penetrate the medial olecranon fossa, the joint should be palpated repeatedly for crepitus and limited range of motion during pin placement. After insertion of an intramedullary pin for stabilizing either middle or distal diaphyseal fractures, persistent rotational instability can be controlled by closed application of a half-Kirschner splint.

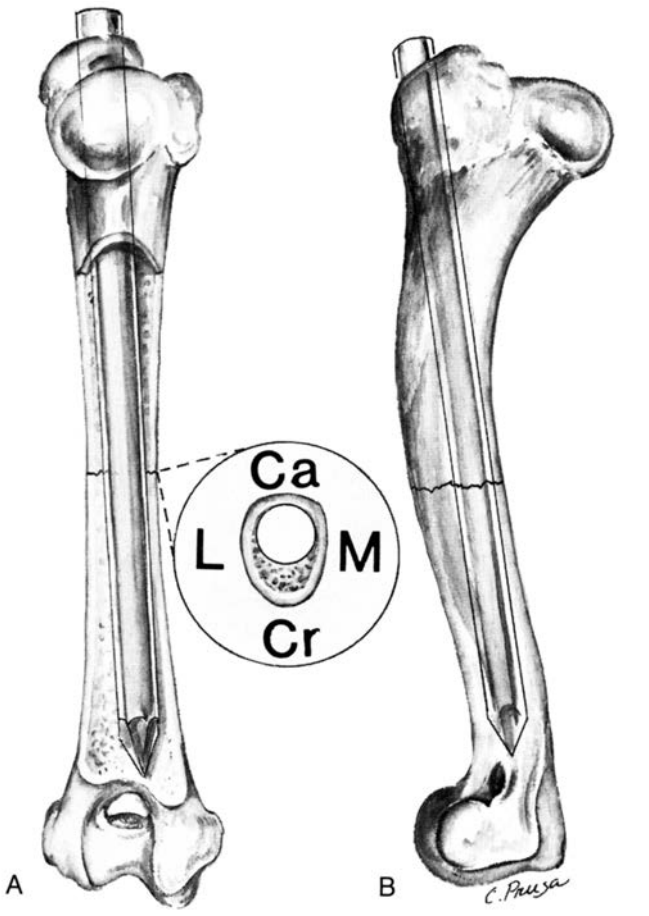


Figure 56-6. A transverse midshaft fracture demonstrating pin placement at the fracture site. The pin, which fills approximately 70 to 75% of the medullary cavity and contacts the caudal cortex of the bone at the fracture site, is inserted into the medullary cavity to a point just proximal to the supratrochlear foramen. **A.** Caudocranial view. *Ca*, caudal cortex; *L*, Lateral cortex; *M*, medial cortex; *Cr*, cranial cortex. **B.** Lateral view.

Open Reduction and Pinning

Although closed reduction is possible, open reduction is preferred for repair of midshaft and distal shaft fractures in all breeds of dogs and cats. The animal is placed in dorsal recumbency to allow for a lateral or medial approach to the shaft. Although the medial approach avoids muscle mass, it does encounter extensive neurovascular structures; for this reason, most fractures are handled by a lateral approach. The lateral approach provides exposure of the proximal three-fourths of the humeral shaft. The superficial cephalic vein and radial nerve lying between the brachialis muscle and the lateral head of the triceps brachii muscle should be identified and preserved. Proximal exposure of the shaft, when necessary, can be obtained by subperiosteal elevation of the deltoideus muscle. Distal exposure can be gained by extending the incision to the lateral epi-condyle and by dissecting the brachialis muscle to allow cranial and caudal retraction of the muscle and radial nerve as a unit. Gelpi retractors placed at either end of the wound facilitate muscle retraction and surgical exposure.

Reduction of shaft fractures often requires considerable traction with bone-holding forceps or the use of a bone distractor in large breed dogs to correct overriding from muscle contraction. In small dogs and in cats, open reduction and fixation may be achieved with a single intramedullary Steinmann pin. A pin of appropriate size is passed in retrograde fashion from the fracture site to the greater tubercle, the fracture is reduced, and the pin is seated in the distal fragment. To ensure proper pin placement, the pin is directed to accentuate placement either in the distal medullary cavity just proximal to the supratrochlear foramen or in the medial epicondyle. For midshaft fractures repaired by intramedullary pinning, the pin is started against the caudal cortex of the proximal fragment and is directed toward the greater tubercle (See Figure 56-6). For distal shaft fractures in which pin placement is desired in the medial epicondyle, the pin is started against the caudomedial cortex of the proximal fragment and is directed toward the midpoint of the greater tubercle (Figure 56-7). If the fracture remains unstable after single intramedullary pinning, additional fixation by cerclage wire, stack-pins, or a half-Kirschner splint is added. The intramedullary pin can be included within a hemicerclage wire to gain additional stability by compressing the pin against the cortex of the bone. Fractures

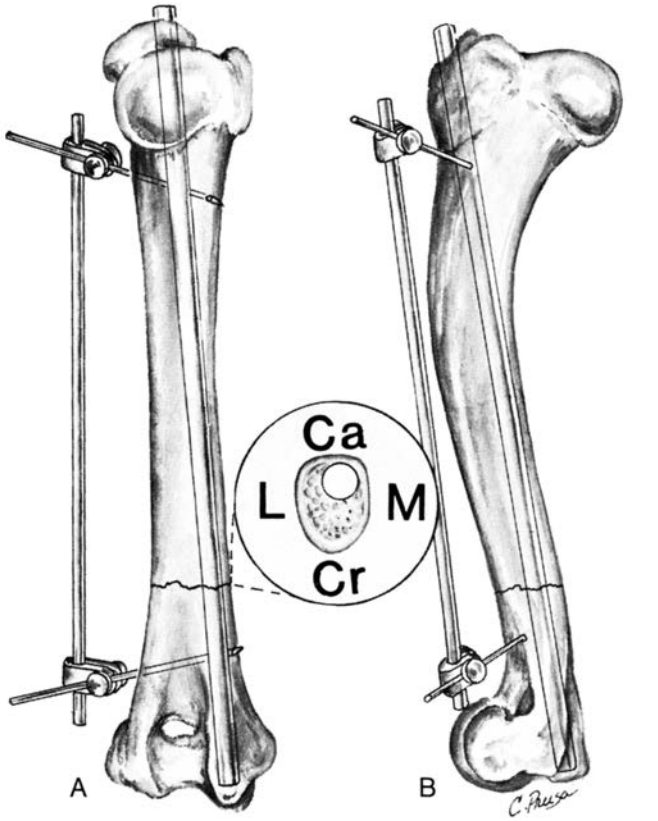


Figure 56-7. A distal transverse shaft fracture showing pin placement at the fracture site and application of a half-Kirschner splint. The intramedullary pin can be directed in a retrograde fashion against the caudomedial cortex of the proximal fragment to accentuate placement in the medial epicondyle. **A.** Caudocranial view. *Ca*, caudal cortex; *L*, Lateral cortex; *M*, medial cortex; *Cr*, cranial cortex. **B.** Lateral view.

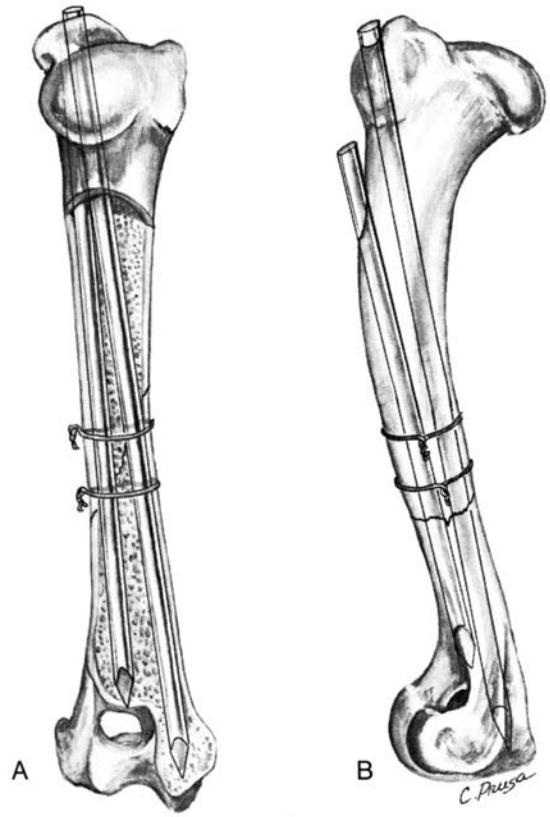


Figure 56-8. An oblique midshaft fracture repaired with stack-pins and full-cerclage wires. The first pin is passed in a retrograde direction from the caudomedial cortex of the fracture site and is placed in the medial epicondyle. The second pin is inserted in a normograde fashion from craniodistal to the greater tubercle to a point proximal to the supratrochlear foramen. **A.** Caudocranial view. **B.** Lateral view.

most applicable to full-cerclage wire technique include fissure fractures, long oblique fractures, and spiral fractures of the shaft. For cerclage techniques, monofilament wire of sufficient size and strength should be used. Twenty- to 22-gauge wire is usually sufficient for small dogs and cats. Eighteen-gauge wire should be used for medium to large breed dogs. When using cerclage, a minimum of two wires is recommended to avoid creating a fulcrum effect.

In large dogs with spacious medullary cavities, stack-pins provide more points of bone contact and improve rotational stability. Two pins or more of appropriate size are placed by directing the first pin in retrograde fashion into the proximal fragment and then seating it in the medial epicondyle. Alternatively, the second or subsequent pins are started at a point cranial and distal to the greater tubercle and are passed in a normograde direction down the medullary cavity to a point just proximal to the supratrochlear foramen. The second and subsequent pins can also be passed in a retrograde direction into the proximal fragment and then seated distally (Figure 56-8).

Half-Kirschner splints may be used with intramedullary pinning to provide rotational stability. A single intramedullary pin is seated in the medial epicondyle, allowing sufficient room between the pin and the cranial cortex of the shaft for placement of two Kirschner pins. Estimation of the combined Kirschner and intramedullary pin diameters can be obtained by studying the preoperative lateral radiograph. A Kirschner pin is placed in each fragment at 35 to 40° to the long axis of the bone and should penetrate both cortices. Both pins enter the bone through separate stab wounds away from the primary incision site. The pins are joined by a connecting bar and two single Kirschner clamps (Figure 56-7). The half-Kirschner splint is usually removed in 3 to 6 weeks after development of a bridging callus, as demonstrated by radiographic examination.

Full Kirschner Splint Fixation

A full Kirschner splint can be used as the sole means of fixation for shaft fractures in cats and in small to medium breed dogs (Figure 56-9). Kirschner splints, when used alone, are placed by closed reduction or by a limited approach to the fracture site to facilitate reduction and fixation. They cause minimal disruption of blood supply and allow for free joint movement and the nursing care of open wounds during the healing period. When deciding on pin placement for a full Kirschner splint, preoperative radiographs should be evaluated carefully for the presence and location of fissure fractures. The presence of fissures may necessitate altering pin placement or may contraindicate the application of a Kirschner splint.

When placing a full Kirschner splint, two pins are positioned craniolaterally in each major fragment. When possible, all pins

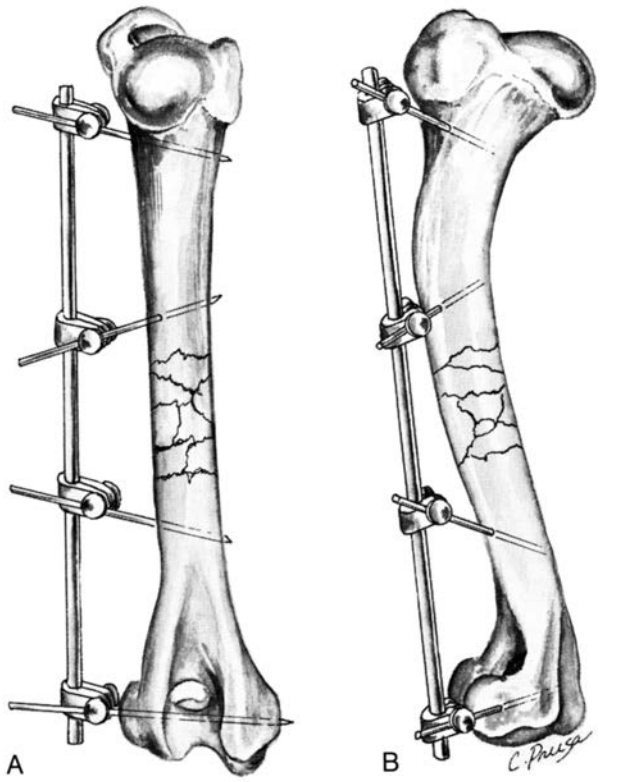


Figure 56-9. A comminuted midshaft fracture repaired with a full Kirschner splint. The splint is positioned on the craniolateral surface of the humerus, with the pins driven through both cortices at approximately 35° to the long axis of the bone. **A.** Caudocranial view. **B.** Lateral view.

are placed at 35 to 40° to the long axis of the bone and should penetrate both proximal and distal cortices. The proximal pin is placed just distal to the greater tubercle, and the distal pin is placed just proximal to the supratrochlear foramen or in transcondylar fashion using the epicondyles as landmarks. The two pins are joined with a connecting bar containing empty Kirschner clamps for placement of the two middle pins. The deltoid tuberosity is used as a landmark for placement of the second pin in the proximal fragment. The second pin in the distal fragment is placed just proximal to the epicondylar ridges. The surgeon must be careful to avoid striking the radial nerve when placing this pin. For Kirschner splinting, a limited lateral approach can be useful to facilitate fracture reduction. For both closed and open repairs, a half-Kirschner splint is initially positioned as described, and traction is applied to obtain axial alignment of the proximal and distal fragments. The two end Kirschner clamps are tightened to maintain reduction while the two middle pins are placed and seated in the bone through clamps previously positioned on the connecting bar. When inserting the two middle pins, medial support should be provided with the surgeon's free hand to prevent medial collapse of the fragments and loss of reduction. When open reduction is performed through a limited surgical approach, lag screws or cerclage wires can be combined with the Kirschner splint as needed to provide additional fixation. Cortical defects should be packed with autogenous cancellous bone grafts harvested from the iliac crest, proximal tibia, or proximal humerus.

Bone Plate Fixation

Bone plates can be applied to most shaft fractures, but they are especially indicated in large and giant breed dogs and for multiple and comminuted fractures. A dynamic compression plate is recommended, with three screws placed on each side of the fracture. When plating the humeral shaft, the surgeon should use as broad a plate as possible. In cases with oblique, spiral, or multiple fractures, lag screws or cerclage wires can be combined with plate fixation as indicated to provide additional fixation.

Exposure is through a craniolateral approach to the proximal shaft, with subperiosteal elevation of the superficial pectoral and deltoideus muscles and caudal retraction of the brachialis and triceps brachii muscles. For midshaft fractures, the plate is conformed to the bone and is placed on the cranial surface of the shaft (Figure 56-10).

For distal shaft fractures, the plate is positioned laterally along the musculospiral groove, the lateral epi-condyle, and the lateral epicondylar crest (Figure 56-11). The plate is conformed to the surface of the distal musculospiral groove and lateral epicondyle and is positioned under the brachialis muscle. Exposure is obtained using a lateral approach to the shaft, and the incision is extended proximally and distally as required.

For distal-third shaft fractures with a comminuted medial cortex, the plate can be applied to the caudal medial surface of the medial shaft and epicondyle (Figure 56-12). Surgical exposure can be

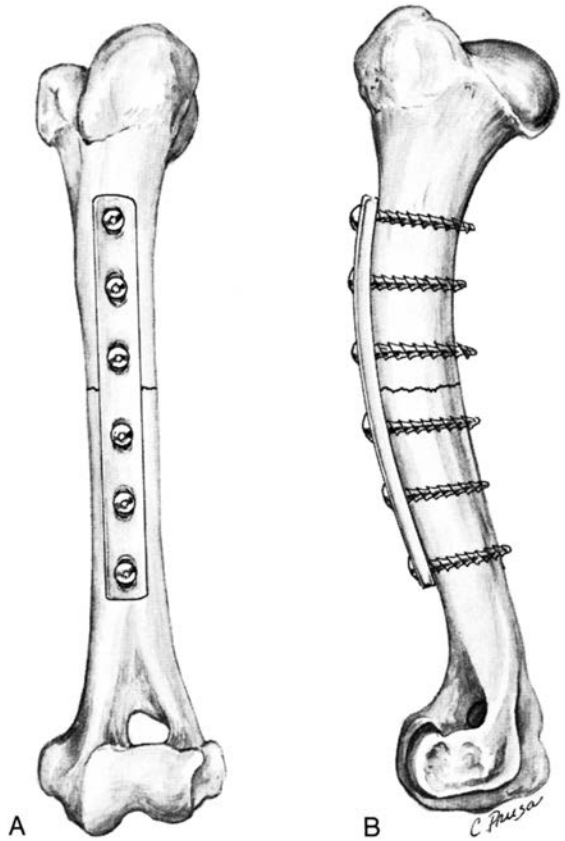


Figure 56-10. A bone plate applied to the cranial surface of the humerus for fixation of midshaft fracture. Three screws should be placed in the plate on each side of the fracture site. **A.** Craniocaudal view. **B.** Lateral view.

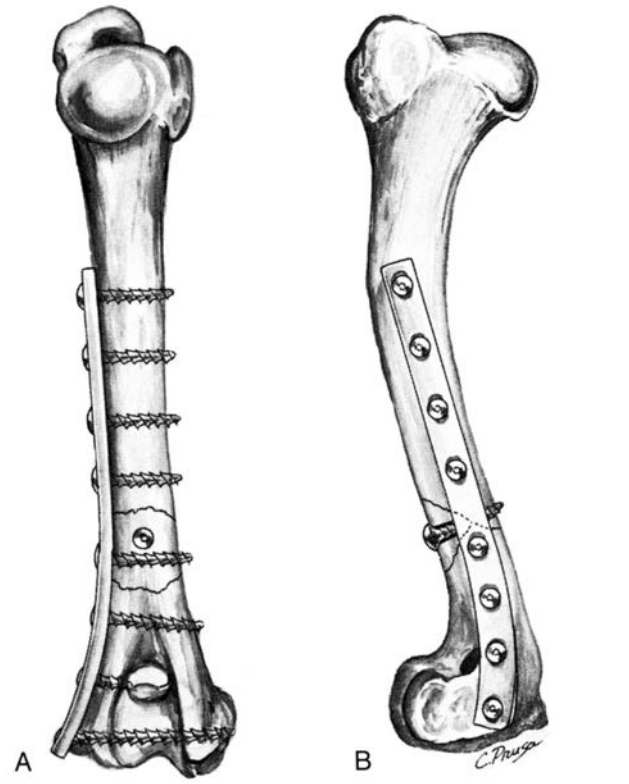


Figure 56-11. A bone plate placed on the lateral surface of the humerus for repair of a distal shaft fracture. The plate is conformed to the musculospiral groove, the lateral epicondyle, and the lateral epicondylar crest. Lag screw compression of a butterfly fragment is combined with plate fixation. **A.** Caudocranial view. **B.** Lateral view.

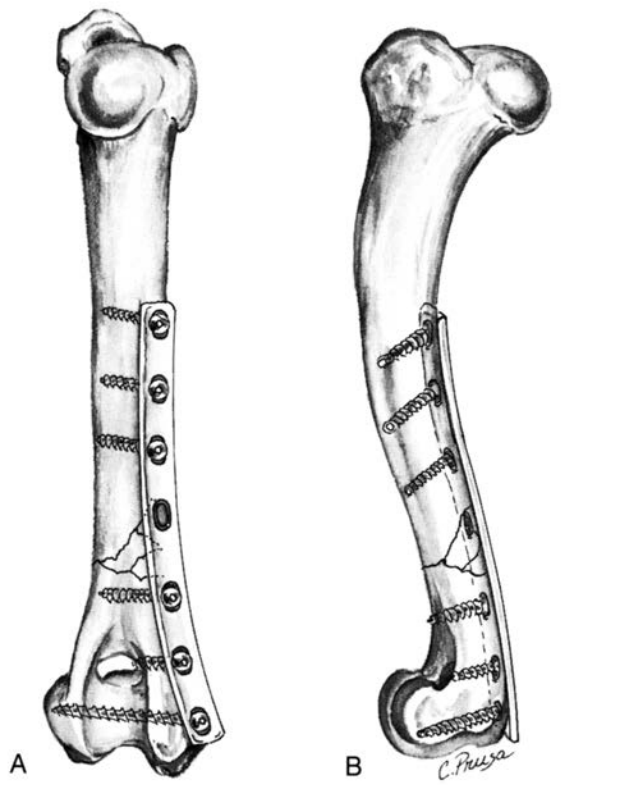


Figure 56-12. A bone plate positioned on the caudomedial surface of the shaft and the medial epicondyle for repair of distal shaft fractures with a comminuted medial cortex. **A.** Caudocranial view. **B.** Lateral view.

achieved using a medial approach to the distal shaft. Care must be taken to preserve the brachial and collateral ulnar vessels and the ulnar and median nerves. The nutrient artery located on the caudal surface of the bone should also be preserved. A transolecranon osteotomy can be performed if additional distal exposure is required.

General Comments for Managing Shaft Fractures

For repair of shaft fractures, the animal is positioned in lateral recumbency with the injured limb suspended and aseptically prepared from the midradius to the proximal scapula. Placing the affected limb outside the body drape facilitates fracture manipulation and reduction.

Midshaft fractures frequently occur where the radial nerve crosses the musculospiral groove medially to laterally. These patients often have considerable overriding of sharp bone fragments, especially with oblique or spiral fractures. Radial nerve function should be evaluated carefully in these animals because of the close proximity of the nerve to the fracture site. The radial nerve courses over the musculospiral groove of the distal humerus in association with the brachialis muscle. During the surgical procedure, the nerve should be identified, tagged, and assessed for damage. A large-diameter Penrose drain is passed around the brachialis muscle and radial nerve and is used to retract these structures cranially and caudally during the reduction process.

Autogenous cancellous bone grafts enhance healing of severely comminuted or multiple shaft fractures repaired with open reduction and internal fixation. Indications include middle-aged and older patients or patients with large bone defects at the fracture site. Cancellous bone is taken from surgically prepared sites at the greater tubercle, the tibial crest, or the wing of the ilium. Once the graft is harvested, it is immediately placed in the fracture site before closure of the soft tissues.

Severely comminuted shaft fractures with large bone defects may require full-cylinder cortical bone grafting. Suitably prepared cortical bone allografts can be used for this purpose. Bone grafts of this type are usually reserved for comminuted shaft fractures that cannot be repaired by conventional reconstructive techniques.

Postreduction radiographs are obtained to evaluate reduction and fixation. Appropriate analgesics are provided to ensure patient comfort. Most patients with shaft fractures benefit from a Robert Jones bandage applied to the limb for 3 to 5 days postoperatively to control swelling. Twice-daily hydrotherapy is recommended to clean pin sites when a Kirschner splint is used. For patients with these fractures, activity is restricted to house and leash for 6 to 8 weeks or until bone healing is demonstrated by radiograph examination.

Supracondylar and Condylar Fractures

Supracondylar Fractures

Most supracondylar fractures pass through the supratrochlear

foramen. In young animals, an epiphyseal separation may occur in association with a supracondylar fracture. Metaphyseal fractures with no involvement of the supratrochlear foramen can also be seen. Closed reduction is not advisable with this type of fracture. Open reduction with internal fixation provides early joint motion and weightbearing and produces the best results. Surgical exposure is through a medial or lateral approach to the distal shaft, or, if necessary, the two approaches are combined to facilitate reduction. A transolecranon approach provides the best exposure for large breed dogs requiring double bone plating for multiple or comminuted supracondylar fractures.

Transverse Fractures

The preferred method for repair of transverse supracondylar fractures involving the foramen is open intramedullary pinning combined with cross-pinning of the lateral epicondyle (Figure 56-13). This technique provides rigid internal fixation for most transverse supracondylar fractures and is applicable to all sizes of dogs and cats. The fracture is reduced, and the proximal fragment is immobilized with bone-holding forceps. With the patient's elbow flexed, a pin of sufficient size to fill the medial epicondyle is passed in normograde fashion from the medial epicondyle to the greater tubercle. The pin is advanced parallel to the caudomedial cortex of the medial epicondyle and penetrates the greater tubercle. During pin placement, reduction is maintained by counterforce applied through Kern bone-holding forceps attached to the proximal fragment. Rotation of the distal fragment is controlled by bone-holding forceps placed over the fracture site of the lateral epicondyle. The fracture site is inspected repeatedly during pin placement to ensure that reduction is maintained. When the pin penetrates the greater tubercle, the bone chuck is removed, and the distal point of the pin is cut off. The bone chuck is reapplied to the proximal portion, the distal part of the pin is drawn into the medial epicondyle, and the proximal pin is cut off at the greater tubercle.

An alternate method advances the pin in a retrograde direction up the caudomedial cortex of the proximal fragment from the fractured site. The fracture is reduced and the pin is passed into the distal fragment and is seated in the medial epicondyle. With both methods, a Kirschner wire or a small Steinmann pin is passed from distal and caudal to the lateral epicondyle to penetrate the medial cortex of the humeral shaft. The pin in the lateral epicondyle should pass between the intramedullary pin and cranial cortex of the shaft (Figure 56-13C).

Double Rush pinning provides an alternative technique for repair of transverse supracondylar fractures. Rush pins of appropriate size are prebent to facilitate their insertion and are placed slightly distal and caudal to the medial and lateral epicondyles. During pin placement, reduction is maintained with bone-holding forceps. Guide holes are made with an intramedullary pin or a Rush awl to allow introduction of the pins at approximately 20 to 30° to the long axis of the bone. The pins should be placed so they cross above the fracture site and provide rigid three-point fixation (Figure 56-14). In small dogs and in cats, Kirschner wires or small Steinmann pins can be substituted for Rush pins and placed in similar fashion.

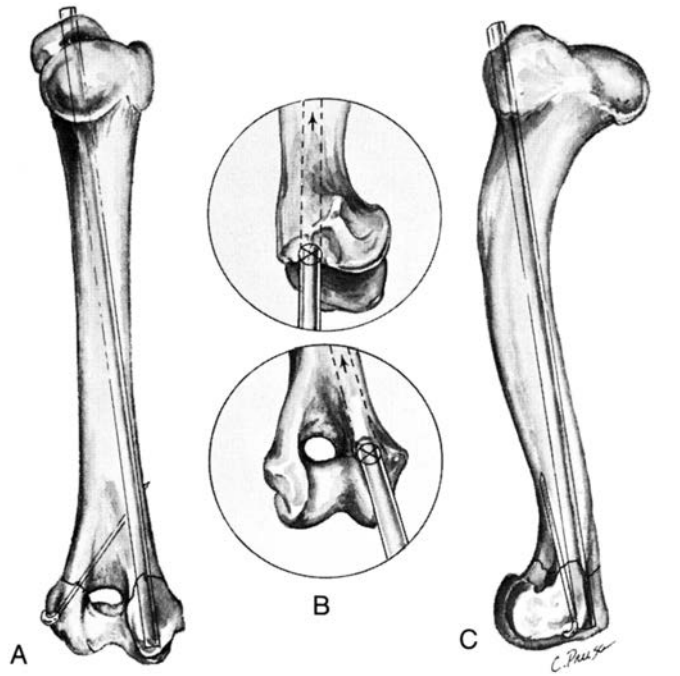


Figure 56-13A-C. A transverse supracondylar fracture showing normograde placement of an intramedullary pin parallel to the caudal cortex of the medial epicondyle. A Kirschner wire or a small Steinmann pin is passed through the lateral epicondyle to penetrate the medial cortex and to provide rotational stability. **A.** Caudocranial view. **C.** Lateral view.

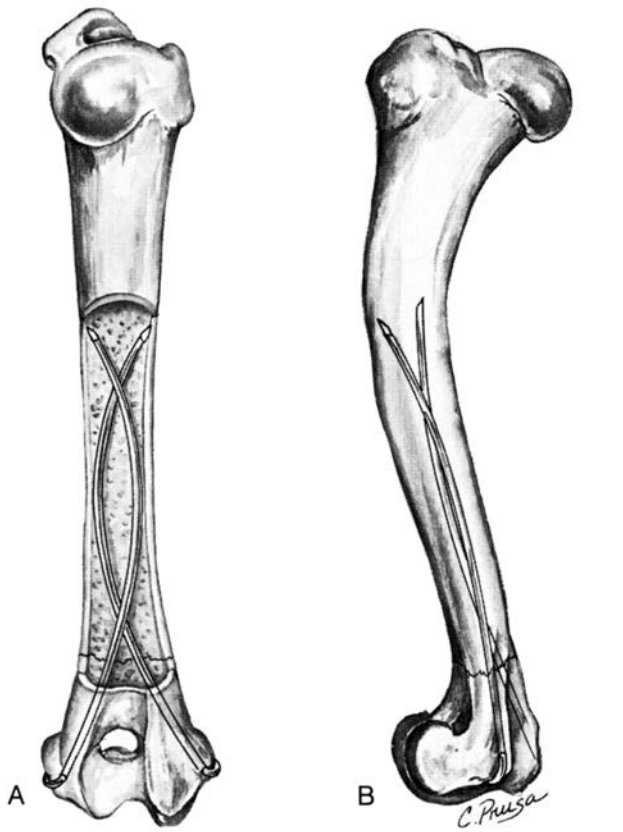


Figure 56-14. A transverse supracondylar fracture repaired using a double Rush pin technique. The pins are placed in the bone slightly distal and caudal to the epicondyles and at an angle of approximately 20 to 30° to the shaft of the humerus. **A.** Caudocranial view. **B.** Lateral view.

Oblique Fractures

Oblique supracondylar fractures in cats and small to medium breed dogs can be repaired with intramedullary pinning and hemicerclage wires. The intramedullary pin is directed from the fracture site in a retrograde fashion into the proximal fragment, the fracture is reduced, and the pin is seated in the medial epicondyle. Hemicerclage wire, preplaced through the bone and around the pin, is tightened to provide additional stability and rotational control. To control rotational forces unstable fractures may require addition of a half-Kirschner splint.

Multiple and Comminuted Fractures

Fixation of multiple and comminuted supracondylar fractures in cats and small to medium breed dogs can be achieved by intramedullary pinning of the medial epicondyle combined with cerclage wire and a full Kirschner splint (Figure 56-15). Surgical exposure for repair of these fractures requires a combined medial and lateral or transolecranon approach. Reduction and repair are first attempted through a combined lateral and medial approach. If surgical exposure is inadequate, a transolecranon osteotomy can be performed. A Steinmann pin is placed in the medial epicondyle in retrograde fashion, and the fracture site is reduced. The pin is advanced in normograde fashion into the proximal fragment and exits at the greater tubercle. For additional fixation, a full-Kirschner splint is applied to the craniolateral aspect of the bone. The proximal Kirschner pin is inserted below the greater tubercle and passes between the intramedullary pin and the cranial cortex of the bone. The distal pin is placed in transcondylar fashion from the lateral epicondyle and angles toward the medial epicondyle. A connector bar containing two single Kirschner clamps for placement of the middle pins is connected between the proximal and distal pins. Traction is applied, and the fragments are placed in axial alignment and are immobilized temporarily by tightening the proximal and distal Kirschner clamps. The Kirschner splint can be adjusted as required to provide for surgical manipulation and reduction. The proximal and distal clamps are tightened once reduction is achieved. Cerclage wires or lag screws are used to stabilize any comminuted or multiple bone fragments. The cortex of the bone is grooved to accept the cerclage wire and to prevent it from becoming loose. At this point, the second Kirschner pin in the proximal fragment is seated in the shaft between the intramedullary pin and the cranial cortex. The second pin in the distal fragment is placed in transcondylar fashion from the lateral to the medial epicondyle. The result is two Kirschner pins placed in cross-pin fashion within the condylar bone. Care is taken to support the fracture site during placement of the two middle Kirschner pins to prevent medial collapse and loss of fracture reduction (Figure 56-16).

In large dogs, double bone plating is usually required to provide fixation for comminuted or multiple supracondylar fractures (Figure 56-17). A transolecranon approach creates the best exposure for application of the plates. To use the bone plating technique, the condylar fragment must be large enough to allow

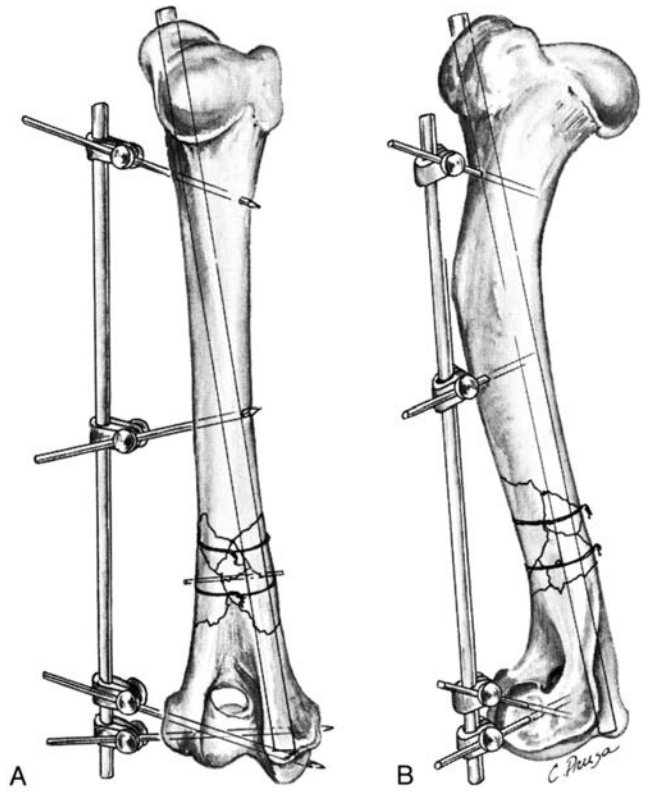


Figure 56-15. A comminuted supracondylar fracture stabilized with an intramedullary pin placed in the medial epicondyle and application of a full Kirschner splint. The intramedullary pin is directed in a retrograde fashion into the medial epicondyle and then is advanced into the proximal fragment. Full-cerclage wires are used to stabilize the multiple bone fragments. **A.** Caudocranial view. **B.** Lateral view.

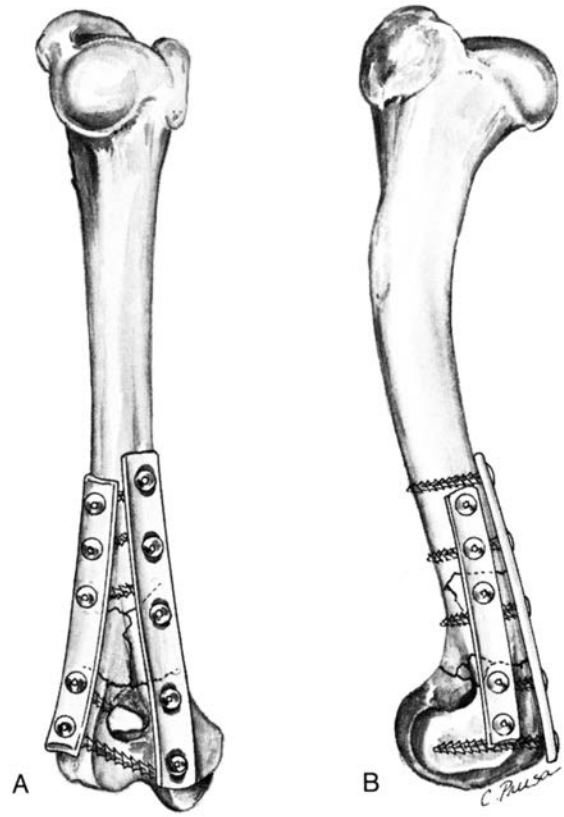


Figure 56-16. A double bone plate repair of a multiple supracondylar fracture. The plates are positioned on the caudomedial surface of the medial epicondyle and the caudal surface of the lateral epicondyle. A minimum of two screws should be placed distal to the fracture site in each plate. **A.** Caudocranial view. **B.** Lateral view.

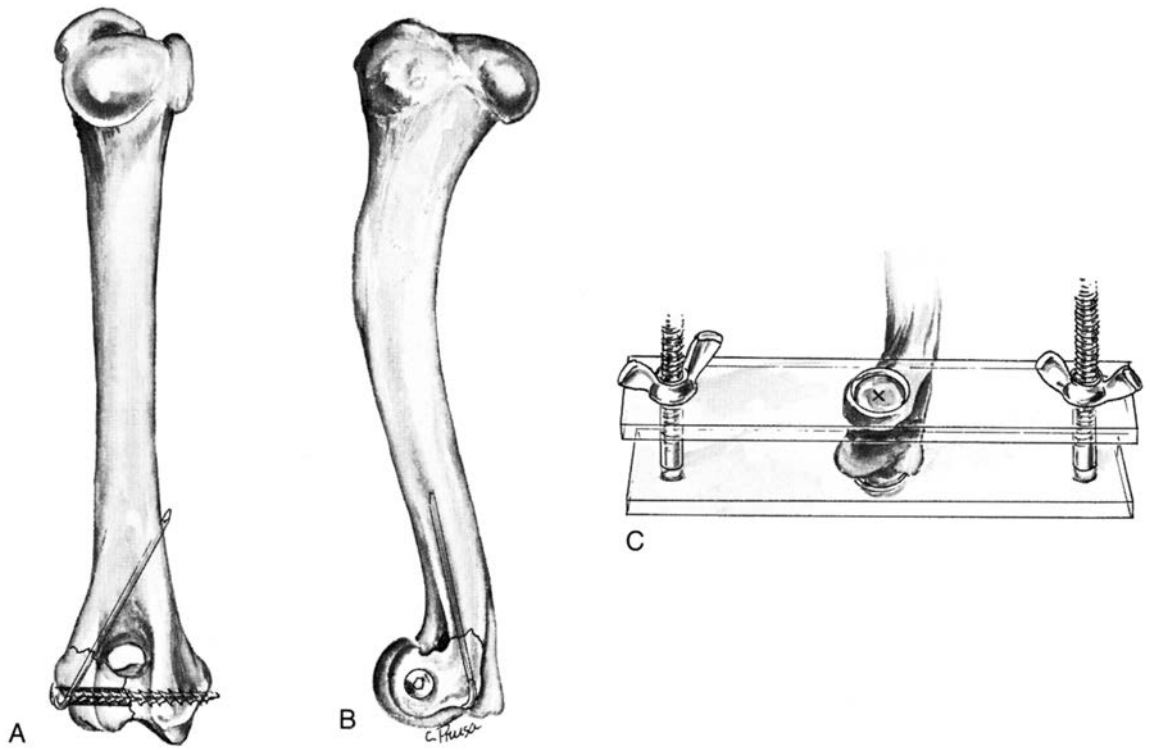


Figure 56-17. A lateral condylar fracture stabilized with a transcondylar cortical lag screw and Kirschner wire. The lateral condyle can be reduced temporarily with a condyle clamp (C) during placement of the transcondylar screw. Overdrilling the lateral condyle provides lag screw compression at the fracture site. The Kirschner wire placed in the condyle prevents rotation of the fragment. A. Caudocranial view. B. Lateral view.

placement of at least two screws distal to the fracture site. The larger plate is positioned on the caudomedial surface of the medial epicondyle. The second, smaller plate is placed on the caudal surface of the lateral epicondyle and the lateral epicondylar crest. Consideration is given to placement of all screws in both plates before drilling the holes to allow interdigitation of the screws. Compression of large bone fragments by lag screws placed through the plates should be performed whenever possible. Inadvertent placement of screws into the joint or olecranon fossa must be avoided to ensure an unrestricted, crepitus-free range of motion and a functional joint.

Condylar Fractures

Fractures of the lateral condyle of the humerus occur more frequently than medial condyle fractures. Forces transmitted along the radius largely affect the lateral condyle, creating shear forces and predisposing it to fracture. Radiographs of lateral condyle fractures usually reveal a subluxated elbow joint with cranial and lateral rotation of the fragment secondary to contraction of the extensor muscles. Fracture of the medial condyle causes caudal and medial displacement of the fragment.

Closed reduction of lateral condyle fractures is possible if soft tissue swelling is minimal and if the fracture is not of more than 24 to 36 hours' duration. Closed reduction requires considerable surgical expertise and is not generally recommended.

Lateral and medial condyle fractures are best managed by open reduction. A transolecranon approach provides the best exposure, although a medial or lateral approach may be adequate in selected cases. Subperiosteal elevation of the extensor carpi radialis muscle provides better visualization for reduction of lateral condyle fractures. Accurate anatomic reduction is paramount to a successful repair of the articular surface. Gentle curettage of the fracture site removes fibrin clots and interposed soft tissue that facilitates reduction. The fragment is reduced by digital manipulation and is stabilized temporarily with a condyle or bone clamp placed over the epicondyles. The clamp is positioned to allow access to an area slightly distal and cranial to the epicondyles for placement of a transcondylar screw. Reduction is evaluated by palpating the caudal surface of the lateral epicondyle, by assessing joint motion and by direct articular visualization. In cats and small breed dogs, a C-clamp placed across the condyles maintains reduction and provides a guide for drilling the condylar hole. The hole is measured with a depth gauge and is tapped to receive a cortical bone screw. The fracture is separated, the condyle fragment is overdrilled to create a glide hole, and the fracture is reduced. A transcondylar cortical screw of appropriate length is inserted and is tightened to provide lag screw compression.

An alternate technique predrills the lateral or medial condyle fragment from the fracture site and uses the hole as a guide to drill the opposite condyle. With both techniques, a Kirschner wire is placed caudal to the screw head and is driven up the lateral or medial epicondyle to the opposite cortex to prevent rotation (Figure 56-18). The transolecranon approach is repaired and is stabilized using a tension band wire technique. The joint is palpated to ensure a crepitus-free and unrestricted range of motion before closure. Postreduction radiographs are taken to assess implant placement, fracture reduction, and alignment of the articular surface.

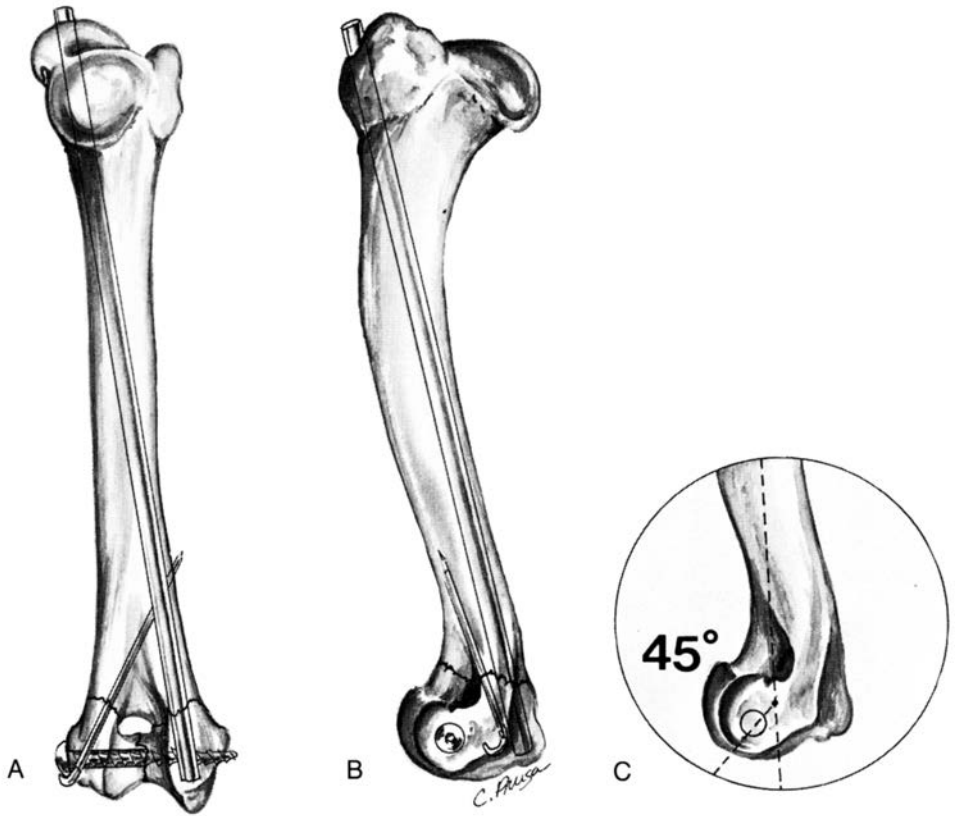


Figure 56-18. A double bone plate repair of a multiple supracondylar fracture. The plates are positioned on the caudomedial surface of the medial epicondyle and the caudal surface of the lateral epicondyle. A minimum of two screws should be placed distal to the fracture site in each plate. **A.** Caudocranial view. **B.** Lateral view.

General Comments for Management of Supracondylar and Condylar Fractures

For repairs of this type, the animal is positioned on its back, and the affected limb is aseptically prepared from the scapula to the carpus. A lateral approach is made, and the skin and subcutaneous layer are undermined and reflected as required to expose both sides of the elbow joint and distal shaft. When approaching the supracondylar area in cats, special care should be taken to preserve the median nerve, which passes through the supratrochlear foramen, and the ulnar nerve, which is located under the medial head of the triceps brachii muscle. Comminuted or multiple supracondylar fractures may require autogenous cancellous bone grafting, as described for comminuted shaft fractures. When bone grafting is anticipated, one or more donor sites are prepared preoperatively. After reduction and fixation, the graft is harvested and is placed in the fracture site immediately before closure.

A Robert Jones bandage is placed on the limb for 2 to 3 days postoperatively to control soft tissue swelling. Early physical therapy and restricted weightbear-ing are encouraged for the first 6 to 8 weeks. Unless contraindicated, removal of implants is recommended when the bone has healed, as demonstrated by radiograph examination. Appropriate analgesics are administered postoperatively to provide for patient comfort.

Intercondylar Fractures

Supracondylar fractures of the humerus occurring simultaneously with a condyle fracture are referred to as T or Y fractures. They are usually seen in mature animals in which the epiphysis has fused. Closed reduction with external fixation is not advisable. These fractures involve articular surface, and open reduction with internal fixation should be recommended as early as possible.

A transolecranon approach provides good visualization and facilitates anatomic reduction of the articular surface. The fracture site is exposed and is curetted to remove fibrin clots and interposed soft tissue. Reduction is performed and evaluated by observing the articular surface of the condyles and the alignment of the humeral shaft with the epicondylar ridges. The multiple fracture is converted to a single supracondylar injury by first repairing the intercondylar fracture. The condyles are immobilized with a condyle clamp or bone forceps, and two small Kirschner wires are passed in a transcondylar fashion to provide temporary fixation. A guide hole for a drill bit is placed distal and cranial to the lateral epicondyle using a small intramedullary pin. The drill site is located on a line 45° cranial and distal to a line passing through the lateral epicondyle and shaft of the humerus (Figure 56-19). The drill is directed toward a similar point cranial and distal to the medial epicondyle. Placement of the screw should be in the center of the condyles and parallel to the joint surface. In small breed dogs and cats, a C-clamp can be used to immobilize the condyles and to provide a guide for screw placement. A depth gauge is used to determine the screw length, and the hole is threaded with a bone tap. The lateral fragment is overdrilled to create a glide hole, and a cortical screw is inserted to create lag screw compression. Care must be taken to avoid over-compressing the fracture when tightening the screw and collapsing the soft cancellous bone of the condyle.

An alternative method for drilling the condyle is to predrill the proximal hole from the fracture site to a point cranial and distal to the lateral epicondyle. The hole is carefully centered in the lateral condyle. The fracture is reduced and is immobilized with a condyle clamp or small Kirschner wire. The medial condyle is drilled using the hole in the lateral condyle as a guide. The depth of the hole is measured, and the entire length is threaded with a bone tap. The lateral condyle is overdrilled, and a cortical screw is selected and inserted to provide lag screw compression. The transcondylar Kirschner wires are removed, except when additional fixation may be desirable. In cats and extremely small dogs, threaded pins or Kirschner wires can be substituted for screws to provide fixation.

Before repairing the supracondylar fracture, the condyles are palpated to ensure a crepitus-free, unrestricted range of motion. The condyles are attached to the shaft using the intramedullary pinning technique described for supracondylar fractures. After reduction of the supracondylar fracture, a pin of sufficient size to fill the medial epicondyle is selected, based on assessment of the preoperative craniocaudal radiograph. The pin is passed parallel to the caudal cortex of the medial epicondyle and is advanced in normograde fashion to penetrate the greater tubercle. The distal pin is cut off, and the bone chuck is applied to the proximal pin. The distal pin is drawn into the medial epicondyle, and the proximal portion is cut off at the greater tubercle. During placement of the intramedullary pin, the supracondylar and condylar fracture sites are checked repeatedly to ensure that reduction is maintained.

An alternative method of intramedullary pin placement passes the pin in retrograde fashion through the medial epicondyle. The fracture is reduced, and the pin is passed in normograde fashion up the humeral shaft, penetrating the greater tubercle. The pin is cut off as described in the previous technique. A Kirschner wire or a small Steinmann pin of appropriate size is directed up the lateral epicondyle to provide rotational stability. This pin enters the epicondyle immediately caudal to the transcondylar screw head, passes between the intramedullary pin and the cranial cortex of the humeral shaft, and penetrates the medial cortex (See Figure 56-18B). The combination of transcondylar screw fixation with pinning of the supracondylar fracture is applicable to all sizes of dogs and cats and provides an excellent method of fixation for this type of fracture.

A third technique for repair of these fractures uses double Rush pinning or cross-pinning of the supracondylar fracture combined with transcondylar lag screw fixation of the condylar fracture. This technique is more challenging, and maintaining anatomic reduction between the condyles and the shaft during pin placement can be more difficult (Figure 56-19).

Comminuted T or Y condylar fractures are unstable and usually require double bone plating for repair. These challenging fractures require exact anatomic reduction to achieve the best functional results. A trans-olecranon approach provides good exposure for reducing and stabilizing the fracture. A transcondylar lag screw is used to stabilize the condyles, and two bone plates are applied. One plate is positioned over the medial epicondyle and humeral shaft, and the other is placed over the lateral epicondyle and lateral epicon-dylar crest. For each plate, two screws are placed in the condylar fragment, and three screws are positioned in the humeral shaft. An autogenous cancellous bone graft is harvested and is placed in the fracture site before closure. The transolecranon osteotomy is repaired with a tension band wire technique.

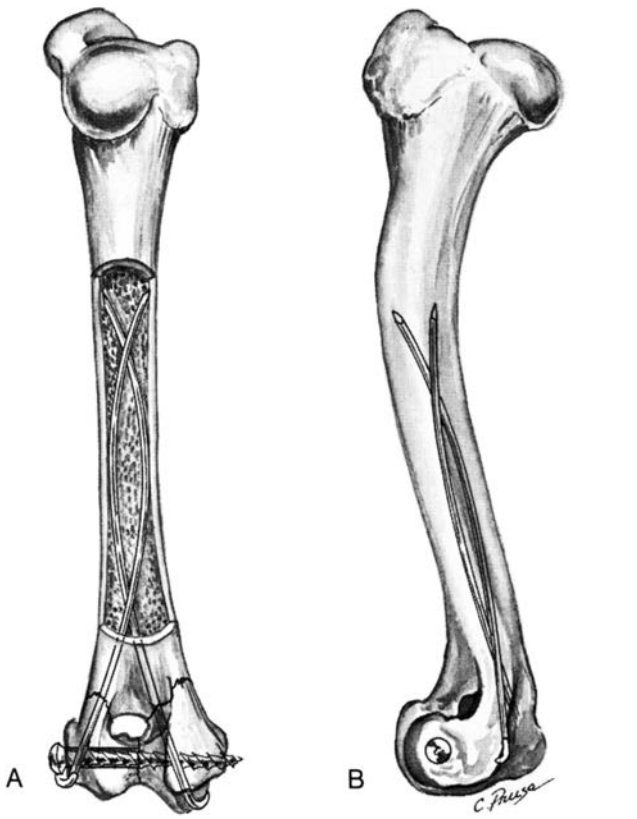


Figure 56-19. An intercondylar T fracture is stabilized with a transcondylar cortical lag screw and double Rush pins. **A.** Caudocranial view. **B.** Lateral view.

Postreduction radiographs are obtained to assess articular reduction and implant placement. Analgesics are administered to ensure patient comfort in the postoperative period. A Robert Jones bandage is applied to the limb for 3 to 5 days, followed by swimming physical therapy and range-of-motion exercises with controlled weightbearing for 6 to 8 weeks. The intramedullary pin should be removed when the bone has healed. The transcondylar screw, Kirschner wires, Steinmann pin, and bone plates are usually not removed unless they loosen or cause soft tissue irritation.

Suggested Readings

Brinker WO, Piermattei DL, Flo GL. Handbook of small animal orthopedics and fracture treatment. Philadelphia: WB Saunders, 1983.

Egger EL. Complications of external fixation: a problem-oriented approach. Vet Clin North Am 1991;21:705.

Evans HE, Christensen GC. Miller's anatomy of the dog. 2nd ed. Philadelphia: WB Saunders, 1979.

Hulse D, Hyman B. Biomechanics of fracture fixation failure. Vet Clin North Am 1991;21:647.

Lipowitz AJ, Caywood DD, Newton CD, et al. Complications in small animal surgery: diagnosis, management, prevention. Baltimore: Williams & Wilkins, 1996.

Newton CD, Nunamaker DM. Textbook of small animal orthopaedics. Philadelphia: JB Lippincott, 1985.

Olmstead ML. Complications of fracture repaired with plates and screws. Vet Clin North Am 1991,-21:669.

Piermattei DL, Greely RG. An atlas of surgical approaches to the bones of the dog and cat. 2nd ed. Philadelphia: WB Saunders, 1979.

Treatment of Elbow Luxations

Robert A. Taylor

Elbow luxation refers to the disruption of the articular congruity of the three bones that constitute the elbow joint. Luxation can be traumatic or congenital, with the former more common. Most acute traumatic luxations can be reduced by closed methods; chronic luxations sometimes require open reduction. Surgical repair of congenital elbow luxation is directed at the underlying defect.

The elbow joint is a compound joint formed by the articulation of the humeral condyle, the radial head, and the semilunar notch of the ulna. It is classified as a hinge joint; that is, its major motion is confined to swinging in one plane. The humeral radial articulation allows for 90° supination of the distal extremity.[1] The unique configuration of the articulation with the anconeal process located deep in the olecranon fossa, the prominent medial epicondyle of the humerus, and the ligaments of this joint creates a stable articulation. The medial and lateral collateral ligaments connect all three bones; in addition, the oblique ligament, olecranon ligament, and annular ligament further enhance the stability of the elbow.

Congenital Luxations

Congenital elbow luxation is most common in small breed dogs and is thought to have a hereditary basis.[2] Agenesis or hypoplasia of the medial collateral ligament allows for rotation of the proximal radius and ulna with subsequent subluxation. The humeral trochlea and anconeal process usually are underdeveloped, and other secondary joint changes may exist in affected animals. This disorder has been reported to occur in combination with ectrodactyly.[3]

Closed and open methods of reduction of congenital elbow luxation have been reported.[4] Limb salvage and function, rather than complete articular reconstruction, should be the main objectives of surgical correction. Closed reduction has been recommended for dogs under 4 months of age. In older animals with long-standing luxation, open reduction is necessary.

Surgical repair of congenital elbow luxation may involve capsulorrhaphy, reconstruction of the humeral trochlea, reconstruction of the semilunar notch, partial removal of the anconeal process, and capsular imbrication. One should be aware of possible iatrogenic injury to the physis associated with elbow development during surgical reduction. In some cases, owners may elect conservative treatment or euthanasia. Owners should be counseled with regard to the probable hereditary nature of this problem.[2]

Traumatic Luxations

In the absence of fractures, traumatic elbow luxation results in caudolateral or lateral displacement of the radius and ulna. The larger size of the medial condylar surface of the humerus compared with the lateral condyle partly explains the motion of luxation. In addition, the orientation of the oblique ligament and the olecranon ligament is such that lateral luxation is more likely than medial luxation.

Animals with acute traumatic elbow luxation present with a nonweightbearing lameness of the affected limb. The limb usually is flexed, abducted, and pro-nated. Pain is evident on manipulation, and crepitus and articular incongruity are present. The elbow usually is twice its normal width.

Radiographs taken in two planes are needed to confirm the diagnosis (Figure 56-20). The surgeon must rule out articular fractures before attempting closed reduction of a luxated elbow.

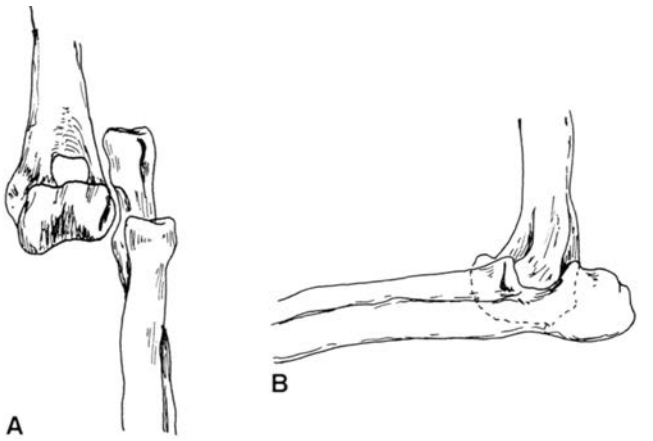


Figure 56-20. Craniocaudal and lateral views of the elbow showing the typical position of the radius and ulna after lateral luxation of the elbow.

Closed Reduction

General anesthesia is required for closed reduction of elbow luxations. Because the animal has sustained a recent trauma, a careful physical examination and assessment of associated injury must be performed before anesthesia is induced.

The animal is positioned in lateral recumbency with the affected limb uppermost. In long-haired patients, clipping the hair may be helpful to aid in the manual reduction of the luxation. Radiographs should be examined to determine the location of the anconeal process. If the anconeal process is laterally luxated, the elbow is flexed and the forepaw is rotated internally to force the anconeal process into the olecranon fossa.

With digital pressure on the radial head, the elbow is held flexed and the radius is pushed onto the humeral capitulum; the leg is then extended and flexed several times to ensure joint congruity. With the elbow flexed 90°, the forepaw can be rotated medially and laterally to check for collateral ligament integrity. If marked postreduction instability is present, surgical repair of the ligaments is indicated.

A soft padded bandage is used to support the limb and to limit swelling. Because early mobilization of the joint surfaces is necessary, the duration of immobilization is limited to 5 to 7 days. During this time, passive range-of-motion exercise should be encouraged.

The trauma necessary to produce luxation in a joint as stable as the elbow invariably results in damage to the articular cartilage, joint capsule, and collateral ligamentous support. Given time, some degree of degenerative joint disease usually results, and owners should be made aware of this possibility.

Open Reduction

Open reduction rarely is required in patients with acute elbow luxations; however, those with chronic luxations with associated capsular adhesions and contractures may require open reduction. In general, a lateral approach to the elbow is satisfactory, although in long-standing cases, a transolecranon approach gives greater exposure.[5] It is helpful to lever the radius and ulna[6] into place with a smooth periosteal elevator. Caution is necessary to avoid undue articular cartilage damage. Once reduced, the joint is worked through a normal range of motion, and any fibrin tags and debris are removed. If the lateral collateral ligament has been ruptured, the surgeon must decide to select primary repair or use screw and suture augmentation of the ligament.

Postreduction support is similar both with surgically reduced elbow luxations and with manually reduced luxations. Early activity, range-of-motion exercise, and weightbearing are important for proper rehabilitation.

References

1. Evans H, Christensen G. Miller's anatomy of the dog. 2nd ed. Philadelphia: WB Saunders, 1979.

2. Bingel SA, Rizer, WH. Congenital elbow luxation in the dog. J Small Anim Pract 1977;18:45.

3. Montgomery M, Tomlinson J. Two cases of ectrodactyly and congenital elbow luxation in the dog. J Am Anim Hosp Assoc 1985;21:781.

4. Nunamaker DW. Fracture and dislocation of the elbow. In: Small animal orthopedics. Philadelphia: JB Lippincott, 1985.

5. Piermattei DL, Greeley RG. Atlas of surgical approaches to the bones of the dog and cat. Philadelphia: WB Saunders, 1979.

6. Stayak JW. Elbow luxations. In: Bojrab MJ, ed. Current techniques in small animal surgery. Philadelphia: Lea & Febiger, 1975.

Surgical Treatment of Ununited Anconeal Process of the Elbow

Ursula Krotscheck

Anatomy

The elbow, or cubital, joint is the convergence of three separate bones: the humerus, radius, and ulna. These form a hinge (ginglymoid) joint composed of three smaller joints: the humeroulnar (trochlea and trochlear notch), humeroradial (capitulum and radial head), and proximal radioulnar joints. The olecranon fossa of the humeral condyle articulates with the anconeal process (AP) of the ulna during joint extension beyond 90 degrees and restricts elbow movement in the sagittal plane.[8,38] The normal elbow joint has 3 distinct areas of contact: the craniolateral aspect of anconeus, the radius, and medial coronoid process (MCP). The latter two are continuous across the radioulnar articulation. There is no articular contact at the medial aspect of the anconeus as well as the central trochlear notch. Neither the size nor the location of the contact areas is affected by the amount of axial loading.

The soft tissue structures surrounding and supporting the elbow joint are important for examination purposes as well as for surgical and arthroscopic procedures. The joint capsule encloses all three bones into one space; its cranial and caudal pouches are important for arthroscopy and arthrocentesis.[6] The lateral collateral ligament originates on the lateral epicondyle, splits into cranial and caudal crura, and inserts on the proximal radius and ulna, respectively. The medial collateral ligament originates on the medial humeral epicondyle, crosses the annular ligament, and also divides into cranial and caudal crura. The annular ligament of the radius encloses the cranial aspect of the radial head and inserts on medial and lateral extremities of radial incisure of ulna. Several important nerves surround the elbow joint. The ulnar and median nerves are on the medial aspect of the joint. The ulnar nerve is caudal and superficial, and can easily be palpated as it crosses the caudomedial aspect of the joint. The median nerve, on the other hand, is deeper and more cranial. It crosses the joint distal to the medial epicondyle, continues deep to the pronator teres muscle along the median artery, and may be seen during a medial arthrotomy. The radial nerve is on the cranial and lateral aspect of the elbow joint; a deep branch extends under the extensor carpi radialis muscle while two superficial branches course along the medial and lateral borders of the cephalic vein.

In small dogs the MCP and AP mature by 16 weeks of age, while in large dogs AP ossification is not completed before 14 weeks of age and MCP ossification is completed approximately 6 weeks later.[1]

Pathogenesis

Ununited anconeal process (UAP) is defined as the failure of the anconeal process to undergo normal bony fusion with the proximal ulnar metaphysis by 20 weeks of age.[4] The anconeal process may exhibit partial or complete separation or it may be fused in an abnormal location.[23] Several explanations for development of an ununited anconeal process have been proposed, including abnormal formation of the trochlear notch, osteochondrosis, and most recently, articular incongruency secondary to asynchronous growth of the radius and ulna.[34,39] In chondrodystrophic breeds, a shortened ulna relative to the radius occurs due most likely to growth retardation or premature closure of the distal ulnar physis. The resultant short ulna causes the radius to push upward on the humeral condyle during its continued growth, thereby forcing the ventral margin of the anconeal process against the humeral trochlea. This upward force leads to separation or lack of fusion of the physis, resulting in an ununited anconeal process. This theory has been supported by clinical evidence: in 15 of 18 dogs examined, the anconeal process was proximally displaced the same distance

as the radius relative to the ulna.[34] Though spontaneous fusion of an UAP has been reported, it is considered rare.[9,10,34] If an ununited anconeal process is left in situ, elbow osteoarthritis (OA) will progress leading to suboptimal limb function.[41]

Clinical Presentation

Ununited anconeal process occurs much less frequently than fragmented coronoid process (FCP) or osteochondritis (OC).[19,27] It is most commonly seen in large to giant breed dogs as well as chondrodystrophic breeds such as the Basset hound and Dachshund.[23,34] Of the large to giant breed dogs, German Shepherds are over-represented.[33,39] Breeds with a secondary center of ossification of the anconeal process are likely predisposed to UAP,[38] though asynchronous growth may play a secondary role (chondrodystrophic breeds). Males are affected approximately twice as commonly as females, and breeding of affected animals is not recommended.[3,9,34,36,42]

Radiographic Examination

Radiographs are indicated in any dog in which UAP or any other form of elbow dysplasia is a differential diagnosis for forelimb lameness. The diagnosis of a UAP can usually be made using a maximally flexed lateral radiograph of the elbow joint (Figure 56-21). The cranio-caudal view is indicated to document the degree of OA. Many patients will resist flexion of the elbow due to the discomfort associated with UAP and may require sedation to obtain diagnostic quality radiographs. Radiographs of both elbows are always indicated as this is considered a developmental disease. A definitive diagnosis of UAP can be made if a line of cleavage separating anconeal process from ulnar metaphysis is radiographically apparent. This line can be of differing widths and the anconeal process can be normal or abnormal in position, size, shape and radiographic density. The degree of osteoarthritis apparent radiographically depends on the chronicity of disease (Figure 56-22).



Figure 56-21. Maximally flexed lateral radiograph of a dog with a non-displaced UAP. Note the cleavage line between the anconeal process and the proximal ulnar metaphysis *(arrow)*.

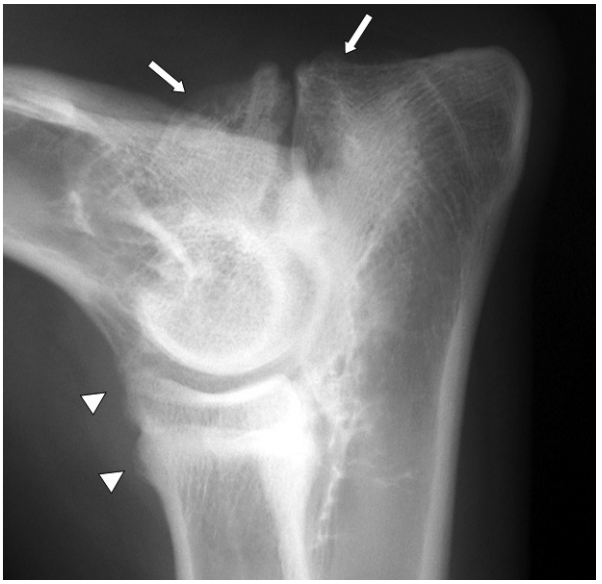


Figure 56-22. Severe OA secondary to UAP. Note the osteophytes on the dorsal aspect of the AP, surrounding the cleavage plane *(white arrows)* and on the radial head *(white arrow heads)*.

Treatment Options and Indications for Surgery

Surgical intervention is recommended for treatment of UAP.[38] If an ununited anconeal process is treated conservatively (left in situ), elbow OA will progress and likely cause less than optimal limb function.[41] Medical therapy includes weight management, controlled exercise, and appropriate medications (non-steroidal anti-inflammatories, osteoarthritis modifying supplements).[38] Conservative management is less successful than surgery and results in rapid progression of osteoarthritis.[4] The goal of treatment of an ununited anconeal process is the complete restitution of normal joint function.

Surgical options for UAP are its removal, reattachment to the ulna, and osteotomy/partial ostectomy of the ulna with or without surgical fixation of the anconeal process to the ulna.[7,8,11,13,17,25,29,30,32,33,34,37,39]

Surgical Removal of the Anconeal Process

(Table 56-1)

Initially, the recommendation was that all UAPs be surgically removed.[2,5,14,21,28,34] However, due to the inherent instability of the elbow following removal of the anconeal process,[41] the prognosis associated with this procedure has been variable. The lack of the anconeal process causes an unstable joint, reliably leading to a decreased range of motion of the elbow joint, increased osteoarthritis and a high incidence of post-operative clinical dysfunction.[9,10,18,21] One study reported that even though 70% of patients improved clinically following removal of the UAP, only 50% were free of lameness[9] whereas in another retrospective study, surgical removal resulted in good to excellent long term function.[29] Long-term results with excision are generally considered unsatisfactory because patients are not free of lameness. Removal of the anconeal process may still be an appropriate decision when it is misshapen and its preservation

Table 56-1. Published Outcomes of Anconeal Process Removal OA = Osteoarthritis, AP = Anconeal Process

Source	# joints	AP excision	Mean age (months)	Mean follow-up (months)	Change in osteoarthritis score
Sinibaldi 1975[32]	19	19		19.5	1 slight, 9 min, 5 mod, 4 severe
Parrisius 1985[21]	56	56		24.7	14% no change, 69% increase 1 grade, 17% increase 2 grades
Guthrie 1989[9]	19	19		6 to 72	7/7 re-evaluated progressed in OA
Meyer-Lindenberg 1991[18]	53	53		25	0 none, 8 minimal, 12 moderate, 7 severe (27 total)
Roy 1994[29]	7	7	8.7	73	all progressed in OA

would not restore joint congruity or if the dog has advanced osteoarthritis.

Reattachment of the Anconeal Process

(Table 56-2)

In an attempt to improve outcome, a technique was described whereby a compression screw is utilized to stabilize the ununited anconeal process.[10,25,26] This can be done from either the anconeal process into the ulna, or vice versa, though the latter is preferred because no implants are left within the joint. Results were encouraging and showed the stability afforded the joint by preserving the anconeal process.[7] Compression of the cleavage plane utilizing a screw placed in lag fashion stabilizes the anconeal process in a normal anatomic position and encourages bony fusion. By preserving the anconeal process, elbow joint stability is maintained, decreasing the potential for future development of osteoarthritis.[7] However, a complication encountered with any compression screw fixation is breakage of the screw.[31] This most likely occurs secondary to continued shear forces across the cleavage plane between the anconeal process and the ulnar metaphysis when the underlying elbow incongruity is not corrected. Stabilizing the anconeal process in an obviously incongruent joint may actually increase the forces acting on the articular cartilage of the anconeal process and the humeral trochlea, resulting in increased cartilage wear and potential screw failure. Continued incongruity will cause osteoarthritis to progress.

Reestablishment of Joint Congruity (Ulnar Osteotomy/Partial Ostectomy)

(Table 56-2)

An ulnar osteotomy or partial ostectomy is advocated to allow dynamic repositioning of the radius, relative to the ulna, thereby improving elbow congruity. It also lessens the pressure directed against the anconeal process, encouraging ossification of the cleavage plane.[20,33,34] Radiographic union of the anconeal process to the ulnar metaphysis has been variable with this technique,[34,39] but this appears to be dependent on the age of the dog at the time of surgery as well as whether or not the anconeal process is firmly attached to the ulna by fibrous tissue or is loose. Patients in whom the anconeal process is firmly fixed to the ulna appear to be more likely to proceed to bony union with only an ulnar osteotomy/partial ostectomy than those in which the anconeal process is loose at the time of surgery.[17] Failure to observe fusion of an ununited anconeal process after only an ulnar osteotomy/partial ostectomy is more prevalent when the age of the dog at the time of surgery is greater than seven to eight months.[11,39] These patients should have combination fixation (see below). A more favorable outcome is achieved with an ulnar osteotomy or partial ostectomy compared to surgical excision of the anconeal process.[34] Any time an intra-articular step with the ulna being shorter than the radius is evident within the joint at the time of surgery an ulnar osteotomy/partial ostectomy is indicated.

Overall, ulnar osteotomy or partial ostectomy alone should be performed in cases where the anconeal process is stable at the time of surgery or in animals 6 months of age or less. Additional fixation (lag screw) is indicated in any animal whose anconeal process is not stable at the time of surgery regardless of age.[17,38]

Combination Fixation Approach

(Table 56-2)

Combining both the ulnar osteotomy/partial ostectomy with lag screw fixation of the anconeal process has shown the most consistently promising results,[11,17] likely because it addresses the underlying cause (elbow incongruency) as well as the resultant pathology (UAP). The ulnar osteotomy improves the underlying elbow incongruency and relieves pressure directed against the anconeal process. Placement of the compression screw achieves the stability necessary to encourage fusion of the cleavage plane between the ununited anconeal process and ulna. In the long term, maintaining joint stability (preserving the anconeal process) and improving joint incongruency (osteotomy) should result in optimal clinical outcome.[11] Excellent long-term outcome with no to minimal OA progression has been achieved. Of 39 joints reported in the literature, radiographic fusion was achieved in over 97% of cases.[11,17] In another study, 13 of 20 dogs with UAP treated with the combination of an AP fixation and ulnar osteotomy/ostectomy were re-examined clinically and radiographically at a mean of two and a half years later. Nine (69%) had no lameness, four (31%) had no arthrosis, and 80% (16/20) of owners were satisfied with the outcome.[12] Best results are expected in dogs less than 6 months of age at the time of surgery.[16]

Surgical Techniques

Surgical options for UAP are its removal, reattachment to the ulna,

Table 56-2. Published Outcomes of Anconeal Process Fixation and/or Ulnar Osteotomy/Ectomy
OA = Osteoarthritis, AP = Anconeal Process

Source	# joints	AP fixation	Ulna only	AP fixation and ulna	Mean age (months)	Mean follow-up (months)	% fused	Change in osteoarthritis score	Comments
Sjostrom 1995[34]	22		22		5.9	21		6 none,10 mild, 3 moderate, 1 severe	6 dogs had narrow radiolucent line without lameness
Thomson 1995[37]	3		3				66		
Fox 1996[7]	10	8		2		20.2	60	1 minimal, 2 mild, 5 moderate	Remainder lost to follow-up prior to radiographic fusion
Turner 1998[39]	23		23		7.7		22		
Meyer-Lindenberg 1999[17]	15	9			5.5	2.2	11	1 no/mild OA progression, 8 moderate to severe OA progression	Prospective data included in 2001 paper, retrospective data only
			6		4.9	2	17	1 no/mild OA progression, 5 moderate to severe OA progression	Anconeal process implant failed in 8/8 AP dogs w/o fusion
Krotscheck 2000[11]	4			4	7.8	30.5	100	minimal to no OA progression	
Meyer-Lindenberg 2001[17]	44		9		5.4	10.3	100	9/30 joints had mild OA progression	Implant loosening in one dog with two misdrills
				35	5.8	20.5	97		

and osteotomy/ partial ostectomy of ulna with or without surgical fixation of the anconeal process to the ulna.[7,8,11,13, 17,25,29,30,32,33,34,39]

Anconeal Process Removal

Anconeal process removal can be performed via a caudomedial or caudolateral approach,[22] though the caudolateral approach is preferred due to the smaller size of the lateral humeral condyle making visualization, surgical manipulation, and fragment removal easier. Surgical removal using arthroscopy has also been described.[40]

Arthrotomy

The dog is placed in lateral recumbency with the affected limb up. During surgical manipulation, the elbow can be stabilized by placing a roll of towels or other padding underneath it. Two different surgical approaches have been described, one based on a procedure by Snavely and Hohn[35] (described here), and another based on a procedure by Chalman and Slocum.

Based on the procedure of Snavely and Hohn (Figure 56-23A-D): A curvilinear skin incision is made over the caudolateral aspect of the joint, centering over the lateral humeral epicondyle (Figure 56-23A). The incision extends from just proximal to the lateral epicondylar crest to several centimeters distal to the radial head. The subcutaneous fascia is incised along the same line, exposing the brachial fascia (Figure 56-23B). The radial nerve may be encountered if the incision is made too far proximally. The brachial fascia is then incised just cranial to the lateral head of the triceps brachii muscle where it inserts on the olecranon. The triceps brachii muscle is then elevated and retracted caudally to visualize the anconeus muscle underneath (Figure 56-23C). The anconeus muscle is incised at its periosteal origin at the lateral epicondylar crest and subperiosteally elevated (Figure 56-23D). Retracting the anconeus muscle caudally exposes the caudolateral joint compartment of the elbow and the anconeal process. Gelpi retractors can be used to maintain exposure. For closure, absorbable sutures are recommended in a simple interrupted or continuous pattern. The anconeus muscle is sutured to the origin of the antebrachial extensor muscles. The brachial and subcutaneous fasciae are closed in separate layers, followed by the skin closure.

Anconeal Process Removal

With the anconeal process exposed, the joint is placed in maximum flexion. The anconeal process can be removed with tissue or towel forceps. Usually fibrous attachments between the anconeal process and the ulna need to be severed.

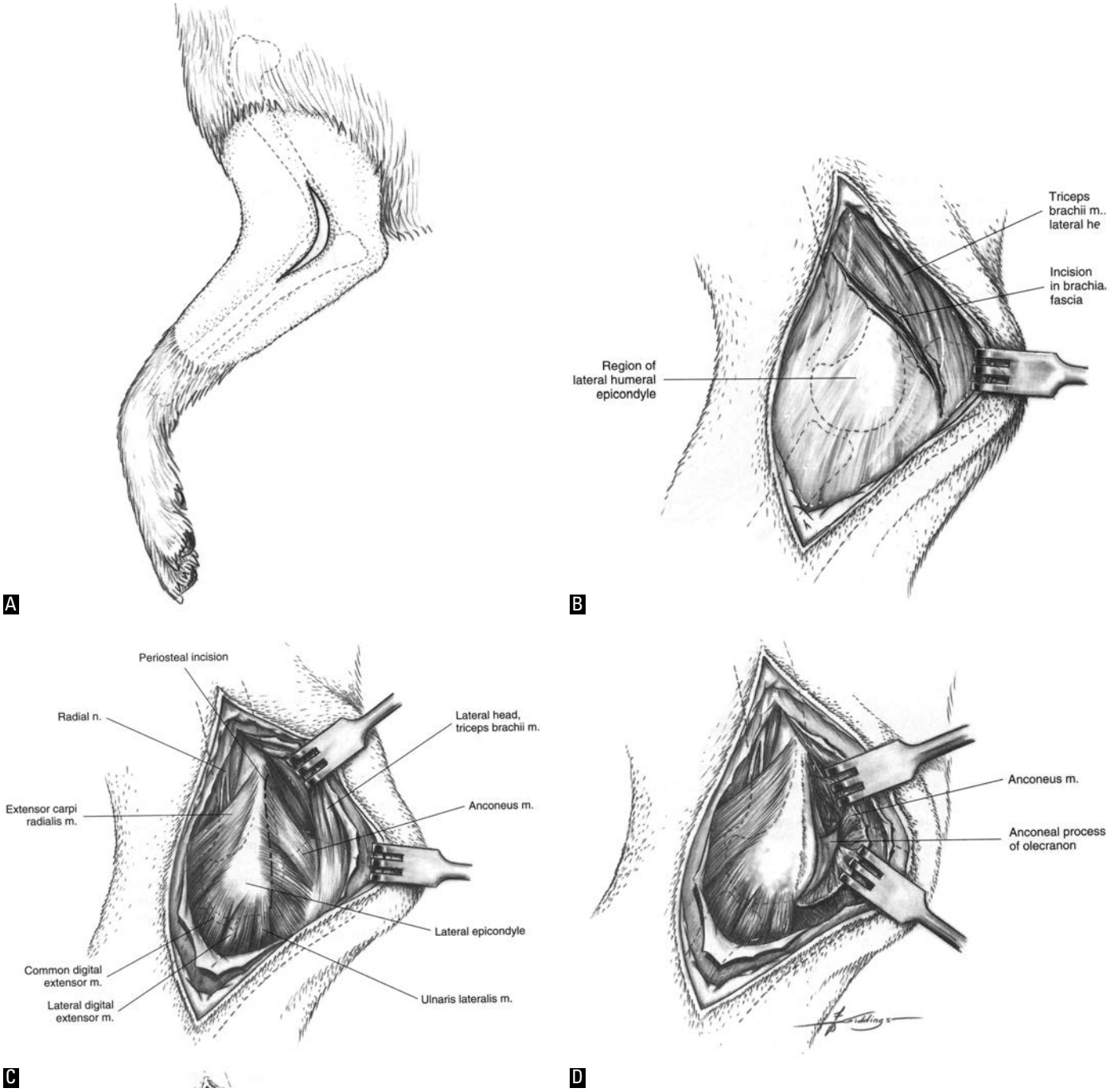


Figure 56-23A-D. Lateral approach to the elbow, see text for explanation. Reprinted from An atlas of surgical approaches to the bones and joints of the dog and the cat, 4th edition, Piermattei DL, Johnson KA. Approach to the lateral humeroulnar part of the elbow joint, 187-189, © 2004 Elsevier Copyright, with permission from Elsevier.

Ulnar Osteotomy

In chondrodystrophic and short-legged breeds, a distal ulnar ostectomy is recommended to prevent the creation of a painful nonunion that may occur after proximal or midshaft ulnar transection, while in long-legged dogs and non-chondrodystrophic breeds a proximal osteotomy or partial ostectomy is preferred.[15,38] Placing an intramedullary Kirschner wire is recommended for the fixation of proximal ulnar osteotomies or ostectomies to prevent caudal "kicking" of the proximal ulnar segment due to the pull of the triceps brachii muscle. Anconeal process removal or further fixation may be necessary if fusion is not observed 12 to 18 weeks after ulnar ostectomy and clinical signs remain.[38]

Proximal Ulnar Osteotomy/Partial Ostectomy

The skin is incised caudolaterally directly over the proximal ulna, followed in the same line by an incision in the underlying deep fascia. Periosteal incisions are then made in the origin of the flexor carpi ulnaris muscle medially and the ulnaris lateralis muscle laterally. The ulna is freed from its surrounding muscular attachments using a periosteal elevator. The ostectomy or osteotomy is performed 2 to 3 cm distal to the radial joint surface. The amount of dissection depends on whether a partial ostectomy or osteotomy is chosen. Hohmann retractors can be used to protect the soft tissues surrounding the ulna during the osteotomy. A sagittal saw is generally used for the ulnar cut(s). It is essential

to ensure that the osteotomy penetrates the entire ulna in order for joint congruity to be reestablished. The osteotomy may be straight or oblique at a 45° angle to the long axis of the ulna (caudoproximal to craniodistal) to minimize caudal angulation of the proximal piece and encourage rapid healing. In dogs in which this is the only method of UAP treatment, an ostectomy may be indicated as the oblique osteotomy may result in healing prior to restoration of joint congruence.[34] For the ostectomy, approximately 5 mm of bone and the surrounding periosteum are removed. The intramedullary pin can be applied normograde or retrograde. Normograde insertion is more difficult due to the small diameter of the target, but it will result in it exiting the ulna at a site amenable to surgical removal should that be needed. The surgical site is closed using absorbable sutures. The ulnaris lateralis and the flexor carpi ulnaris are sutured to each other over the caudal border of the ulna. The deep fascia, subcutaneous tissues and skin are closed routinely.

The intramedullary pin may cause discomfort, presumably due to interference with triceps muscle tendon of insertion. Once ulnar osteotomy or ostectomy site has healed, the intramedullary pin can easily be removed through a small incision.

Distal Ulnar Ostectomy

A skin incision is made directly over the distal lateral surface of the ulna, from the midshaft to the styloid process. Subcutaneous tissues are incised along the same line, exposing the underlying tendon of the ulnaris lateralis muscle over the distal ulna or slightly caudal to it and the tendon of the lateral digital extensor muscle is immediately cranial to the ulna. After identification of these tendons, the fascia between them is incised and retracted. The surrounding tissues, including part of the origin of the abductor pollicus longus if needed, are elevated from the ulna and protected from the sagittal saw using Hohmann retractors. The ostectomy is performed as above. Closure is routine: the fascia is closed, followed by the subcutaneous tissues and the skin.

Lag Screw Fixation of the Anconeal Process

The original procedure described screw placement from the anconeal process into the ulna, countersinking the screw head into the articular cartilage.[10] This has since been modified by placing the screw in the opposite direction, preventing the presence of an implant within the joint, creating a smaller hole in the anconeal process, and removal (if necessary) is easier and does not involve an arthrotomy.[25] A further modification is the addition of K-wires as a visual guide for screw placement and for anti-rotational purposes.[7]

The surgical approach to the joint for this procedure is as described above based on Snavely and Hohn (see Anconeal process removal). Once the anconeal process and the cleavage plane are visualized, a Kirschner wire (K-wire) is inserted into the anconeal process passing perpendicular to the cleavage line. It enters the caudal surface of the ulna, passes through the proximal quadrant of the anconeal process and exits 1mm beyond the articular margin. This allows visualization of the wire to assure its proper placement. A second K-wire and a compression screw are inserted sequentially using a drill guide. An aiming device can be used to facilitate proper K-wire and screw placement. The screw should be aimed towards the tip of the anconeal process. Either an appropriate length of partially threaded cancellous screw or a fully threaded cortical screw placed in lag fashion can be used. It is very important that there is no screw purchase within the ulnar metaphysis for both the lag screw and the partially threaded cancellous screw in order to ensure maximal compression of the cleavage plane. To achieve this with a fully threaded screw, a glide hole must be drilled through the existing thread (guide) hole to the cleavage plane. Its depth can be estimated by measuring the distance from the caudal aspect of the ulna to the cleavage plane along the line of the proposed screw placement. Screw sizes vary depending on the size of the anconeal process to be purchased, but 2.7 and 3.5 mm cortical screws and 4.0 mm partially threaded cancellous screws are most commonly used. After satisfactory screw placement, the initially placed K-wire is backed out until it is in the subchondral bone of the anconeal process, cut and bent in order to prevent migration into the joint. Its ideal position is 10 to 20 degrees divergent from the screw.[17] Post-operative radiographs are indicated (See Figure 56-24).

Proximal Ulnar Osteotomy and Lag Screw Fixation of the Anconeal Process

The combination of an ulnar osteotomy and lag screw fixation is used to address the underlying cause of the problem (elbow incongruity) and its resultant pathology (UAP). The procedure is performed as described above in the sections for lag screw fixation of the anconeal process and ulnar osteotomy/partial ostectomy. The general order of procedures is as follows: caudolateral arthrotomy, evaluation of the anconeal process and the tightness of its attachment, evaluation of joint incongruity, and lag screw fixation of the anconeal process followed by the ulnar osteotomy/



Figure 56-24. Post-operative radiographs using both lag screw fixation and proximal ulnar osteotomy.

partial ostectomy (Figure 56-24). It is thought that oblique ulnar osteotomy cuts may result in healing which is too rapid to allow for restoration of joint congruency.[34] This author concurs with that premise if the ulnar osteotomy is the only method of treatment for the UAP. If placing a lag screw in addition, the sliding oblique proximal ulnar osteotomy with an intramedullary pin appears to be adequate and comfortable for the patient. If in doubt, the joint should be evaluated for congruence after the ulnar osteotomy. If a large step remains, a partial ostectomy may be indicated. In dogs less than 6 months of age at the time of surgery that have minimal anconeal process instability, fixation using two K-wires is often sufficient.[16] This should always be combined with ulnar osteotomy or partial ostectomy in order to prevent continued incrongruency resulting in implant failure. In basset hounds, dachshunds and other chondrodystrophic breeds, a distal ulnar osteotomy/partial ostectomy is performed because the proximal procedure carries a higher risk of pseudoarthrosis formation in these breeds.[16] In dogs with longer legs, a proximal ulnar osteotomy/partial ostectomy is performed for better correction of joint incongruity, though it is associated with greater morbidity.[16]

Post-operative Care

Most surgeons recommend that the animal be placed in a soft support wrap for 2 to 5 days to decrease the immediate post-op swelling and minimize seroma formation. Exercise is generally restricted for 2 to 4 weeks[8,10,32] following anconeal process removal and until bony union has occurred in all other procedures. Passive range of motion exercise, heat and cold therapy, and non-steroidal anti-inflammatory drugs usually are implemented during the healing phase. Controlled walking on the limb is also encouraged. Removal of implants can be performed after bony healing is complete (Figure 56-25).



Figure 56-26. Failure on bony union of the UAP after treatment with a proximal ulnar osteotomy.

Complications

All surgeries described above carry a risk of infection, seroma formation, and bleeding. Osteoarthritis of the elbow may also continue after any of these procedures. Anconeal process removal itself does not carry any other major complications other than the probable increase in osteoarthritis. If only an ulnar osteotomy/partial ostectomy is performed, complications may include failure of the anconeal process and ulna to proceed to bony union, continued elbow incongruency, non-union of the ulnar osteotomy, chronic post-operative pain, and pin migration (Figure 56-26). Lag screw fixation of the ulna carries the possible complications of implant failure, failure of the anconeal process to undergo bony union with the ulnar metaphysis, and penetration of the joint surface with the screw or K-wire. When a combined treatment approach is used, all of the complications listed above are possible. Use of combined treatment does, however, appear to increase the likelihood of a positive outcome.



Figure 56-25. Radiograph of the dog in Figue 56-24 at three months after surgery. Note the lack of progression of OA.

Prognosis

Currently, there is no clinical trial definitively comparing all of the previously mentioned techniques, though some generalizations can be made based on the literature: Removal results in an increase of osteoarthritis in 93% of animals reported in the literature, though some lamenesses may temporarily improve, probably secondary to removal of the loose fragment. This procedure is likely indicated in those cases presenting as adults with severe osteoarthritis. The reported outcome with only lag screw fixation of the anconeal process has been disappointing with only 38% of reported cases achieving bony union. In one study, all dogs which did not achieve bony union had implant failure. Of the cases reported in the literature treated solely with an ulnar osteotomy, the overall rate of progression to bony union was 51%. Patient selection appeared to be important. If a fragment was firmly attached at surgery and the dog was less

than 7 months of age, it is reasonable to expect radiographic union and a good to excellent clinical outcome with only an ulnar osteotomy. If the animal is over 7 months of age or if the fragment is loose, combination fixation with a lag screw and ulnar osteotomy/ostectomy is recommended. Ninety-seven percent of cases which had this type of fixation continued to radiographic fusion (See Figure 56-26). Normal function even after strenuous exercise can be achieved in 82% of these dogs.

References

1. Breit S, Kunzel W, Seiler S: Variation in the ossification process of the anconeal and medial coronoid processes of the canine ulna. *Res Vet Sci* 77:9, 2004.

2. Brinker WO, Piermattei DL, Flo GL: Handbook of small animal orthopedics and fracture treatment. Philadelphia: Saunders, 1990, p 502.

3. Cook JL: Forelimb lameness in the young patient. *Vet Clin North Am Small Anim Pract* 31:55, 2001.

4. Cross AR, Chambers JN: Ununited anconeal process of the canine elbow. Comp Cont Ed Pract Vet 19:349-361, 1997.

5. Denny HR: A guide to canine and feline orthopedic surgery. London: Blackwell, 1993, p 229.

6. Evans HE: Miller's anatomy of the dog. 1993.

7. Fox SM, Burbidge HM, Bray JC, et al: Ununited anconeal process: Lag-screw fixation. *J Am Anim Hosp Assoc* 32:52, 1996.

8. Goring RL, Bloomberg MS: Selected development at abnormalities of the canine elbow: Radiographic evaluation and surgical management. *Comp Cont Ed Pract Vet* 5:178-192, 1983.

9. Guthrie S: Some radiographic and clinical aspects of ununited anconeal process. *Vet Rec* 124:661, 1989.

10. Herron MR: Ununited anconeal process in the dog. *Vet Clin North Am* 1:417, 1971.

11. Krotscheck U, Hulse DA, Bahr A, et al: Ununited anconeal process: Lag-screw fixation with proximal ulnar osteotomy. *Vet Comp Ortho Trauma* 13:212, 2000.

12. Kurzbach T: Retrospektive langzeituntersuchung von operativ versorgten ellbogen- und schultergelenkfrakturen bei hund und katze. *Vet Med Diss* Munich 2000.

13. Lewis R, Leighton RL: Surgical stabilization of the ununited anconeal process in the dog using cerclage wire. *Calif Vet* 49:10, 1995.

14. Loeffler K: Der isolierte processus anconaeus beim deutschen schaeferhund. *Dtsch Tieraerztl Wochenschr* 71:291, 1963.

15. Matis U. Lag screw fixation of ununited anconeal process, in *Surgical Fixation of Fractures, 24th annual advanced canine course in AO/ASIF Technique* 2001.

16. Matis U. Management of the UAP by internal fixation, in *10th ESVOT Congress* 2000.

17. Meyer Lindenberg A, Fehr M, Nolte I: Short- and long-term results after surgical treatment of an ununited anconeal process in the dog. *Vet Comp Ortho Trauma* 14:101, 2001.

18. Meyer-Lindenberg A, Fehr M, Nolte I: Der isolierte processus anconaeus des hundes - vorkommen, behandlung, und ergebinsse. *Kleintierpraxis* 36:671, 1991.

19. Olsson SE: Pathophysiology, morphology, and clinical signs of osteochondrosis in the dog. In Bojrab MJ, ed.: Disease Mechanisms in Small Animal Surgery. Philadelphia: Lippincott Williams & Wilkins, 1993, p 778.

20. Olsson SE, Jerre S, Kasstrom H. Pathogenesis of ununited anconeal process, fragmented medial coronoid process, and OCD of the canine elbow, in *9th Congress of the Society for Veterinary Radiology* 1991.

21. Parrisius A: Detached anconeal process in the dog. treatment and results between 1975 and 1983. 1985.

22. Piermattei DL, Johnson KA: Atlas of surgical approaches to the bones and joints of the dog and cat. 2004.

23. Presnall K: Ununited anconeal process of the elbow. In Bojrab MJ, ed.: Current Techniques in Small Animal Surgery. Philadelphia: Lea and Febiger, 1990, p 778.

24. Preston CA, Schulz KS, Kass PH: In vitro determination of contact areas in the normal elbow joint of dogs. *Am J Vet Res* 61:1315, 2000.

25. Pritchard DL: Anconeal process pseudoarthrosis: Treated by lag-screw fixation. *Canine Pract* 3:18-23, 1976.

26. Punzet G: Ellbogengelenksdysplasie mit isoliertem processus anconaeus - eine neue moeglichkeit der chirurgischen behandlung. *Kleintierpraxis* 18:121, 1973.

27. Remy D, Neuhart L, Fau D, et al: Canine elbow dysplasia and primary lesions in german shepherd dogs in france. *J Small Anim Pract* 45:244, 2004.

28. Renegar WR, Farrow CS: OsteochondrosisIn Whittick WG, ed.: Canine orthopedics. Philadelphia: Febiger, 1990, p 620.

29. Roy RG, Wallace LJ, Johnston GR: A retrospective long-term evaluation of ununited anconeal process excision on the canine elbow. *Vet Comp Ortho Trauma* 7:94, 1994.

30. Sikkema DA, Roush JK: Unusual presentation of an ununited anconeal process in a 6-year-old great dane. *Vet Comp Ortho Trauma* 7:177, 1994.

31. Sinibaldi KR: Ununited anconeal process in the dog. In Bojrab MJ, ed.: Current Techniques in Small Animal Surgery. Philadelphia: Lea and Febiger, 1983, p 719.

32. Sinibaldi KR, Arnoczky SP: Surgical removal of the ununited anconeal process in the dog. *J Am Anim Hosp Assoc* 11:192, 1975.

33. Sjostrom L: Ununited anconeal process in the dog. *Vet Clin North Am Small Anim Pract* 28:75, 1998.

34. Sjostrom L, Kasstrom H, Kallberg M: Ununited anconeal process in the dog. pathogenesis and treatment by osteotomy of the ulna. *Vet Comp Ortho Trauma* 8:170, 1995.

35. Snavely DA, Hohn RB: A modified lateral surgical approach to the elbow of the dog. *J Am Vet Med Assoc* 169:826, 1976.

36. Stevens DR, Sande RD: An elbow dysplasia syndrome in the dog. *J Am Vet Med Assoc* 165:1065, 1974.

37. Thomson MJ, Robins GM: Osteochondrosis ot the elbow, a review of the pathogenesis and a new approach to treatment. *Aust Vet J* 72:375, 1995.

38. Trostel CT, McLaughlin RM, Pool RR: Canine elbow dysplasia: Anatomy and pathogenesis. *Comp Cont Ed Pract Vet* 25:754, 2003.

39. Turner BM, Abercromby RH, Innes J, et al: Dynamic proximal ulnar osteotomy for the treatment of ununited anconeal process in 17 dogs. *Vet Comp Ortho Trauma* 11:76, 1998.

40. van Bree HJJ, van Ryssen B: Diagnostic and surgical arthroscopy in osteochondrosis lesions. *Vet Clin North Am, Small Animal Practice* 28:161, 1998.

41. Wind AP: Elbow dysplasia. In Slatter D, ed.: Textbook of Small Animal Surgery. Philadelphia: WB Saunders Co, 1993, p 1966.

42. Wind AP, Packard ME: Elbow incongruity and developmental elbow diseases in the dog: Part II. *J Am Anim Hosp Assoc* 22:725, 1986.

Surgical Treatment of Fragmented Coronoid Process

Ursula Krotscheck

Anatomy

See previous section on ununited anconeal processes.

Pathogenesis

In dogs, the medial coronoid process (MCP) develops exclusively by appositional ossification. The normal radioulnar articulation is a smooth transition between the ulnar trochlear notch and the proximal articular surface of the radial head.[58] During a dog's growth phase, the relatively early development of a trabecular pattern within the MCP reflects significant mechanical loading at an early age. It is loaded primarily in a direction perpendicular to the humeroulnar surface during normal weight bearing as evidenced by the primary axis of its trabecular orientation, while the tensile stress from the annular ligament forms a secondary axis.[62] Initially, a fragmented medial coronoid process (FCP) was believed to be a form of osteochondrosis (OCD),[39,40] but it has since been suggested that mechanical overload at an early age may lead to this condition.[17] The histologic and ultrastructural appearance of an FCP is more consistent with mechanical failure of the cartilage, its associated subchondral bone, and subsequent unsuccessful fibrous repair[17,22] than an osteochondrosis type of lesion. The characteristic osteochondral fissures or fractures associated with an FCP may be due to excessive loads experienced by the developing MCP secondary to conformational abnormalities, such as elbow incongruity.[17,58-60] Elbow incongruity is speculated to result from underdevelopment of the ulnar trochlear notch[8,15,58,59,61] or asynchronous growth of the radius and ulna (short radius, long ulna).[30,59,61]

In large, heavy-set breeds of dogs, the ulnar trochlear notch may not be large enough to accommodate the relatively big humeral condyle. When evaluating lateral radiographs of the elbow, the proximal ulna is significantly longer in breeds commonly affected with FCP compared to other breeds.[59,61] Additionally, heavy-set breeds have a slightly wider, larger, and less steeply sloping MCP than sight hounds.[58] When comparing the radius of the curvature of the ulnar notch in rottweilers and greyhounds, a significant and consistent difference was found, with greyhounds having a significantly greater mean radius of curvature at the end of the medial coronoid process, in comparison to rottweilers. The significance of these findings for dogs with FCP is unclear.[12]

As with an ununited anconeal process, the rate of growth of the radius and ulna in relation to each other is speculated to be part of the pathogenesis of FCP. Necropsies of dogs with FCPs have revealed that the MCP and the distal edge of the ulnar trochlear notch are often positioned slightly proximal to the adjacent articular surface of the radial head.[59,61] This incongruity then places excessive load on the developing MCP during weight-bearing and is implicated as the cause of fragmentation.[58-61] This agrees with the ultrastructural appearance of the FCP.[22] The most likely cause of this is a genetic predisposition to elbow incongruency leading to subsequent mechanical overload of the MCP.[18,50] Worsening of the phenotypic expression may be caused by caloric oversupplementation[58,61,65] and excessive calcium intake.[44]

Both osteochondritis dissecans and FCP have a polygenic mode of inheritance.[41] The heritability estimates vary from 0.27 to 0.7721,[48,49] and it is not recommended to breed dogs with this disorder, dogs producing offspring with this disorder, as well as phenotypically normal dogs with first degree relatives with this disorder.[41]

Clinical Presentation

FCP is one of most frequent canine developmental orthopedic disorders[8,26,34] and can occur in conjunction with OCD in the same joint. Often, the disease is bilateral.[30]

The age of presentation for clinical signs consistent with FCP in retriever-type dogs has two peaks: 5.9 months and 4.5 years.[31] Dogs bilaterally affected seem to present later because the lameness may be more difficult to recognize.[8] Male dogs account for 65 to 75% of cases in some studies,[19,28] while in a controlled breeding study to determine the inheritance of FCP and OCD males and females were equally affected.[41]

Clinical signs often consist of stiffness and a stilted gait or lameness occurring between four to seven months of age.[28,39] When the patient is standing, inward rotation of the elbow and external rotation, or supination, of the paw may be present. Pain on hyperextension or hyperflexion of the elbow is common and joint effusion of variable degree is usually present in more advanced cases. The development of osteoarthritis (OA) associated with FCP is influenced by the size of the fragment, its mobility, and the amount of time it has been present.[39] These fragments can be single or multiple and may involve only a small section of the MCP or its majority. It is interesting to note that the boxer is one of most frequently affected breeds presenting over 18 months of age, but radiographic evidence of OA in the affected joint is either absent or mild for unknown reasons.[34]

Diagnosis

Definitive diagnosis of FCP can be difficult. Techniques which have been used include plain film radiography, xeroradiography, linear tomography,[14] arthrography,[29] CT,[9,11] MRI and arthroscopy.[55,56]

Visualizing or definitively diagnosing an FCP using plain film radiography can be challenging. The MCP is a small ulnar projection obscured in normal dogs by the radial head and the ulnar shaft on standard views. The cleavage line cannot be seen if it is at all oblique to the x-ray beam. In young dogs radiographs can appear normal (Figure 56-27) while in older dogs only secondary OA changes are seen (Figure 56-28). Radiographic changes characteristic of secondary OA include periarticular osteophytosis of the dorsal aspect of the anconeal process (AP), the cranial articular margin of the radial head, the medial humeral epicondyle, and the MCP, as well as bony sclerosis of the ulnar trochlear notch.[5,28] The most significant radiographic lesion of FCP is osteophyte formation on the proximal margin of the AP.[24,36,57] Most osteophytes associated with FCP do not appear until the dog is 7 to 8 months of age.[2] Often, the radiographic diagnosis



Figure 56-27. Normal lateral radiograph of the dog in Figure 56-29. A and B.

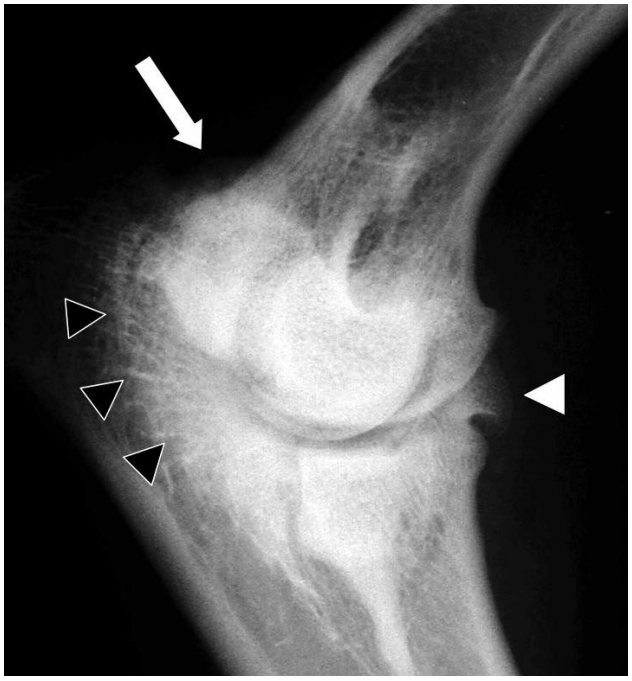


Figure 56-28. Radiographic changes consistent with osteoarthritis secondary to an FCP. Note the osteophytosis on the anconeal process *(white arrow)* and radial head *(white arrow head)*, and the sclerosis of the trochlear notch *(black arrow heads)*.

of FCP is based on these secondary OA changes.[4,6,18, 39,45,57] The accuracy and sensitivity of survey radiographs in detection of FCP is 56.7% and 23.5%, respectively.[11] Several alternative radiographic projections have been evaluated for their ability to definitively diagnose FCP. In one study, the MCP was best visualized on a mediocaudal-laterocranial 15° oblique (extended and supinated mediolateral) radiographic projection when compared to the standard mediolateral and flexed mediolateral views.[36,57] Another study agreed with these findings, stating that the Cr15L-CdMO provided greatest sensitivity (62%) for definitive identification of an FCP when it existed and the greatest agreement among evaluators.[64] A more recent study compared the Cr15L-CdM oblique and the Di35M-PrL oblique views (in addition to standard radiographic views) and found that a normal MCP was best identified on the Di35M-PrL oblique view, concluding that the Di35M-PrL oblique view enhances the identification of anomalies and fragmentation of MCP compared to other views.[23]

Because of the inherent difficulty with the definitive diagnosis of FCP on plain radiographs, other imaging modalities have been evaluated. Using arthroscopy as the definitive diagnostic method for FCP, computed tomography (CT) had the highest accuracy (86.7%) and sensitivity (88.2%) and negative predictive value (84.56%) when compared to standard radiographs, linear tomography, and xeroradiography.[11] Other advantages of CT are the ability to not only evaluate the MCP, but also other aspects of the articular surfaces for defects and incongruities (Figure 56-29A and B). Sagittal reconstruction of CT images can be helpful in evaluating joint incongruity. Magnetic resonance imaging (MRI) is also more accurate than conventional radiography for FCP detection in dogs.[46] Magnetic resonance arthrography permits classification of an FCP into 2 categories: completely loose fragments and fragmented processes that are still attached to the ulna by a cartilaginous bridge, but this did not provide substantial additional information about changes on MCP compared to MRI without contrast.[47] In general, CT and MRI have higher accuracy, sensitivity and specificity than plain radiographs.[11,46] Regardless, no noninvasive imaging modality currently available to veterinary medicine can make a diagnosis of an FCP with 100% certainty.[53] It was recently proposed that arthroscopy is the best diagnostic technique for determining the cause of elbow disease when there is no radiographic proof of FCP.[34] Comparison of standard radiographs, CT and arthroscopy in lame dogs elucidated that only arthroscopy allows consistent definitive diagnosis of elbow lesions before the development of OA.[56]

Treatment Options and Indications

Osteoarthritis is expected to progress in most dogs with FCP. Because of this, all dogs with FCP should be started on conservative medical management regardless of surgical intervention. This consists of dietary control of growth, weight management, exercise moderation, non-steroidal anti-inflammatory drugs, and chondroprotective agents. Early surgical removal of an FCP has been the treatment of choice.[31,42,43,54] This may have a better outcome than conservative medical management; especially if the dog is a companion animal and the surgery is performed prior to 2 years of age. According to owner questionnaires, 78% of dogs which had surgery at less than two years of age returned to apparent soundness.[31] Traditionally, in older dogs with severe OA secondary to FCP, medical management has been recommended over surgical FCP removal.[4,6,18,39] Evidence suggests that with only conservative therapy, elbow OA progresses significantly and the duration of lameness increases,[6,18,35,62] thus leading to the recommendation for surgery even in older patients with chronic OA.[33] Over half of patients followed radiographically after FCP removal did not increase in OA grade, suggesting that surgery may prevent worsening of the secondary OA.[19]



Figure 56-29. Computed tomography images of the dog in Figure 56-27. Note the normal left MCP **A.** and the area of chondromalacia on the right MCP **B.** *(white arrow).*

On the other hand, there are studies documenting a lack of positive influence of surgical intervention on the progression of secondary OA.[7] Part of the lack of improvement after surgical intervention and continued OA may be explained by remaining elbow incongruity. If present at the time of surgery, it can be addressed with an ulnar ostectomy/osteotomy.[30,37] It has been recommended that this surgery should be performed early to prevent changes to other ulnar structures. When combining FCP removal with a proximal ulnar osteotomy, the average time to improvement was 8.6 weeks. Nine of 10 dogs had a good to excellent clinical outcome with almost full range of motion (ROM), absence of pain and crepitation in the elbow, and no signs of lameness. Late follow-up radiographs showed mild caudomedial rotation of proximal ulna: 10 to 15 degrees caudally and zero to five degrees medially compared to the pre-operative images, with the author commenting that the fear of excessive rotation of the proximal ulnar fragment is unfounded.[38] OA did progress in most of these dogs. It has been recommended not to stabilize the osteotomy even though this might speed recovery and reduce callus formation. The risk of maintaining the fragment in an inappropriate location is minimized with an unstable osteotomy and optimizes the chance of achieving good functional elbow joint anatomy.[38] Along these lines, it has been hypothesized that with an early ulnar osteotomy/ostectomy, the removal of an FCP may be unnecessary because it could consolidate following relief of the excessive pressures it is subjected to in an incongruous elbow.

Several surgical approaches to the elbow for FCP removal have been described: triceps tenotomy,[6] olecranon osteotomy,[6] proximal ulnar diaphyseal osteotomy,[27] osteotomy of the medial epicondyle,[24] muscle separation with tenotomy of the pronator teres and/or in combination with tenotomy of the flexor carpi radialis,[16,32] muscle separation between the pronator teres and flexor carpi radialis muscles,[13,18,42] muscle separation between the flexor carpi radialis and flexor digitorum profundus muscles,[18] and longitudinal myotomy of the flexor carpi radialis muscle.[1] Adequate exposure to the medial compartment of the elbow joint for medial humeral condylar OCD and FCP evaluation and treatment can be obtained with either medial epicondylar osteotomy or a muscle separation technique with or without tenotomy of pronator teres or flexor carpi radialis muscle(s).[8] Significantly increased complications requiring additional surgery have been reported with the osteotomy approach and multiple authors suggest using one of the muscle separation techniques instead.[28,52] There are no other significant differences between the muscle separation and epicondylar osteotomy techniques in gait, range of motion, joint thickness or joint pain, but muscle mass measurements were significantly greater in the osteotomy group.[52]

Surgical Treatment by Arthrotomy

(Figure 56-30A-D)

The muscle separation approaches provide adequate exposure and a medial humeral epicondylar osteotomy is generally not needed. The approach described here is one of the more commonly used, varying from others only by which muscles are separated. The dog is placed in dorsal recumbency with the affected limb suspended for surgical preparation and draping. The limb is abducted once draped and the elbow is stabilized by placing a roll of towels or other padding underneath it.

A curvilinear skin incision is made over the medial aspect of the joint, centering on the medial humeral epicondyle and extending along the proximal ulna. The ulnar nerve crosses the medial epicondyle of the humerus just proximal to the origin of the humeral head of the superficial digital flexor and then continues on under the ulnar head of the flexor carpi ulnaris muscle. It should be protected during the fascial incision. The antebrachial fascia is incised along the same line as the skin and retracted, exposing the flexor muscle group. The muscular septum between the flexor carpi radialis and the deep digital flexor muscles or the pronator teres and flexor carpi radialis muscles is identified and bluntly separated (Figure 56-30A). The median artery and nerve will be visible in most dogs when dissection is complete. Hemostasis from intermuscular vessels is achieved with cautery and ligation. The muscles can now be separated by retraction, exposing the underlying joint capsule (Figure 56-30B). Desmotomy of the medial collateral ligament can be performed to increase exposure, though it is generally not needed for FCP removal. The joint capsule is carefully incised either along the same line as the muscles or horizontally along the joint line. It is then tagged and retracted to expose the articular surfaces of the humerus and ulna (Figure 56-30C). In order to completely visualize the MCP, the incision may need to be extended parallel to the ulnar trochlear notch, being careful not to sever the medial collateral ligament. Pronation and

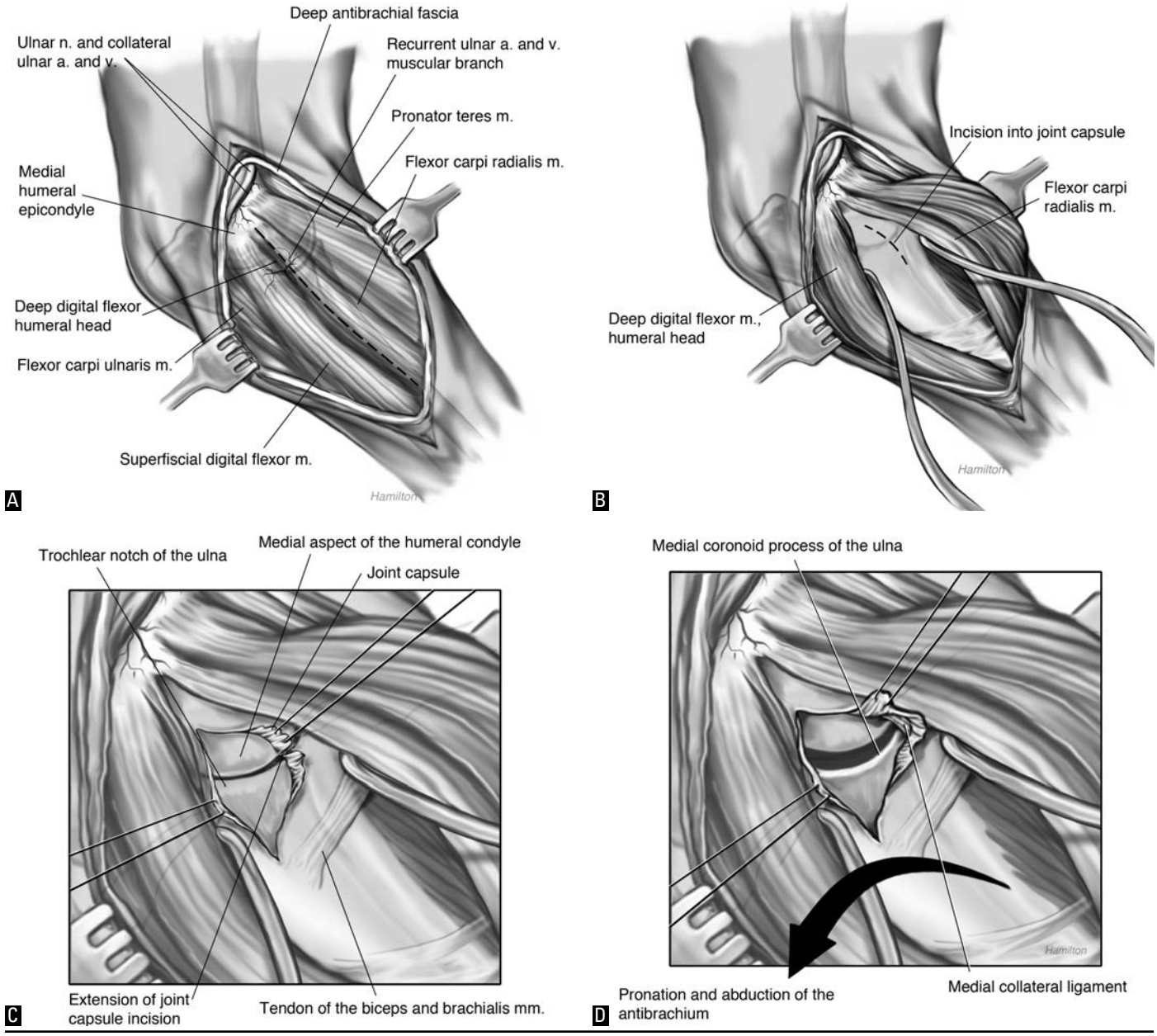


Figure 56-30. A-D. Medial approach to the elbow by an intermuscular dissection technique, see text for explanation.

abduction of the antebrachium opens the medial joint surface; the previously placed towels or padding under the elbow facilitate this maneuver (Figure 56-30D). A fair amount of pressure may be required for adequate visualization. The FCP can then be removed using rongeurs, curettes, or hemostatic forceps depending on its soft tissue attachments, size, location and remaining bony attachments. After fragment removal, the joint is flushed profusely and closed in a simple interrupted pattern using absorbable suture material. Following this, the intermuscular septum, brachial fascia, and subcutaneous tissues are closed in separate layers, followed by the skin closure.

Treatment by Arthroscopy

Arthroscopy is rapidly becoming a common method of FCP removal and joint exploration. Advantages include the minimally invasive approach, a greater area of visualization within the joint, and lower risks of complications usually associated with an arthrotomy. Its main disadvantages are the equipment requirements and the time needed to become proficient at arthroscopy.

The following is adapted from Beale et al,[3] and the reader is referred to this resource for a more in depth discussion. The arthroscopic procedure for evaluation of the elbow joint was originally described using a 2.7 mm, 30° rigid arthroscope. Beale et al recommend a 1.9 mm, 30° short scope because it causes less cartilage trauma in small joint such as the elbow.

Fluid inflow

For larger joints gravity inflow can be used, however small joints need a fluid pump due to higher pressures required to keep the joint open. It is recommend using 60 to 70 mm Hg pressure with a relatively low flow rate (10 to 20%) to avoid sudden surges.

Instrumentation

Power instruments are not required for elbow arthroscopy, but they can make surgery quicker, especially if large fragments are to be removed. An aggressive power shaver and a burr can be used. Arthroscopic cautery units or radiofrequency instrumentation are not recommended as they may pose a risk to the median and ulnar nerves.

Patient Preparation

The patient is prepared for open elbow surgery as if using the standard medial approach (see above) in case arthroscopy is unsuccessful and an arthrotomy must be pursued. The dog is placed in dorsal recumbency, especially if bilateral arthroscopy is planned, but can be placed in lateral recumbency with the affected limb down if only one side is affected. The surgery table, custom-made braces or towels can be used as a fulcrum for joint distraction.

Procedure

The assistant surgeon maintains the leg in a normal standing angle, positions the joint over the fulcrum, and places moderate downward (lateral) pressure on the antebrachium to open the medial compartment of the joint. Internal rotation also enlarges the joint space. For arthroscopic treatment of an FCP, 3 portal sites are generally used.

Egress

(Figures 56-31 and 56-33)

The egress is established first. Insert a needle craniodistal and slightly lateral, starting just proximal or adjacent to the anconeus, directing the needle so it sits in the joint pouch just proximal to the anconeus. A syringe is attached to aspirate joint fluid in order to ensure proper placement within the joint. If the needle is not within the joint space and fluid is injected, the difficulty of the procedure rises due to obscured landmarks, and external fluid pressure can cause the joint space to collapse. Lactated ringers solution may cause less damage to cartilage than saline. The joint is filled until moderate backpressure is felt in the syringe plunger. Underfilling makes scope portal establishment difficult and more traumatic, while overfilling may cause rupture of the joint capsule and loss of the fluid into the periarticular soft tissues. The assistant surgeon maintains pressure on the syringe to maintain joint pressurization during the arthroscope portal insertion.



Figure 56-31. Plastic bone specimen demonstrating ideal needle placement for egress establishment for arthroscopy of the elbow.

Arthroscope Portal

(Figures 56-32 and 56-33)

A blunt obturator is usually used within the arthroscope cannula. To determine the appropriate site for portal insertion, a line is drawn from the medial epicondyle distal to the level of the joint line, and then approximately 5 mm caudally. A needle is placed to ensure the appropriate location, after which a proximodistal incision is made through the skin and soft tissues. It is imperative not to incise into the joint capsule, otherwise joint distention is lost and fluid can extravasate. Having the assistant maintain the valgus force on leg, the scope cannula is inserted into the joint through this incision. Removing the obturator, fluid will rush out if the cannula is placed correctly.

Instrument Portal

Once the joint has been examined with the arthroscope, the instrument portal is established. A needle is inserted into the joint at the level of the medial collateral ligament at the same level and angle as the arthroscope. Triangulate the needle and arthroscope until the needle tip is visualized within the joint. Once the needle is visualized, use a blade to make an incision directly adjacent to the needle. Immediately remove the needle

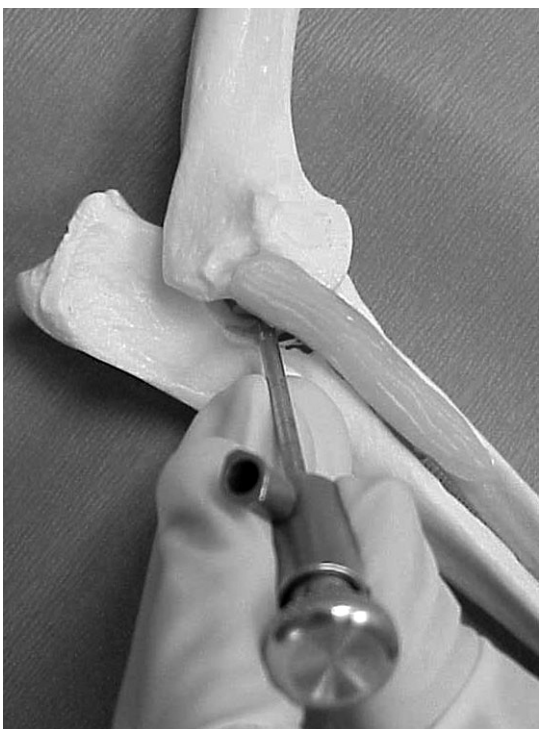


Figure 56-32. Plastic bone specimen demonstrating ideal arthroscope portal placement for arthroscopy of the elbow suspected of having an FCP.



Figure 56-33. Dissected cadaver specimen demonstrating arthroscope portal and egress placement for arthroscopy of the elbow suspected of having an FCP.

and insert a blunt trocar if planning to work through a soft tissue tunnel, or a cannula with trocar if planning to work through an instrument cannula.

FCP Assessment and Removal

(Figure 56-34A and B)

A probe can be used to assess the cartilage texture. If chondromalacia is present, the cartilage should be debrided and the underlying bone assessed. Removal of avascular bone is always indicated, even if it is palpably stable. Care must be taken not to injure the normal articular cartilage.

Ulnar Osteotomy

The use of an ulnar osteotomy has been reported both with and without fragment removal. The osteotomy is performed in a craniodistal oblique direction or transversely as described in the previous section of Chapter 56 (Surgical Treatment of Ununited Anconeal Process of the Elbow).

Postoperative Care

Most surgeons recommend that the animal be placed in a soft support wrap for 2 to 5 days to decrease immediate post-op swelling and minimize seroma formation. Exercise is generally restricted for 2 to 4 weeks following FCP removal. Passive range of motion exercise, heat and cold therapy, and non-steroidal anti-inflammatories usually are implemented during the healing phase. Controlled walking on the limb is also encouraged.

Prognosis

Surgical outcome is strongly dependent on several preoperative conditions. It tends to worsen with increasing age, a longer pre-operative duration of lameness, an increase in elbow incongruence, and an increasing OA grade. It is also negatively influenced by presence of a UAP and/or OCD lesions.[1,4,6,10,18,39,60,62] Other factors that affect prognosis are the age at which elbow dysplasia develops, the rate of disease progression, and the breed.[8] OA is expected to progress in all dogs, regardless of surgical intervention or not, though the severity seems less in operated patients.[33] Some studies do not show a difference between surgical and conservative medical management of FCP,[7,25] but most studies do. Surgical treatment of FCP seems to have a favorable result at both 6 weeks and 6 months post-operatively, despite progression of OA.[51] Interestingly, the severity of "kissing lesion" in the medial humeral condyle and the OA grade did not predict surgical outcome in one study.[51]

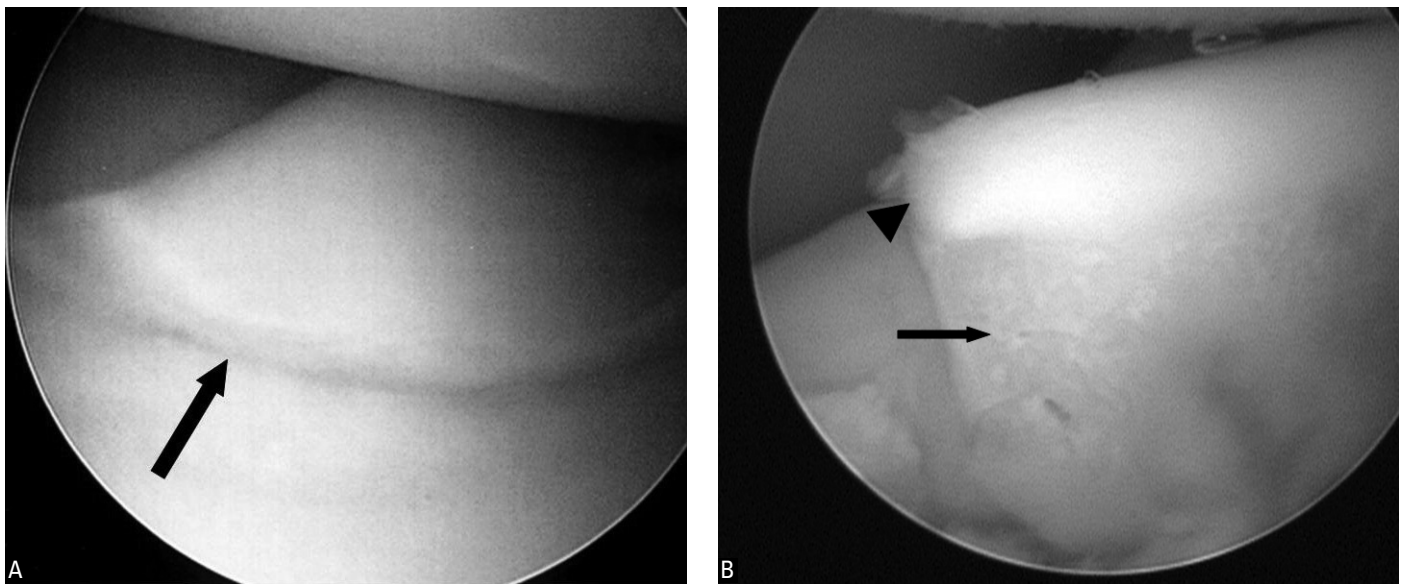


Figure 56-34. Arthroscopy images of two separate dogs with FCP. **A.** nondisplaced FCP. Note the fissure line in the articular cartilage *(black arrow)*. **B.** displaced FCP. Note the "wedding cake" appearance of the fragment: articular cartilage *(black arrowhead)* overlying yellow subchrondral bone *(black arrow)*.

A better outcome is expected with a lower pre-operative OA grade[10,18,19,61] and the progression of OA appears slower in dogs that are surgically managed (4.9 Guthrie points/month for FCP excision and ulnar osteotomy, 6.7 Guthrie points/month for FCP excision only) than those that received only conservative management (9.7 Guthrie points/month). It is important to note that these groups can not be directly compared due to variations in age.[20] Overall, a good outcome can be achieved in up to 75%of the cases operated at 4-6 months of age, decreasing to 42% in older dogs. Pre-existing OA seems to be the major determining factor: in one study animals without OA accounted for 60% of the cases with a good outcome.[10]

References

1. Anderson SM, Lippincott CL, Schulman AJ: Longitudinal myotomy of the flexor carpi radialis: A new approach to the medial aspect of the elbow joint. *J Am Anim Hosp Assoc* 25:499, 1989.

2. Bardet JF: Arthroscopy of the elbow in dogs. part II: The cranial portals in the diagnosis and treatment of the lesions of the coronoid process. *Veterinary and Comparative Orthopaedics and Traumatology* 10:60, 1997.

3. Beale BS, Hulse DA, Schulz KS, et al: Arthroscopically assisted surgery of the elbow jointIn Small Animal Arthroscopy. Philadelphia: Saunders, 2003, p 51.

4. Bennett D, Duff SR, Kene RO, et al: Osteochondritis dissecans and fragmentation of the coronoid process in the elbow joint of the dog. *Vet Rec* 109:329, 1981.

5. Berry CR: Evaluation of the canine elbow for fragmented medial coronoid process. *Veterinary Radiology and Ultrasound* 33:273, 1992.

6. Berzon JL, Quick CB: Fragmented coronoid process: Anatomical, clinical, and radiographic considerations with case analyses. *J Am Anim Hosp Assoc* 16:241, 1980.

7. Bouck GR, Miller CW, Taves CL: A comparison of surgical and medical treatment of fragmented coronoid process and osteochondritis dissecans of the canine elbow. *Veterinary and Comparative Orthopaedics and Traumatology* 8:177, 1995.

8. Boulay JP: Fragmented medial coronoid process of the ulna in the dog. *Veterinary Clinics of North America, Small Animal Practice* 28:51, 1998.

9. Braden TD, Stickle RL, Dejardin LM, et al: The use of computed tomography in fragmented coronoid disease: A case report. *Veterinary and Comparative Orthopaedics and Traumatology* 7:40, 1994.

10. Brunnberg L, Allgoewer I: Age-related results of the treatment of elbow dysplasia (FCP) in the bernese mountain dog. *Veterinary and Comparative Orthopaedics and Traumatology* 9:65, 1996.

11. Carpenter LG, Schwarz PD, Lowry JE, et al: Comparison of radiologic imaging techniques for diagnosis of fragmented medial coronoid process of the cubital joint in dogs. *J Am Vet Med Assoc* 203:78, 1993.

12. Collins KE, Cross AR, Lewis DD, et al: Comparison of the radius of curvature of the ulnar trochlear notch of rottweilers and greyhounds. *Am J Vet Res* 62:968, 2001.

13. Denny R: Surgical treatment of osteochondritis dissecans and ununited coronoid process of the ulna in the elbow joint of the dog. *Kleintierpraxis* 25:343, 1980.

14. Fox SM, Roberts RE: Linear tomography in diagnosing fragemented coronoid process in canine elbows. *Comp Cont Ed Pract Vet* 9:60, 1987.

15. Fox SM, Walker AM: Identifying and treating the primary manifestations of osteochondrosis of the elbow. *Vet Med* 88:132-146, 1993.

16. Goring RL, Bloomberg MS: Selected development at abnormalities of the canine elbow: Radiographic evaluation and surgical management. *Compendium on Continuing Education for the Practicing Veterinarian* 5:178-192, 1983.

17. Grondalen J: Arthrosis in the elbow joint of young rapidly growing dogs. 1981.

18. Grondalen J: Arthrosis in the elbow joint of young rapidly growing dogs. III. ununited medical coronoid process of the ulna and osteochondritis dissecans of the humeral condyle. surgical procedure for correction and postoperative investigation. *Nord Vet Med* 31:520, 1979.

19. Gutbrod F, Festl D: Surgical treatment of a fragmented medial coronoid process of the ulna in dogs and the clinical results. *Kleintierpraxis* 44:405, 1999.

20. Guthrie S: Use of a radiographic scoring technique for the assessment of dogs with elbow osteochondrosis. *J Small Anim Pract* 30:639, 1989.

21. Guthrie S, Pidduck HG: Heritability of elbow osteochondrosis within a closed population of dogs. *J Small Anim Pract* 31:93, 1990.

22. Guthrie S, Plummer JM, Vaughan LC: Aetiopathogenesis of canine elbow osteochondrosis: A study of loose fragments removed at arthrotomy. *Res Vet Sci* 52:284, 1992.

23. Haudiquet PR, Marcellin Little DJ, Stebbins ME: Use of the disto-medial-proximolateral oblique radiographic view of the elbow joint for examination of the medial coronoid process in dogs. *Am J Vet Res* 63:1000, 2002.

24. Henry WB,Jr: Radiographic diagnosis and surgical management of fragmented medial coronoid process in dogs. *J Am Vet Med Assoc* 184:799, 1984.

25. Huibregtse BA, Johnson AL, Muhlbauer MC, et al: The effect of treatment of fragmented coronoid process on the development of osteoarthritis of the elbow. *J Am Anim Hosp Assoc* 30:190, 1994.

26. LaFond E, Breur GJ, Austin CC: Breed susceptibility for developmental orthopedic diseases in dogs. *J Am Anim Hosp Assoc* 38:467, 2002.

27. Lenehan TM, Nunamaker DM: Lateral approach to the canine elbow by proximal ulnar diaphyseal osteotomy. *J Am Vet Med Assoc* 180:523, 1982.

28. Lewis DD, Parker RB, Hager DA: Fragmented medial coronoid process of the canine elbow. *Compendium on Continuing Education for the Practicing Veterinarian* 11:703-715, 734, 1989.

29. Lowry JE, Carpenter LG, Park RD, et al: Radiographic anatomy and technique for arthrography of the cubital joint in clinically normal dogs. *J Am Vet Med Assoc* 203:72, 1993.

30. MacPherson GC, Lewis DD, Johnson KA, et al: Fragmented coronoid process associated with premature distal radial physeal closure in four dogs. *Veterinary and Comparative Orthopaedics and Traumatology* 5:93, 1992.

31. Meij BP, Geertsen KMK, Hazewinkel HAW: Results of FCP [fragmented coronoid process] treatment in retrievers: A follow-up study at the utrecht university small animal clinic. *Veterinary and Comparative Orthopaedics and Traumatology* 9:64, 1996.

32. Meij BP, Hazewinkel HAW: Treatment of canine elbow dysplasia. *Veterinary and Comparative Orthopaedics and Traumatology* 9:61, 1996.

33. Meyer Lindenberg A, Fehr M, Brunnberg L, et al: Detachment of the medial ulnar coronoid process in dogs. occurrence and results of therapy in 101 cases. *Monatsh Veterinarmed* 48:457, 1993.

34. Meyer Lindenberg A, Langhann A, Fehr M, et al: Prevalence of fragmented medial coronoid process of the ulna in lame adult dogs. *Vet Rec* 151:230, 2002.

35. Meyer-Lindenberg A, Fehr M, Nolte I: Der isolierte processus anconaeus des hundes - vorkommen, behandlung, und ergebinsse. *Kleintierpraxis* 36:671, 1991.

36. Miyabayashi T, Takiguchi M, Schrader SC, et al: Radiographic

anatomy of the medial coronoid process of dogs. *J Am Anim Hosp Assoc* 31:125, 1995.

37. Nap RC: Pathophysiology and clinical aspects of canine elbow dysplasia. *Veterinary and Comparative Orthopaedics and Traumatology* 9:58, 1996.

38. Ness MG: Treatment of fragmented coronoid process in young dogs by proximal ulnar osteotomy. *J Small Anim Pract* 39:15, 1998.

39. Olsson SE: The early diagnosis of fragmented coronoid process and osteochondritis dissecans of the canine elbow joint. *J Am Anim Hosp Assoc* 19:616, 1983.

40. Olsson SE: [New type of elbow joint dysplasia in the dog; preliminary report]. *Svensk Veterinartidning* 26:152, 1974.

41. Padgett GA, Mostosky UV, Probst CW, et al: The inheritance of osteochondritis dissecans and fragmented coronoid process of the elbow joint in labrador retrievers. *J Am Anim Hosp Assoc* 31:327, 1995.

42. Probst CW, Flo GL, McLoughlin MA, et al: A simple medial approach to the canine elbow for treatment of fragmented coronoid process and osteochondritis dissecans. *J Am Anim Hosp Assoc* 25:331, 1989.

43. Read RA, Armstrong SJ, O'Keefe JD, et al: Fragmentation of the medial coronoid process of the ulna in dogs: A study of 109 cases. *J Small Anim Pract* 31:330, 1990.

44. Richardson DC, Zentek J: Nutrition and osteochondrosis. *Vet Clin North Am Small Anim Pract* 28:115, 1998.

45. Robbins GM: Some aspects of the radiographic examination of the canine elbow joint. *J Sm Anim Pract* 21:417, 1980.

46. Snaps FR, Balligand MH, Saunders JH, et al: Comparison of radiography, magnetic resonance imaging, and surgical findings in dogs with elbow dysplasia. *Am J Vet Res* 58:1367, 1997.

47. Snaps FR, Park RD, Saunders JH, et al: Magnetic resonance arthrography of the cubital joint in dogs affected with fragmented medial coronoid processes. *Am J Vet Res* 60:190, 1999.

48. Studdert VP, Lavelle RB, Beilharz RG, et al: Clinical features and heritability of osteochondrosis of the elbow in labrador retrievers. *J Small Anim Pract* 32:557, 1991.

49. Swenson L. incidence-selection-heritability-sex-age related factors on elbow arthrosis, in *Third Int Elbow Working Group Meeting* 1991.

50. Swenson L, Audell L, Hedhammar A: Prevalence and inheritance of and selection for hip dysplasia in seven breeds of dogs in sweden and benefit: Cost analysis of a screening and control program. *J Am Vet Med Assoc* 210:207, 1997.

51. Theyse LFH, Hazewinkel HAW, Brom WEvd: Force plate analyses before and after surgical treatment of unilateral fragmented coronoid process. *Veterinary and Comparative Orthopaedics and Traumatology* 13:135, 2000.

52. Tobias TA, Miyabayashi T, Olmstead ML, et al: Surgical removal of fragmented medial coronoid process in the dog: Comparative effects of surgical approach and age at time of surgery. *J Am Anim Hosp Assoc* 30:360, 1994.

53. van Bree H, Van Ryssen B. Arthroscopy in the diagnosis and treatment of front leg lameness. Vet Q. 17: sippl. 1:532-534, 1995.

54. Van Ryssen B, van Bree H: Arthroscopic findings in 100 dogs with elbow lameness. *Vet Rec* 140:360, 1997.

55. Van Ryssen B, van Bree H, Simoens P: Elbow arthroscopy in clinically normal dogs. *Am J Vet Res* 54:191, 1993.

56. Van Ryssen B, van Bree P. Elbow Arthroscopy, in *ECVS Proceedings* 1995.

57. Voorhout G, Hazewinkel HAW: Radiographic evaluation of the canine elbow joint with special reference to the medial humeral condyle and the medial coronoid process. *Vet Radiol* 28:158, 1987.

58. Wind AP: Elbow dysplasiaIn Slatter D, ed.: Textbook of Small Animal Surgery. Philadelphia: WB Saunders Co, 1993, p 1966.

59. Wind AP: Elbow incongruity and developmental elbow diseases in the dog: Part I. *J Am Anim Hosp Assoc* 22:711, 1986.

60. Wind AP: Incidence and radiographic appearance of fragmented coronoid process. *California Veterinarian* 36:19, 1982.

61. Wind AP, Packard ME: Elbow incongruity and developmental elbow diseases in the dog: Part II. *J Am Anim Hosp Assoc* 22:725, 1986.

62. Winhart S: Fracture of the medial coronoid process of the ulna in dogs. 1991.

63. Wolschrijn CF, Weijs WA: Development of the trabecular structure within the ulnar medial coronoid process of young dogs. *Anat Rec A Discov Mol Cell Evol Biol* 278:514, 2004.

64. Wosar MA, Lewis DD, Neuwirth L, et al: Radiographic evaluation of elbow joints before and after surgery in dogs with possible fragmented medial coronoid process. *J Am Vet Med Assoc* 214:52, 1999.

65. Zentek J, Meyer H, Dammrich K: The effect of a different energy supply for growing great danes on the body mass and skeletal development. 3. Clinical picture and chemical studies of the skeleton. *Zentralbl Veterinarmed A* 42:69, 1995.

Total Elbow Replacement in the Dog

Michael G. Conzemius

The Causes and Frequency of Elbow Osteoarthritis

Elbow osteoarthritis (OA) secondary to fragmentation of the medial coronoid process (FCP), osteochondrosis (OCD), ununited anconeal process (UAP), intra-articular fracture, and elbow luxation is the most common cause of forelimb lameness in the dog.[1] Collectively, these conditions represent the cause of lameness for nearly 8% of all dogs that present to university hospitals for lameness.[1] The above conditions can be separated, based upon etiology, into either developmental (FCP, OCD, and UAP) or acquired (fracture and luxation) conditions. In addition, the developmental elbow abnormalities frequently occur bilaterally.

Treatment Alternatives and their Efficacy

The goal of nonsurgical and/or surgical management of the developmental abnormalities is to slow the progression OA in the joint and reduce lameness in the patient. Nonsurgical management includes using nonsteroidal anti-inflammatory medications (NSAIDs), weight reduction (if the patient is overweight), and moderate daily exercise. Surgical management is dependent upon diagnosis. Historically, FCP and OCD are treated with fragment removal via arthrotomy or arthroscopy. An UAP is treated by removal of the process, internal stabilization of the process, proximal ulnar osteotomy or by a combination of therapies. In addition to the surgical treatments listed, procedures to address cartilage defects, such as curettage of a subchondral defect, are commonly performed.

Unfortunately, nonsurgical and surgical management of developmental conditions of the elbow joint frequently lead to unsatisfactory results. Huibregtse et al. studied 22 dogs with forelimb

lameness caused by a FCP and provided evidence that elbow OA progressed radiographically in dogs following nonsurgical or surgical treatment.[2] In addition, they performed force platform gait analysis and found that there was no difference in limb function between groups and the pet owners reported a recurrence of lameness in 78% of dogs treated without and 69% of dogs treated with surgery.[2] Bouck et. al. studied 19 dogs diagnosed with FCP and/or OCD that were treated medically or surgically using physical, radiographic and force platform gait evaluations and found similar results: regardless of treatment, OA progressed radiographically and range of motion decreased over time.[3] Using force platform gait evaluations they did determine that dogs in both groups improved but there was no difference in the amount of improvement between treatments.[3] Read et al. studied the largest groups of dogs, reporting on 130 episodes of FCP in 109 dogs with 62 managed nonsurgically and 68 surgically.[4] In this retrospective study owners reported that the severity of lameness improved to some degree in 59% of dogs, regardless of treatment.[4] Lameness, however, persisted in 75.9% of all dogs studied.[4] Tobias et al. performed a long-term evaluation of 35 dogs that had surgery for FCP.[5] After evaluating an owner questionnaire, physical and radiographic findings they concluded that nearly 65% of dogs still had lameness, 80% had joint pain, and over 95% had joint thickening and a reduced range of motion at follow-up examination.[5] In addition, OA significantly increased in 100% of the cases.[5] Caplan et al. studied the radiographic progression of OA in 24 dogs treated non-surgically and 26 treated surgically for lameness because of a FCP provided and reported that, regardless of treatment, OA progressed in 100% of cases and that the progression of OA was similar regardless of treatment.[6] How prognosis is affected by a growing list of more recent procedures (arthroscopy, medial coronoidectomy, radial head lengthening, humeral osteotomy, etc.) will only be known after thorough investigation and speculation is beyond the scope of this chapter.

The goal of treatment of the acquired conditions is to restore normal anatomy. Conditions that frequently cause elbow OA include intra-articular fracture and luxation.[1,7-11] In addition, fracture of the radius or ulna can lead to OA in the elbow by two mechanisms. First, fracture of the one of the growth plates of the radius or ulna can cause asynchronous growth between the two bones leading to incongruity in the elbow.[12] Second, fracture and subsequent callus formation can cause synostosis between the radius and ulna which, in a growing animal can lead to incongruity in the elbow.[13] Although, treatment for these conditions can lead to a good prognosis, long-term complications are common. In one study, 45% of all cases that had surgery for traumatic luxation had an unacceptable clinical outcome.[11] Similarly, Gordon et al. reported that following surgery for humeral condylar fracture 50% of dogs had visible lameness and 100% had developed OA.[14]

Treatment Alternatives for Dogs with established OA

Treatment alternatives for dogs with moderate to severe elbow OA include nonsurgical management, debridement arthroplasty (removing loose bodies and osteophytes from the joint), and arthrodesis.[8,15,16] In a clinical report, one dog with severe elbow OA had surgery to remove fragmented medial coronoid processes and a fractured anconeal process; this dog returned to near normal function after surgery.[8] This case may be the exception, however, because the dog became acutely lame because of an intra-articular fracture. There are no reports in the peer-reviewed literature addressing debridement arthroplasty for moderate to severe OA in dogs. However, in one abstract it was suggested that this procedure provided good long-term results.[15] deHann et al. retrospectively investigated results after arthrodesis of the elbow and found that although pain in the joint was eliminated, function of the limb was limited.[16] In a review article addressing the surgical treatment of OA, it was stated that debridement was the primary and arthrodesis the secondary option for OA in the elbow. They also stated that total elbow arthroplasty was likely to be the best future option.[17]

Total Elbow Arthroplasty as an option in the Dog

Improvements in implant design and surgical techniques have made total elbow arthroplasty a satisfactory treatment for arthritic disorders of the elbow in man since the mid-1970s.[18] In two separate evaluations, 91% of total elbow arthroplasty cases had excellent long-term (~4 years) outcomes.[19,20] It is important to note that limb use in man after successful total elbow arthroplasty is far from normal. Limb functions that are possible include such activities as opening a door, using a fork, and bringing the hand to the back of the head.[19,20] The success that veterinarians have had in total joint replacement has mirrored that of physicians when it comes to hip and knee. In the dog, 90 to 95% of patients will have a good or excellent outcome after total hip replacement.[21] Current implant designs and surgical techniques for total knee replacement in man are commonly developed in canine models.[22] The similarities in implant design and surgical success found in the hip and knee are likely because of similarities in anatomy and joint mechanics.

The anatomy and mechanics of the elbow joint, unfortunately, are dramatically different between man and dog. The first and most obvious difference is that the dog is a quadruped, and the elbow is a load bearing joint during motion. In fact, the forelimbs have ground reaction forces (GRF) that are 75% greater than the rear limbs at a trot (velocity of 1.5 to 2.0 m/s).[23] Anatomically, the radius is the primary load bearing bone in the dog. In contrast, the ulna seems to be the primary load bearing bone in man. The difference is most likely explained by the fact that dogs almost exclusively load the elbow when in extension, whereas man generally loads the elbow when in flexion.[24] These differences in mechanical demands have led to differences in anatomy. The ulna of the dog is comparatively smaller and the radial head larger. These differences are reflected by the fact that radial head excision arthroplasty can be successfully performed in man.[25] Given an understanding of canine anatomy and joint mechanics, it is easy to understand why radial head excision is not even reported in the dog. This point is further reflected in designs of total elbow components for humans. Many currently used total elbow designs (Coonrad/Morrey elbow replacement prosthesis, GBS II design, Capitello-Condylar design, HSS-Osteonics Linked Semicon-

strained Total Elbow Prosthesis, etc.) utilize a humeral and an ulnar component. The radial head is removed during the surgical procedure.[18-20,25,26] These design concepts, although successful for the human elbow, seem inadequate for the canine elbow.

Total elbow arthroplasty has been reported in the dog. To the author's knowledge, Dr. Ralph Lewis was the first to report on experience with total elbow arthroplasty in the dog.[27] He used constrained (hinge-like) components and although he had some successful outcomes he concluded that because of a high complication rate the system needed to be redesigned. Vasseur et al., at the University of California at Davis designed a nonconstrained system and tested it in three dogs with naturally occurring elbow OA. Although their results are not reported it was suggested, via personal communication, that the dogs in that study had poor short-term and long-term results and the project was abandoned.

Conzemius et al. designed and reported on a semiconstrained, two component (humeral and radioulnar) system, based on a morphometric study in Greyhounds and tested it in six Greyhounds.[28] (Figure 56-35) The design was based on the rationale that a total elbow replacement for the dog should reflect the anatomy of a breed that is not predisposed to developmental elbow diseases. A semiconstrained design was selected because constrained (hinge-like) designs do a poor job of sharing load with intact ligamentous structures. Load is principally absorbed by the implant and concentrated at the implant-bone interface. This type of design has not withstood the test of time in load bearing joints; the best example being the human knee. Constrained total knee designs have a comparatively high rate of aseptic loosening and are reserved for use in revision surgeries of the knee when no ligamentous structures remain intact.[29,30] In addition, semiconstrained and nonconstrained designs can include shorter stem lengths relative to constrained designs. A feature that was appealing because of assumed anatomic differences that would be present amongst dog breeds. Cement fixation was used because it allows for a greater variability in implant design and positioning (Figure 56-36). Cement fixation allows the stems of the implant to be virtually anywhere within the confines of the medullary canal as long as there is room remaining for a cement mantle with a thickness of at least 2.0 mm.[31] Press-fit and porous in-growth designs require a near perfect fit between existing bone anatomy and implant. A two piece design was used to limit the number of working pieces. This minimizes manufacturing costs and makes it technically simpler for the surgeon. For

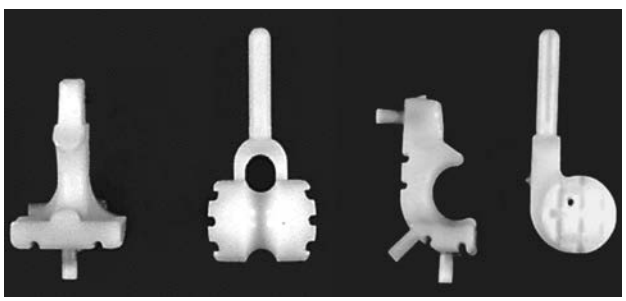


Figure 56-35. Photographs of the initial total elbow implant system evaluated by Conzemius et al.The photographs are oriented from cranial to caudal (left images) and lateral (right images).

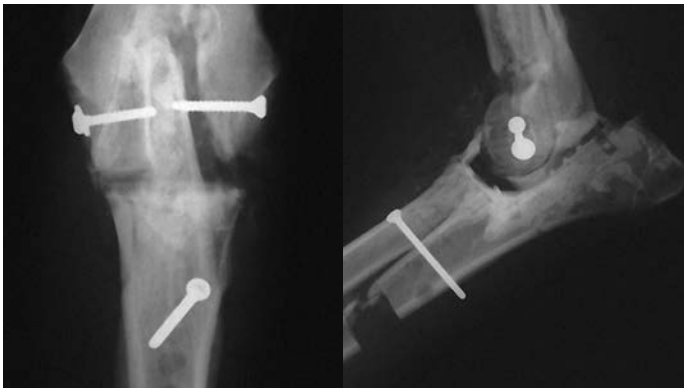


Figure 56-36. Postoperative radiographs of the initial total elbow arthroplasty system tested by Conzemius et al.

example, the radial and ulnar components were made as a single component instead of two or three. Although post-operative complications occurred in 4 of 6 dogs many beneficial things came from this study. First, two dogs had a fair outcome with peak vertical force (PVF) reaching 82% four months after surgery (Figure 56-37). Thus, it was concluded that elbow replacement was possible, just not with the exact design and technique used. In an evaluation of limb use in normal Greyhounds after femoral head and neck excision and total hip replacement limb function improved for the first six months after surgery.[32,33] Second, it was apparent that lateral luxation occurred in two dogs from lateral instability after transection of the lateral collateral and insufficient stabilization. An alternative approach needed to be considered. Third, the cement-bone interface of the radioulnar component was loose in all dogs (See Figure 56-37). This was likely because the snap fit components were too constrained and the 1 cm pegs of the radioulnar component (designed so it could be used in either the left or right limb) were too short. These short pegs provided limited surface area for the cement interface thus increasing stress. Fourth, the humeral component was consistently stable even after a stabilization screw was removed. Finally, radio-ulnar synostosis was incomplete in all dogs and the screw placed between the radius and ulna was loose in 5 of 6 dogs. Radio-ulnar synostosis is necessary when a single component has stems that enter the medullary canal of multiple bones. It was concluded that the ulnar osteotomy was too proximal, the radio-ulna screws were insufficient and that cancellous autograft should be used to encourage fusion.

This was followed by an in vivo study evaluating the efficacy of a modified system in six normal dogs.[34] The system and surgical technique evaluated included several modifications as compared to the initially reported design.[28] The humeral component had been angled in a cranial direction by 5° to reduce the probability of bone contact, dove-tail grooves in the sides of the component were included that were deeper and did not communicate with the load-bearing surface of the humeral component and all articulating surfaces were made with a larger radius. The radioulnar component now had two, 3 cm stems (radial and ulnar), it was designed for either left or right limbs with stem angles and an inter-stem distance that matched that of the anatomy of the a Labrador retriever and the proximal aspect of the component was removed and all articulating surfaces were made with a larger radius. Changes in surgical technique included removal

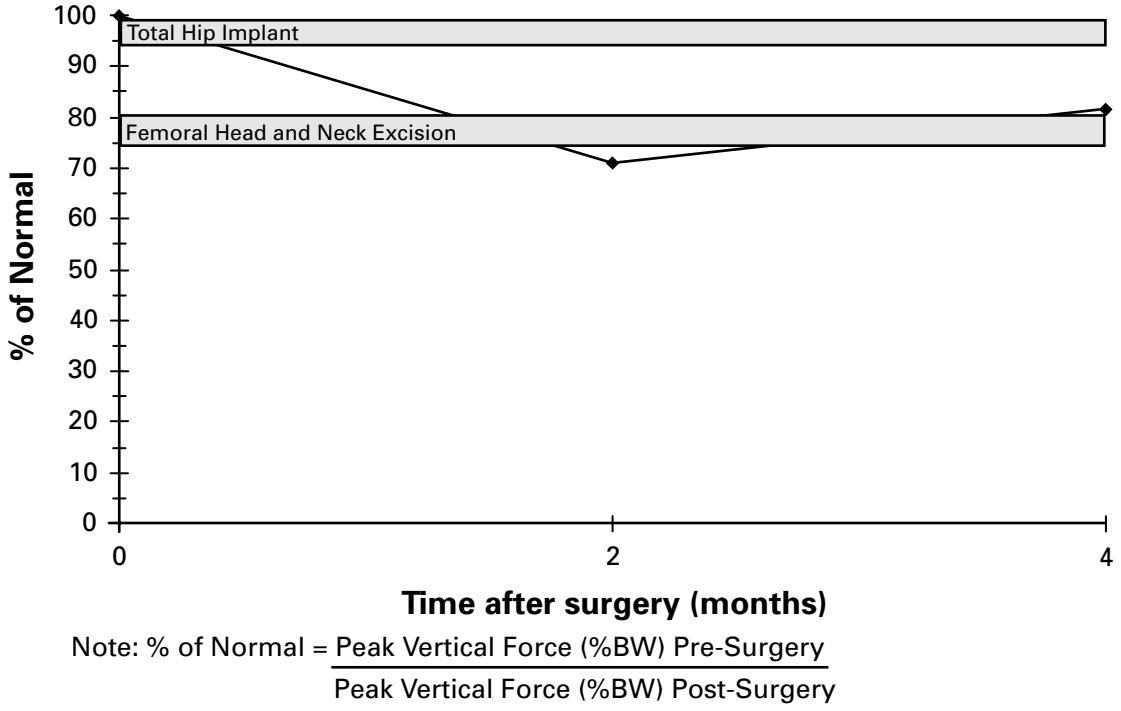


Figure 56-37. A graph of PVF of the operated limb as a percent of body weight at all time periods. The shaded areas in the graph demonstrate limb use in normal Greyhounds after femoral head and neck excision and total hip implantation.

of the lateral collateral ligament at its insertion from the radius, distal ulnar ostectomy (~1 cm of bone), no screws were used with the humeral component or between the radius and ulna and a generous amount of autogenous cancellous bone graft was placed between the radius and ulna just distal to the radioulnar component on the lateral side. Six, healthy, adult medium and large breed dogs ranging from 25 to 38 kg were used in the study. Each dog underwent an orthopedic, radiographic, and force plate gait evaluation before surgery and surviving dogs were reevaluated at 8, 16, 24 and 52 weeks after surgery. Dogs were sacrificed 6, 10, and 20 weeks after surgery, leaving three dogs for long-term evaluation. Treated limbs from the sacrificed animals were harvested and the components were examined. The results from this study were mixed. Post-operative complications occurred in 3 of 6 dogs and included one dog that never used the operated limb, a dog that developed proximal ulnar fracture 9 weeks after surgery and a dog that developed osteomyelitis. Limb function in the remaining 3 dogs consistently improved over the course of the 52 week study to the point that PVF and vertical impulse (VI) were the same as the unoperated, normal limb at 1 year. These dogs were adopted and continue to do well over 5 years after surgery. Important conclusions from this study were that the components could be made even less constrained, a corner on the caudal aspect of the radioulnar component needed to be removed, a hole in the humeral component to simulate a foramen needed to be removed, synostosis between the radius and ulna could be achieved using only the distal ostectomy and bone graft, multiple component sizes were needed and that limb function could return to normal when elbow replacement was performed in a normal dog.[34]

Although that study did not demonstrate that total elbow arthroplasty could yield consistent results or that it would be successful in naturally occurring elbow OA, it provided evidence that it would likely be successful in at least some cases.

Given the frequency of elbow OA in the dog, the poor prognosis provided by other available treatments, and the encouraging preliminary data it was thought to be reasonable to attempt total elbow arthroplasty in severely affected cases. Prior to clinical use, several design changes were made to enhance the nonconstrained total elbow arthroplasty components. First, the corners at the articulating surface of the humeral and radioulnar component were softened. This made the articulation less constrained which should reduce the formation of particulate wear debris. Second, the hole in the humeral component was eliminated. Third, the surface area for the component-cement interface was increased. Fourth, the caudal peg of the radioulnar component was angled to better fit the ulnar metaphysis. Fifth, the caudal non-articulating surface that rests on the ulna was made semicircular. This will preserve ulnar bone stock and reduce the chance of ulnar fracture. Finally, three were made available, with a 10% increase in size from small to medium to large.

This implant system was tested in twenty, adult, client owned dogs with elbow OA that were treated with nonsurgical management unsuccessfully for at least 1 year.[35] Following inclusion into the study dogs were evaluated clinically, radiographically and by force platform gait analysis before surgery and at 3, 6, and 12 months after surgery. At 1 year it was concluded that 16 of the 20 dogs had a satisfactory outcome, as defined by an improvement in quality of life and a reduction in pain and lameness. On average, 1 year ground reaction forces were 25% greater on the operated limb when compared to preoperative function. Unsatisfactory outcomes were associated with infection, lateral luxation and an iatrogenic humeral condylar fracture. Similar to

previous investigations potential improvements in component design and surgical technique were identified. The humeral component had large proximal shoulders that required removal of an unnecessarily large amount of bone. These shoulders have been removed. It was nearly impossible to establish a good cement mantle at the interface between the sides of the humeral component and the remaining bone of the humeral condyle. The sides of the humeral component have been beaded for porous ingrowth fixation. Although no problems were identified with the articulating surface in this 1 year study, it was thought that a surface that was similar to that or a human knee component would be ideal. Technical challenges that remained were development of drill and cutting guides that would allow for a more reproducible outcome and provision for lateral stabilization to reduce the probability of lateral luxation. These changes and an additional component have been implemented into a total elbow replacement system (Figure 56-38) that is commercially available and taught to surgeons in training courses.



Figure 56-38. Photograph of the two components currently used for total elbow replacement in the dog. In this photo cranial is left and caudal is right.

Surgical Procedure

Dogs are placed in lateral recumbancy and standard aseptic preparation of the affected forelimb is performed. A caudolateral approach to the elbow through the anconeus muscle that is extended proximally along the triceps and distally along the ulna is made. The insertion of the lateral collateral ligament on the radius is identified and removed close to its bony attachment. The elbow is luxated laterally (this can be difficult in many cases that have severe periarticular fibrosis or a large osteophyte on the cranial aspect of the radius). A 5 mm access hole is made in the humeral diaphysis. The humeral mounting pin is placed into the humerus and the humeral cutting guide mounted. The arthritic, articular aspect of the condyle is removed using the cutting guide and a trial component is implanted. (Figure 56-39) A 3.5 mm hole is drilled from proximal to distal down the radius diaphysis. The radial cutting guide is mounted and the cut started on the radius. The radial cutting guide is removed and the radial cut completed. The ulnar cutting guide is then mounted and used to drill multiple holes along the proximal ulnar metaphysis (Figure 56-40). The cutting guide is removed and the drill holes are connected with a high speed bur which results in removal of the ulnar trochlea and the medial and lateral coronoid processes. The diaphysis of the radius and ulna are then prepared to accept the component and cement. A trial radioulnar component is positioned and the joint is reduced to ensure that both components are positioned correctly. A distal ulnar ostectomy (1 cm) is performed. The components are cemented in position and the joint is reduced. As the cement polymerizes an autogenous, cancellous bone graft harvested from the removed bone is placed between the proximal aspects of the radius and ulna just below the body of the lateral aspect of the radioulnar component. Prior to closure, two suture anchors are placed (one in the lateral aspect of the humeral condyle and one between the proximal radius and ulna) to provide additional lateral stability during the early postoperative period. Following closure a splint is applied and postoperative radiographs are taken (Figures 56-41 and 56-42). Postoperative management generally should include removal of the splint 2 to 3 days after surgery, restriction to short leash walks for 8 weeks and a re-exam at 8 weeks. At this time more aggressive postoperative rehabilitation for the joint can be considered.

In the author's experience with this commercially available system, an outcome that is satisfactory to the surgeon and owner(s) can be expected 80 to 85% of the time. The most common complications that can be expected include infection, luxation, and fracture of the ulna. In 5% of humans undergoing total elbow replacement, fracture of the olecranon has been reported as a major complication.[36] Since perpendicular bone cuts create a stress riser in the ulna and have been identified as a predisposing factor for an olecranon fracture,[37] it is hoped that the technical modifications in place will reduce this problem. Again, in the author's experience, the majority of complications occur in the first 8 weeks after surgery.

References

1. Johnson JA, Austin C, Breur GJ. Incidence of canine appendicular musculoskeletal disorders in 16 veterinary teaching hospitals from 1980 through 1989. Vet Comp Orthop Traumotol 7:56, 1994.

2. Huibregtse BA, Johnson AL, Muhlbauer MC, Pijanowski GJ. The effect of treatment of fragmented coronoid process on the development of osteoarthritis of the elbow. JAAHA 30:190, 1994.

3. Bouck GR, Miller CW, Taves CL. A comparison of surgical and medical treatment of fragmented coronoid process and osteochondrosis dissecans of the canine elbow. Vet Comp Orthop Traumotol 8:177, 1995.

4. Read RA, Armstrong SJ, O'Keefe JD, Eger CE. Fragmentation of the medial coronoid process of the ulna in dogs: A study of 109 cases. J Small An Prac 30:330, 1990.

5. Tobias TA, Miyabayashi T, Olmstead ML, Hedrick LA. Surgical removal of fragmented medial coronoid process in the dog: Comparative effects of surgical approach and age at time of surgery. JAAHA 30:360, 1994.

6. Caplan E, Conzemius MG, Riedesel E, Miles K. Long term radiographic follow-up of elbow dysplasia treated surgically or non-surgically. Presented at the Annual Meeting of the Veterinary Orthopedic Society, Val d'Isere, France, March 2000.

7. Yovich JC, Read RA. Traumatic fracture of the medial coronoid process in two dogs. Vet Comp Orthop Traumotol 7:173, 1994.

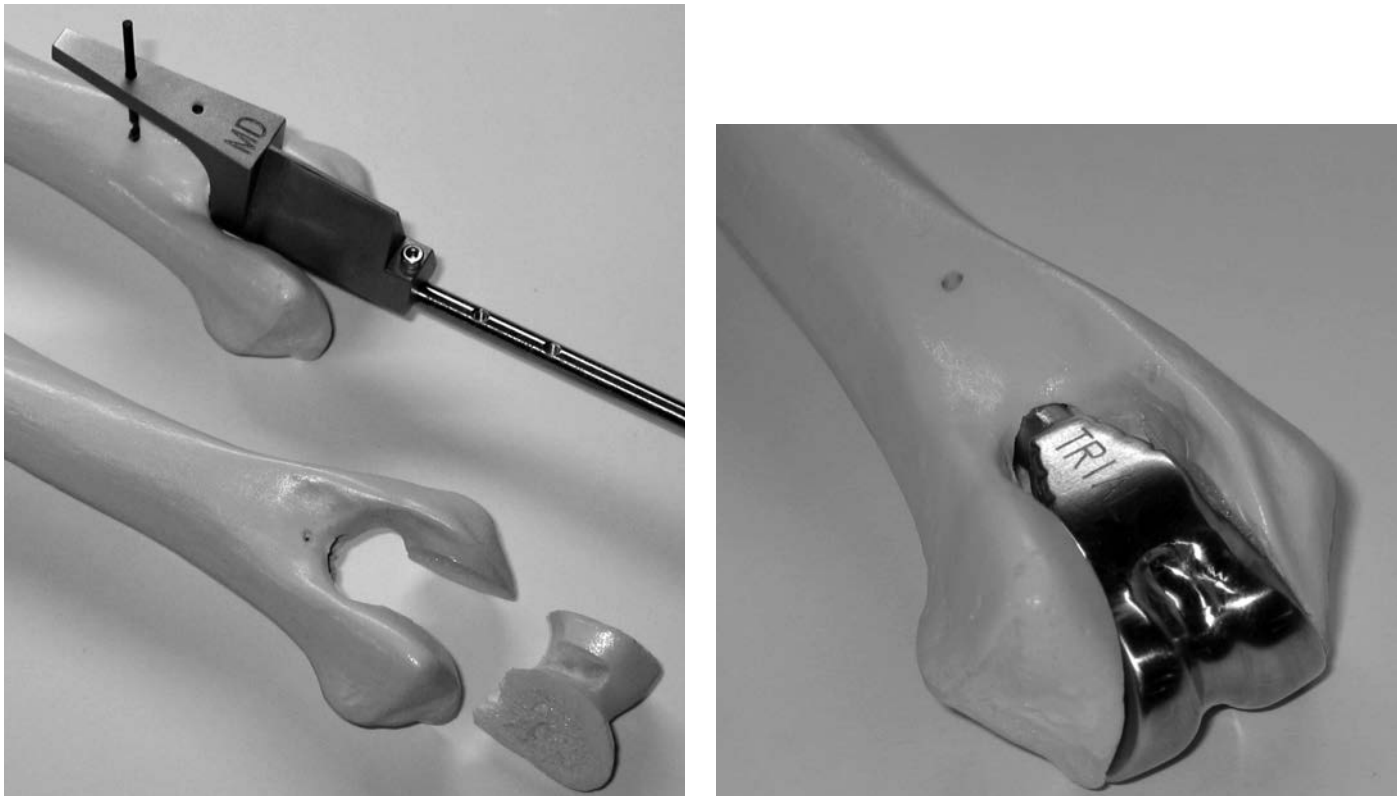


Figure 56-39. A photograph of the humeral cutting guide mounted on the humerus (left). A trial humeral component has been inserted into the cut humerus.

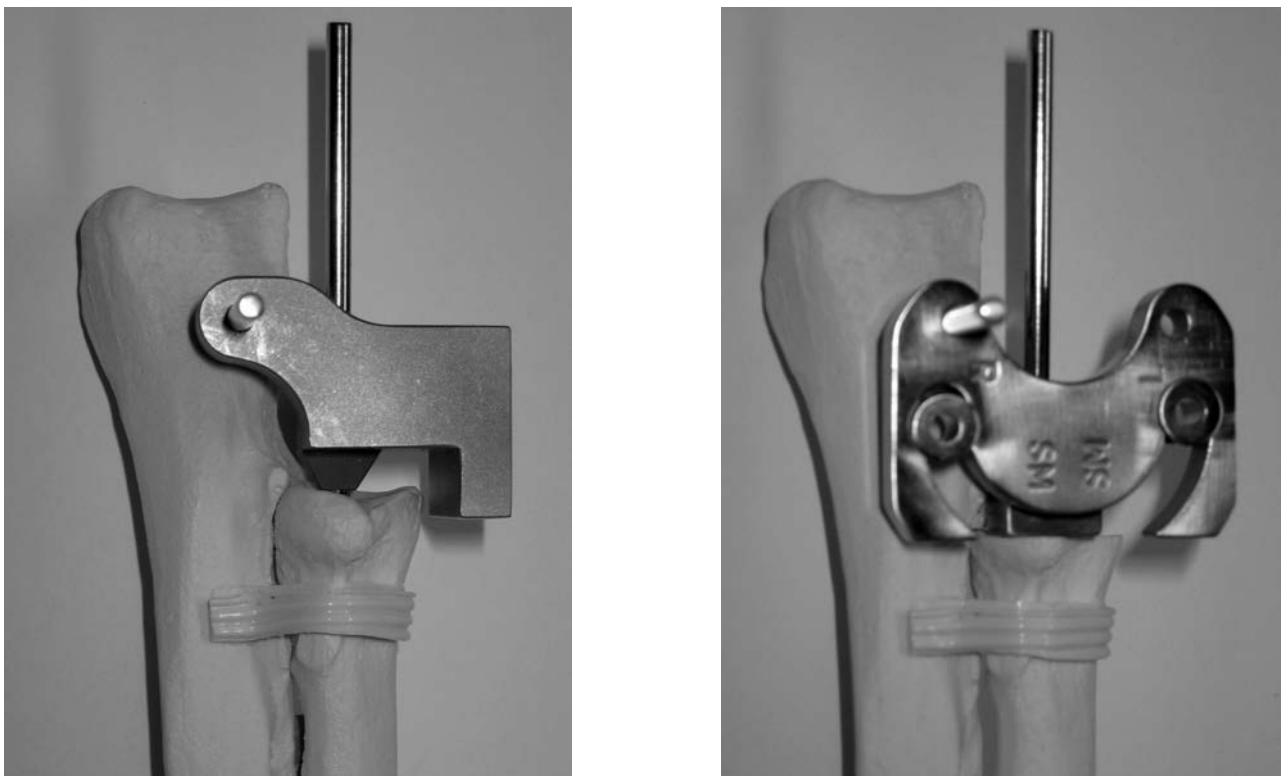


Figure 56-40. A photograph of the radial (left) and ulnar (right) cutting guides mounted on a 3.5-mm radial diaphysis pin.



Figure 56-41. Photograph (left) of a dog with lameness and elbow pain in the right elbow. The preoperative radiographs of this elbow (right) demonstrate severe elbow OA.

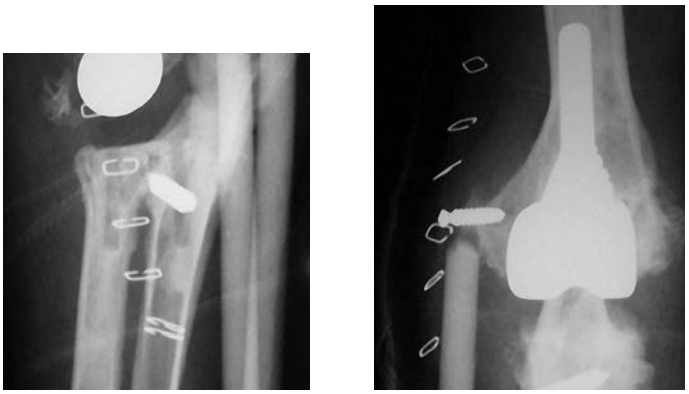


Figure 56-42. Radiographs taken immediately after surgery of the case presented in Figure 56-41.

8. Flo GL. Surgical removal of fragmented coronoid process and fractured anconeal processes in an older dog with evidence of severe degenerative joint disease. JAVMA 213(12): 1780, 1998.

9. Lewis DD, Elkins AD, Oakes MG. Repair of a Salter IV physeal fracture of the humeral condyle in a Chow-Chow using a cannulated screw. Vet Comp Orthop Traumotol 4:140, 1991.

10. Marcellin-Little DJ, DeYoung DJ, Ferris KK, Berry CM. Incomplete ossification of the humeral condyle in spaniels. Vet Surg 23:475, 1994.

11. O'Brien MG, Boudrieau RJ, Clark GN. Traumatic luxation of the cubital joint (elbow) in dogs: 44 cases (1978-1988). JAVMA 201(11):1760, 1992.

12. MacPherson GC, Lewis DD, Johnson KA, Allen GS, Yovich JC. Fragmented coronoid process associated with premature distal radial physeal closure in four dogs. Vet Comp Orthop Traumotol 5:93, 1992.

13. MacPherson GC, Johnson KA. Radio-ulnar synostosis complicating partial mid-diaphyseal ulnar ostectomy in growing dogs. Vet Comp Orthop Traumatol 5:26, 1992.

14. Gordon WJ, Besancon MF, Conzemius MG, Miles KG, Kapatkin AS, WTN Culp. Frequency of post-traumatic osteoarthritis in dogs after repair of a humeral condylar fracture. Vet Comp Orthop Traumatol 16:1, 2003.

15. Bardet JF. Treatment of elbow degenerative joint disease with arthroscopy. Proceedings from the 1st World Orthopaedic Veterinary Congress, Munich, Germany. 2002 Pp 44-5.

16. deHann JJ, Roe RC, Lewis DD, et al. Elbow arthrodesis in twelve dogs. Vet Comp Orthop Traumatol 9:115, 1996.

17. Cook JL, Payne JT. Surgical Treatment of Osteoarthritis. Veterinary Clinical of North America: Small Animal Practice 27(4):931, 1997.

18. Kraay MJ, Figgie MP, Inglis AE, Wolfe SW, Ranawat CS. Primary semiconstrained total elbow arthroplasty. J Bone Joint Surg [Br] 76-B: 636, 1994.

19. Morrey BF, Adams RA. Semiconstrained elbow replacement for distal humeral nonunion. J Bone Joint Surg [Br] 77-B: 67, 1995.

20. Morrey BF, Adams RA. Semiconstrained arthroplasty for the treatment of rheumatoid arthritis of the elbow. J Bone Joint Surg [Am] 74-A: 479, 1992.

21. Olmstead ML. The canine cemented modular total hip prosthesis. JAAHA 31:109, 1995.

22. Sumner DR, Berzins A, Turner TM, Igloria R, Natarajan. Initial in vitro stability of the tibial component in a canine model of cementless total knee replacement. J. Biomechanics 27(7):929, 1994.

23. Rumph PF, Lander JE, Kincaid SA, Baird DK, Kammermann JR, Visco DM. Ground reaction force profiles form force platform analyses of clinically normal mesomorphic dogs at the trot. Am J Vet Res 55(6):756, 1994.

24. DeCamp CE, Soutas-Little RW, Hauptman J, Oliver B, Braden T, Walton A. Kinematic gait analysis of the trot in healthy greyhounds. Am J Vet Res 54(4):627, 1993.

25. Woods DA, Williams JR, Gendi NST, Mowart AG, Berge PD, Carr AJ. Surgery for rheumatoid arthritis of the elbow: A comparison of radial-head excision and synovectomy with total elbow replacement. J Shoulder Elbow Surg 8:291, 1999.

26. Lewis G. The elbow joint and its total arthroplasty. Part I. A state-of-the-art review. Medical Materials and Engineering 6:353, 1996.

27. Lewis RH: Development of elbow arthroplasty (Canine) clinical trials. Proceedings from the 6th Annual ACVS Symposium. San Francisco, CA, p.110, October 1996.

28. Conzemius MG, Aper RL. Development and evaluation of semiconstrained arthroplasty for the treatment of elbow osteoarthritis in the dog. Vet Comp Orthop Traumatol, 11(4):54A, 1998.

29. O'Driscoll SW, An KN, Korinek S, Morrey BF. Kinematics of semiconstrained total elbow arthroplasty. J Bone Joint Surg [Br] 74-B:297, 1992.

30. Cameron HU, Hu C, Vyamont D. Hinge total knee replacement revisited. Can J Surg 40(4):278, 1997.

31. Fisher DA, Tsang AC, Paydar N, Milionis S, Turner CH. Cement-mantle thickness affects strains in total hip replacement. J Biomech 30(11-12):1173, 1997.

32. Mann FA, Tangner CH, Wagner-Mann C, Read WK, Hulse DA, Puglisi TA, Hobson HP: A comparison of standard femoral head and neck excision and femoral head and neck excision using a biceps femoris muscle flap in the dog. Vet Surg 16(3):223, 1987.

33. Manley PA, Vanderby R, Dogan S, Kohles SS, McBeath AA: Ground reaction force comparison of canine cemented and cementless total hip replacement. Clin Biomech 5:199, 1990.

34. Conzemius MG, Aper RL, Hill CM. Evaluation of a canine total elbow arthroplasty system. A preliminary study in normal dogs. Vet Surg, 30:11, 2001.

35. Conzemius MG, Aper RL, Corti LB. Total elbow arthroplasty in dogs with severe naturally occurring osteoarthritis. Vet Surg, 32:545, 2003.

36. Zafiropoulos G, Amis AA. Fixation strength of the ulnar component of total elbow replacement. J Shoulder Elbow Surg 5:97, 1996.

37. Zafiropoulos G, Attfield SF. An intramedullary aligned bone cutting jig for elbow replacement. Med Eng Phys 17:111, 1995.

Elbow Arthrodesis

Arnold S. Lesser

Indications

Arthrodesis of the elbow or any midlimb joint is some what controversial. There are some surgeons that believe that the result after fusion of the elbow or stifle is not good enough to warrant the procedure. Certainly pancarpal or pantarsal arthrodesis gives better and more consistent results but there are dogs that can function fairly well after fusion of the elbow, especially smaller patients that tend to walk with a stiff gait. The decision to fuse a joint is only made when other alternatives are not feasible or successful. The indication for arthrodesis of the elbow is any condition that leaves the elbow chronically painful and nonfunctional. These can be divided into traumatic and developmental. Traumatic includes fractures that cannot be repaired or that have failed to heal or healed as painful malunions. The elbow's configuration can make primary repair difficult especially in miniature breeds. Highly comminuted articular fractures or gun shot trauma with bone loss are examples of fractures that may not be repairable or lead to painful malunions. In the majority of cases a primary repair should be attempted first but there may be situations where finances allow only one procedure to be performed and then it is the surgeon's judgment whether to go right to the arthrodesis or attempt the repair. With non unions the question also arises as to whether to attempt another osteosynthesis or go right to an arthrodesis. If a malunion cannot be revised to allow for good function or has led to severe DJD and the patient is not using the limb then fusing the elbow is indicated. Also the elbow joint is especially susceptible to loss of motion after difficult fracture repair and if the joint becomes ankylosed in too flexed a position the dog will not use the leg due to the physiologic shortening. Arthrodesis of the joint at the proper angle is then indicated.

The other major indication for elbow arthrodesis is severe arthritis, most commonly secondary to elbow dysplasia (ununited anconeal process or fragmented coronoid process). When conservative therapy is no longer giving sufficient relief then surgery is indicated. Recently a Total Elbow prosthesis has become available and where applicable would be the first choice. There are size restrictions and the presence of infection affects the use of a prosthesis more than arthrodesis, but this is a promising alternative and further clinical use will be needed to fully evaluate its potential.

Procedure

Plate fixation along the caudal aspect of the humerus and ulna is by far the best method (Figure 56-43). This places the plate on the tension band side. It is necessary to perform an olecranon osteotomy to provide a smooth transition and bed for the plate. Part of the olecranon can be sacrificed for graft (all fusions should be grafted) and the remainder reattached to the bone next to the plate. The angle of the cut can be determined by placing the leg in the desired angle (reported from 110 to 130 degrees) and running a line off the caudal edge of the humerus onto the ulna (Figure 56-44). The lateral collateral ligament is transected and the extensor muscles are elevated to provide exposure for the removal of cartilage from the radial head, coronoid process and

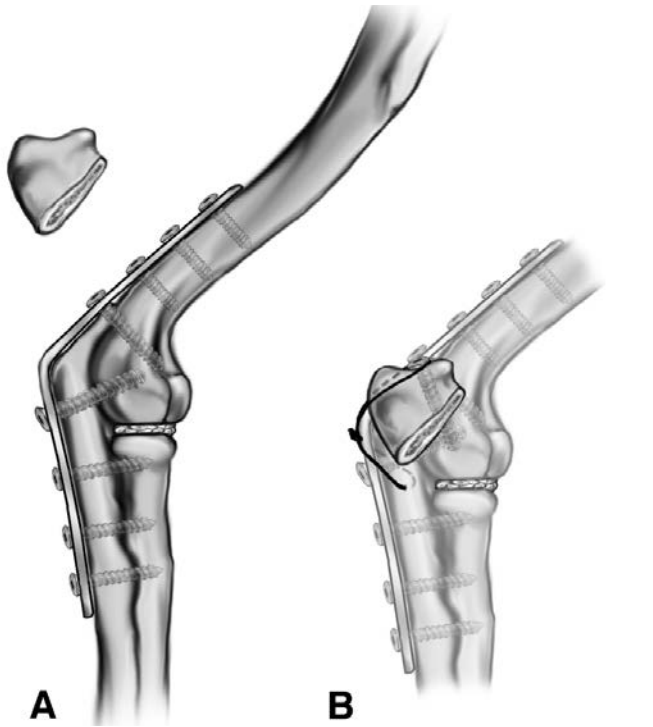


Figure 56-43. A. The plate is paced on the caudal aspect of the elbow with a minimum of 3 screws in both the humerus and the ulna. Screws crossing the arthrodesis should be placed under compression. **B.** The olecranon can be sacrificed as graft and the triceps sutured down, or it can be attached to the humerus adjacent to the plate with a screw and tension band wire.

humeral condyle. These surfaces should be shaped to create good contact. The ulnar and median nerves should be identified and protected on the medial aspect of the joint. Once the angle has been determined from the standing angle of the normal leg, the joint is held with a pin driven from the ulna into the medial humeral condyle. A goniometer or an old plate prebent can be used to measure this angle at surgery. If there has been bone loss then the angle is increased (straighter). However, there is more of an acute angle at the elbow than appears from looking at the leg because of the thick muscle caudal to the humerus and the curvature of the radius, so there is a tendency to make the leg too straight. Be sure to measure the bone and not the leg when determining the angle of arthrodesis (Figure 56-45). A sterile preparation of the controlateral leg provides a quick reference. The triceps muscles can be elevated to allow placement of the plate. A minimum of 3 screws are used in the humerus and ulna respectively, with additional intervening screws crossing the joint under compression. A 9 or 10 hole, self compressing or locking plate is sufficient for a 30 kg dog.

Screw fixation has been advocated for elbow arthrodesis and may have a place in smaller patients when combined with an external skeletal fixator(Figure 56-46), With the availability the small 2.0 mm cuttable plates, I would recommend staying with plate fixation. These plates can be doubled for greater stiffness. External fixators can be used but are more difficult to adapt in this area due to the presence of the body wall medial to the humerus. Modified type 1b fixators can be used but are more complicated to construct. Fixators can also be used as a secondary fixation rather then a bulky spica where the primary fixation is suspect. If the plate fixation is sufficient only a padded bandage is used for a few weeks.

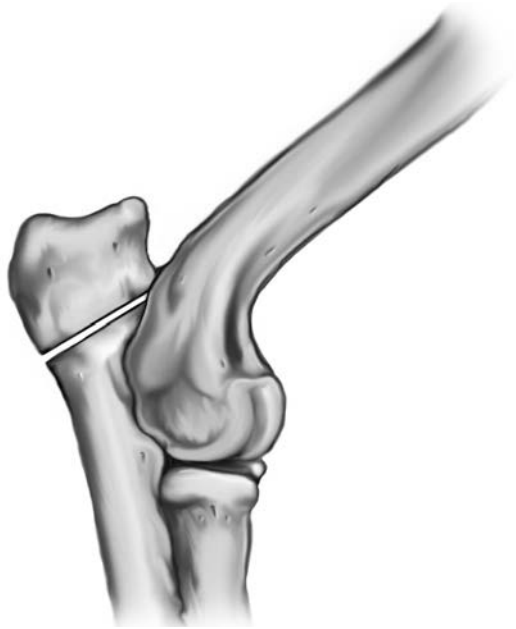


Figure 56-44. The olecranon is osteotomized at an angle parallel to the caudal aspect of the humerus to facilitate plate placement.

Suggested Readings

Piermattei DL, Flo GL: Brinker, Piermattei, and Flo's Handbook of Small Animal Orthopedics and Fracture Repair 3rd Edition. W.B. Saunders. Philadelphia. 1997.

Lesser: Arthrodesis. In Slatter: Textbook of Small Animal Surgery. Saunders. Philadelphia. 2003 Humerus and Elbow Joint p 929.

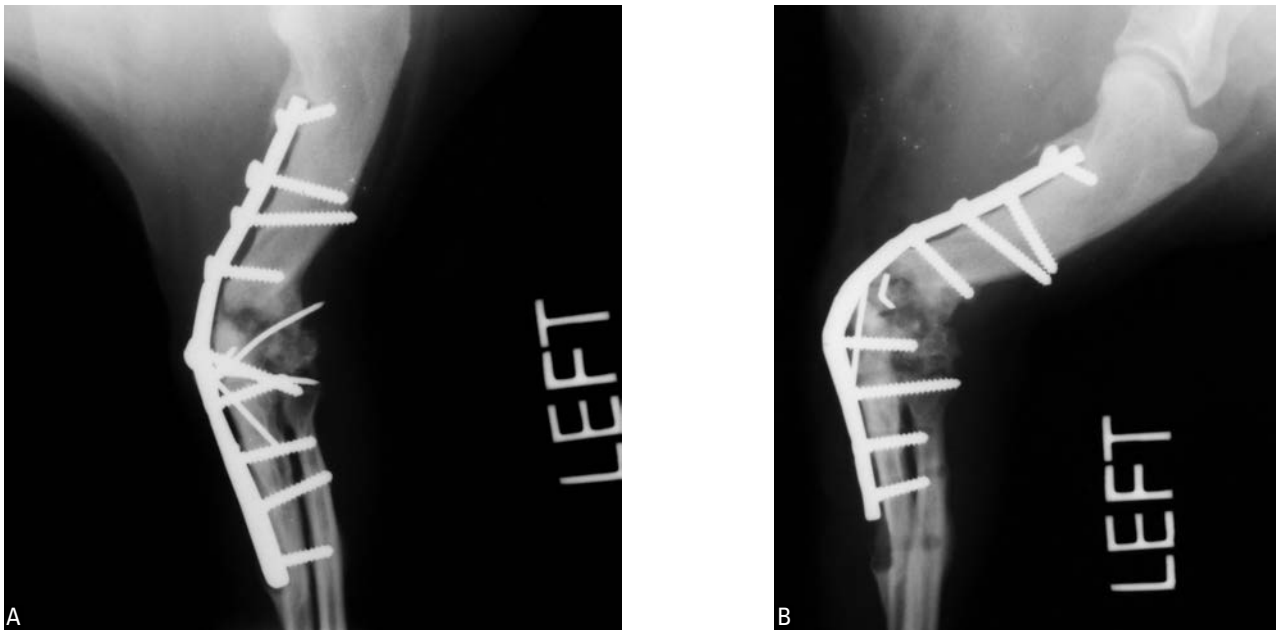


Figure 56-45. The angle made by the bones of the elbow joint is more acute (flexed) than appears from looking at the leg because of the asymmetry of the brachial musculature. In this case what appeared as the proper angle **A.** was too obtuse and had to be revised. **B.** The plate is bent at approximately 120 degrees.

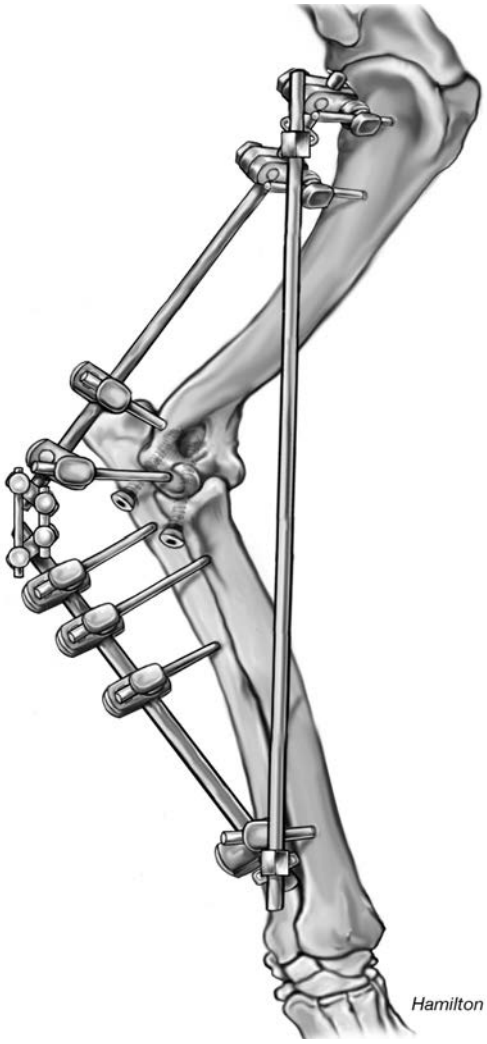


Figure 56-46. An alternate method is the use of an external skeletal fixator and a compression screw spanning the arthrodesis from the olecranon into the humerus.

Chapter 57

Radius and Ulna

Repair of Fractures of the Radius and Ulna

Curtis W. Probst

Introduction

Radial and ulnar fractures are seen frequently in small animal practice. These fractures often, but not always, involve both bones. Most fractures are the result of automobile trauma; however, fractures in toy breeds often result from jumps or falls.

As with all traumatized animals, the first step in managing patients with radial and ulnar fractures is to perform a complete physical examination. The surgeon should pay particular attention to the cardiovascular and respiratory systems. Approximately 40% of animals that have been hit by a car have some type of respiratory system damage; therefore, thoracic radiographs are advisable. One should also carefully assess the patient for the presence of cardiac arrhythmias that may result from traumatic myocarditis. Once the patient's condition has been stabilized, the surgeon can attend to the fracture.

Radiographs (at least two views) of the radius and ulna are essential to define the fracture properly. The fractured limb should be protected by applying a Robert Jones bandage until definitive treatment can be performed. This bandage should extend from the toes to well above the elbow. Half circumference splints applied distal to the elbow joint are ineffective in immobilizing radial and ulnar fractures.

Fractures of the radius and ulna may be associated with a higher complication rate than fractures of other long bones. Because of the potential complications, which include delayed union, nonunion, joint stiffness, and growth deformities, one should not dismiss these fractures lightly.

I prefer to group radial and ulnar fractures into several categories because of the difference in principles of treatment. These categories include olecranon fractures, Monteggia fractures, isolated ulnar or radial diaphyseal fractures, radial or ulnar styloid fractures, radial head fractures, combined radial-ulnar diaphyseal fractures, and radial physeal fracture-separations.

Olecranon Fractures

The olecranon,the proximal portion of the ulna, serves as a fulcrum for the extensor muscles of the elbow joint. Fractures of the olecranon can occur proximal to the trochlear notch (i.e., extra-articular fractures) or through the trochlear notch (i.e., intra- articular fractures). These fractures can be simple two-piece fractures or complex comminuted fractures. Regardless of the type of fracture, the proximal fragment usually is severely displaced because of the pull of the triceps muscle

(Figure 57-1). Open reduction and internal fixation of these fractures are required because external coaptation (e.g., a cast or splint) is unable to counteract the distractive force of the triceps muscle.

Generally, olecranon fractures are exposed through a caudal approach in which the extensor carpi ulnaris and flexor carpi ulnaris muscles are subperiosteally elevated, thus exposing the ulnar diaphysis and olecranon. The skin incision is made slightly lateral to rather than directly over the caudal surface of the olecranon.

With an intra-articular fracture, the anconeus muscle and joint capsule must be incised so the surgeon can see the articular surface. Perfect reduction of articular fractures is essential to minimize the development of secondary degenerative joint disease. Extension of the elbow relaxes the triceps pull, thus facilitating fracture reduction. After reduction, olecranon fractures can be stabilized with pins and tension band wire or bone plates and screws.

Tension Band Fixation

The preferred technique for repairing extra-articular olecranon fractures and transverse or short oblique intra-articular fractures involves pinning and placement of a tension band wire. After exposure of the fracture and removal of blood clots and fibrous tissue the elbow is extended, and the fracture fragments are reduced. Reduction usually can be maintained with digital pressure or a bone clamp.

The reduced fracture is initially stabilized by driving two Kirschner wires or Steinmann pins across the fracture. The pins are driven in a normograde fashion through the proximal

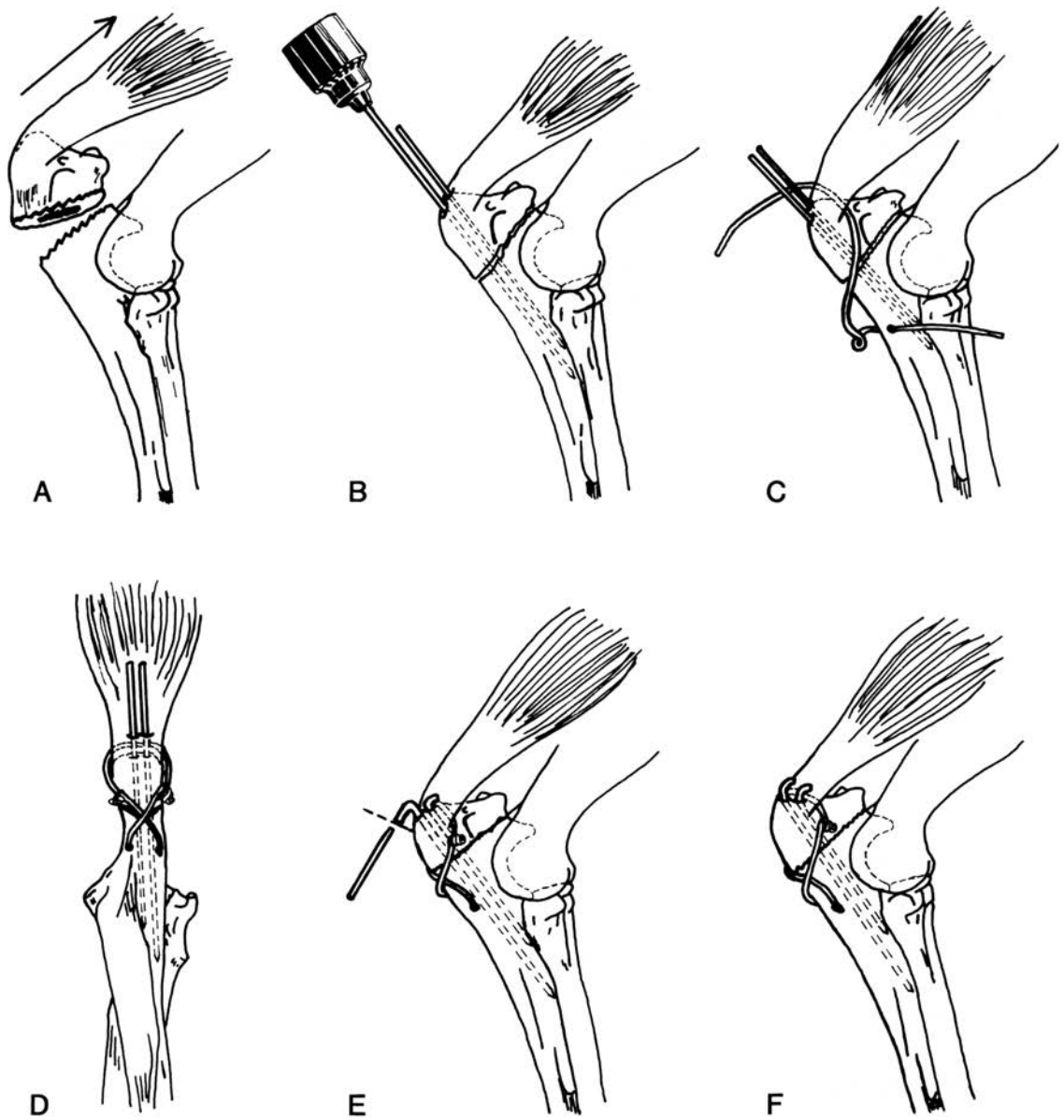


Figure 57-1. Fixation of extra-articular olecranon fracture with a tension band wire. **A.** Typical fracture location proximal to the trochlear notch. **B.** Placement of two Kirschner wires or Steinmann pins across the reduced fracture in a normograde fashion. **C.** Insertion of orthopedic wire through a hole in the distal fragment. **D.** Figure-of-eight tension wire in place. **E.** Trimming of bent pin ends. **F.** Completed repair with pin ends lying flat against triceps tendon. See text for details.

fragment, across the fracture, and into the distal fragment with a Jacob's pin chuck. The proximal olecranon is quite dense bone, so it may be helpful to pre-drill pilot holes of a slightly smaller diameter than the pins. The pins should be parallel to each other to allow compression of the fracture with the tension band wire. The pins should be directed so they engage the cranial cortex of the distal ulnar fragment, rather than extending directly down the medullary cavity, because the latter placement may not counteract rotation effectively (Figure 57-1B); similarly, a single pin does not counteract rotation. A hole is then drilled transversely in the caudal aspect of the distal fragment. The hole should be large enough to accept 18-gauge orthopedic wire (20-gauge wire in small dogs and cats) and should be placed roughly the same distance distal to the fracture as the length of the proximal fragment. A single tightening twist is made in the center of an appropriate length of wire, and one end is then passed through the hole. The other end of the wire is then passed underneath the triceps tendon and cranial to the pins (Figure 57-1C). The free ends of the wire are twisted together, thus forming a figure-of-eight (Figure 57-1D). The two twist points on the medial and lateral portions of the figure-of-eight wire are alternately tightened until the fracture is compressed. The wire should not be over-tightened because this may cause a gap to form in the cranial aspect of the fracture. The excess wire is cut, leaving three or four twists, and the two ends of the wire are bent so they lie flat against the bone. The pins are bent in a caudal direction and are cut to leave 4 to 5 mm's of pin; the ends are then turned cranially so they lie flat against the triceps tendon (Figure 57-1E and F). If the pins are initially bent in a cranial rather than a caudal direction, the cut ends will not lie flat against the triceps tendon.

If properly applied, the tension band wire is strong enough that no postoperative support is needed. The wound is covered with a sterile dressing, and the limb is placed in a light support wrap for 48 hours postoperatively. The animal's activity should be limited to leash walks for 6 to 8 weeks after surgery. The implants are not removed unless they loosen, break, or cause soft tissue irritation.

Bone Plating

I prefer to use a bone plate and screws to repair comminuted olecranon fractures and olecranon fractures in large and giant breed dogs. A plate applied to the caudal aspect of the ulna acts as a tension band, provided no cortical fragments are missing from the cranial cortex. Screws can be applied through the plate using the lag principle, thus achieving interfragmentary compression in comminuted fractures (Figure 57-2A and B). Screws must not be placed through the articular surface of the trochlear notch. With fractures that are sufficiently proximal to require plating up to the most proximal aspect of the ulna, pressure sores frequently develop over the olecranon if the plate is applied caudally. The plate should be applied to the lateral aspect of the ulna and inter-fragmentary lag screws may be used as necessary (Figure 57-2C).

Monteggia Fractures

Fractures of the proximal half of the ulna with luxation of the radial head are known as Monteggia fractures. The radial head usually luxates cranially, and the ulna may be fractured anywhere from the middle of the diaphysis to the trochlear notch. The proximal annular and interosseous ligaments may be torn (Figure 57-3A) or may remain intact, as is common when the ulnar fracture is at the base of or into the trochlear notch (Figure 57-3B). Early treatment is helpful for ease of reduction of the luxation and fracture.

A caudal approach usually provides adequate exposure to allow reduction of both the radial head luxation and the ulnar fracture. A craniolateral approach can be used in addition to the caudal approach if the luxation cannot be reduced.

If the proximal annular ligament is torn, as occurs when the ulnar fracture is distal to the annular ligament (See Figure 57-3B), one must not only stabilize the ulnar fracture but also secure the radial head in its normal relationship with the ulna. Although suture repair of the annular ligament has been described, this is seldom possible. I prefer to secure the radial head to the ulna with lag screws alone or in conjunction with a bone plate. If the ulnar fracture is oblique enough, lag screws alone are sufficient

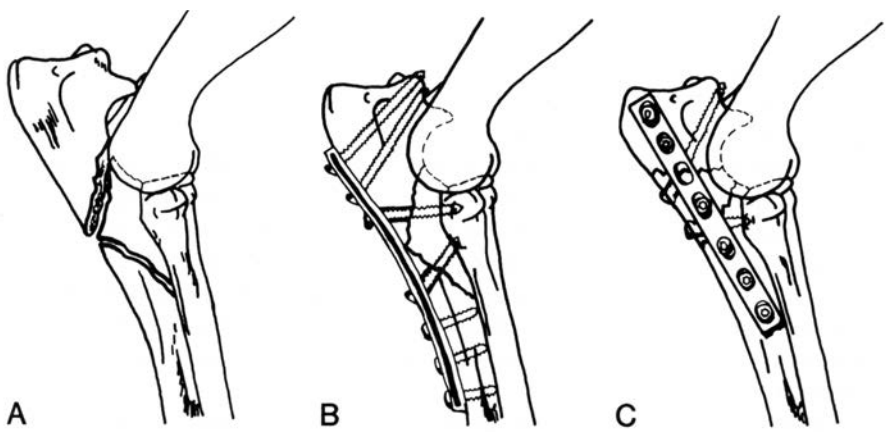


Figure 57-2. A comminuted intra-articular olecranon fracture **A.** repaired with a bone plate applied to the caudal aspect of the ulna. **B.** Screws have been applied through the plate in lag fashion, thus achieving interfragmentary compression. With more proximal fractures **C.** that must be plated to the most proximal end of the ulna, the plate is applied on the lateral surface. Lag screws can be applied in a caudal to cranial direction if necessary.

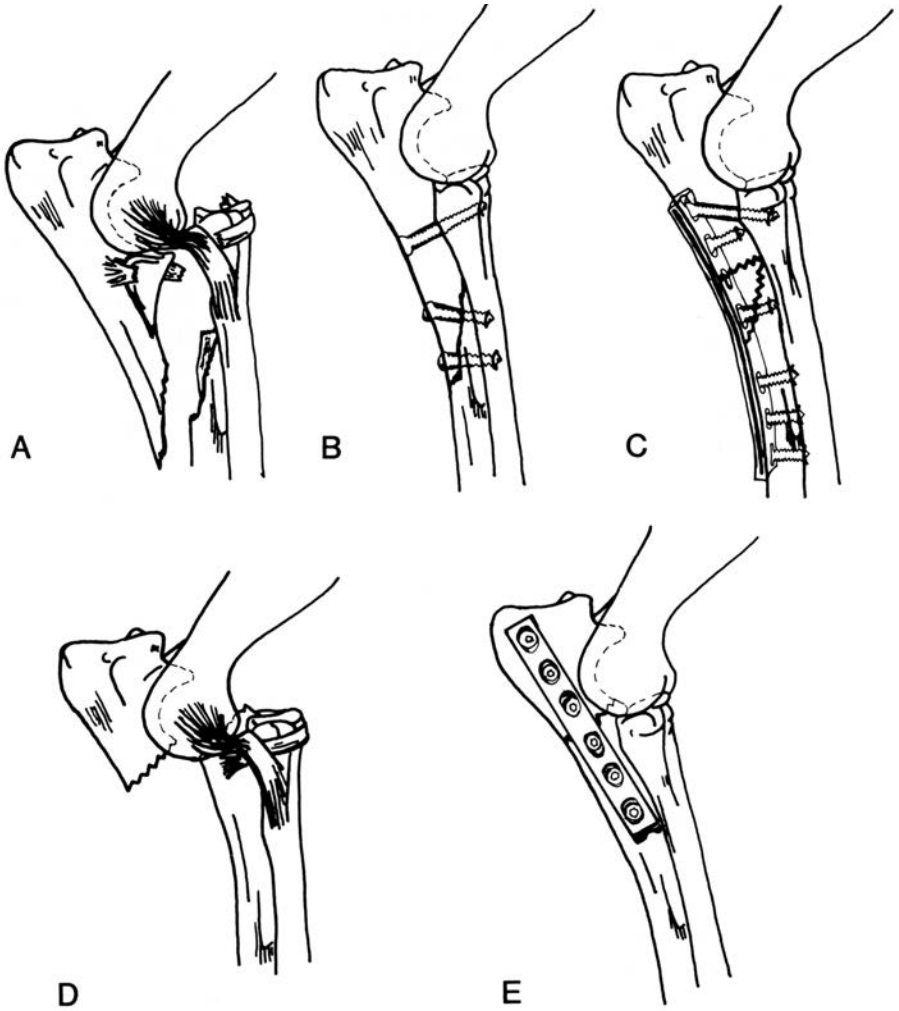


Figure 57-3. Stabilization of Monteggia fractures. An oblique fracture with ruptured proximal annular ligament **A.** can be repaired with three lag screws **B.**; if the fracture is comminuted, a bone plate is applied to the caudal aspect of the ulna. **C.** In both cases, the most proximal lag screw holds the radial head in its normal position. A Monteggia fracture with an intact proximal annular ligament **D.** can be repaired with a bone plate applied to the lateral aspect of the ulna. **E.**

to repair the fracture (See Figure 57-3A) (Figure 57-3C). If the ulnar fracture is comminuted, I prefer to use a bone plate and place one or two screws through the plate into the proximal radius (Figure 57-3D).

If the proximal annular ligament is intact, reduction of the ulnar fracture can be accomplished only with concurrent reduction of the radial head luxation. Because the intact annular ligament maintains the normal relationship between the radial head and the ulna, the surgeon only needs to stabilize the ulnar fracture. I prefer to use a bone plate and screws to stabilize this type of ulnar fracture (Figure 57-3E and F), although repair with pin(s) and tension wire has been described.

Postoperatively, the incision is covered with a sterile dressing, and the limb is placed in a modified Robert Jones bandage. The bandage helps to minimize postoperative swelling and is left in place for several days. The animal's activity should be limited to leash walks only for 10 to 12 weeks after surgery, but early movement of the elbow is encouraged to minimize stiffness.

Isolated Ulnar or Radial Diaphyseal Fractures

Isolated radial or ulnar fractures generally are the result of falls, gunshot wounds, or the patient being kicked by a horse, for example, rather than automobile accidents. Isolated ulnar diaphyseal fractures occur more frequently than isolated radial diaphyseal fractures. These fractures usually are minimally displaced because the intact companion bone acts as an internal splint. Radiographic diagnosis of these fractures may be difficult because of the minimal displacement; therefore, one should obtain two radiographic views of diagnostic quality.

Most isolated radial or ulnar fractures can be stabilized with a properly applied fiberglass cast. The joints proximal and distal to the fracture must be immobilized to stabilize a fracture properly with external coaptation. Half circumference splints, although used frequently, are an unacceptable means of stabilizing radial or ulnar fractures because they do not immobilize the elbow joint adequately.

A cast should be applied with the patient under general anesthesia. The fracture is manually reduced. The reduced fracture should have at least 50% purchase (i.e., contact between fracture ends)

before the reduction is considered adequate. One should avoid casting the limb with a varus or valgus angulation at the fracture. This type of angulation can lead to secondary arthritis because of abnormal stresses placed on the joints during weight-bearing. The cast should extend from the midshaft of the humerus to the digits, with only the distal phalanx of the third and fourth digits left exposed distal to the cast.

External coaptation is not without complications, but many problems can be avoided by applying the cast properly. Pressure sores over the accessory carpal bone and olecranon are common. They can be avoided by applying "donuts",layers of cast padding with a hole cut in the center,over these pressure points (Figure 57-4A). Donut pads placed around a pressure point alleviate the pressure directly on the bone. Simply adding more padding directly over a pressure point actually increases the pressure and should be avoided. The distal end of the cast can cause severe erosions to the dorsal aspect of the protruding toes as the animal walks. Adding extra padding and applying a walking bar (i.e., aluminum rod) to the distal end of the cast helps prevent damage to the dorsum of the protruding toes (Figure 57-4B). The walking bar can be incorporated into the cast or can be secured to the dried cast with adhesive tape. A cast also may not immobilize the elbow joint properly. This problem usually occurs because the cast is not applied as far proximal to the elbow as it should be or because the cast is applied too loosely proximal to the elbow.

Diaphyseal fractures of the radius or ulna that are the result of gunshot wounds may not be amenable to treatment by external coaptation. Because such fractures frequently are severely comminuted, restoration of cortical continuity may be difficult, if not impossible. Fractures involving only the radial diaphysis are best treated with an external fixator (Figure 57-5). The external fixator provides direct skeletal fixation and allows treatment of open wounds. Generally, the major segments of the radius are not severely displaced; therefore, the external fixator can be applied after closed reduction. This technique minimizes further disruptions of the blood supply to the fracture fragments. If the major fracture segments are displaced, or if one chooses to use a cancellous bone graft, then open reduction is required. It is best to use a minimal approach and avoid handling the fracture fragments (i.e., the "look but don't touch" method) to avoid further iatrogenic disruption of blood supply. The application of external fixators is described later, in the discussion of combined radio-ulnar diaphyseal fractures.

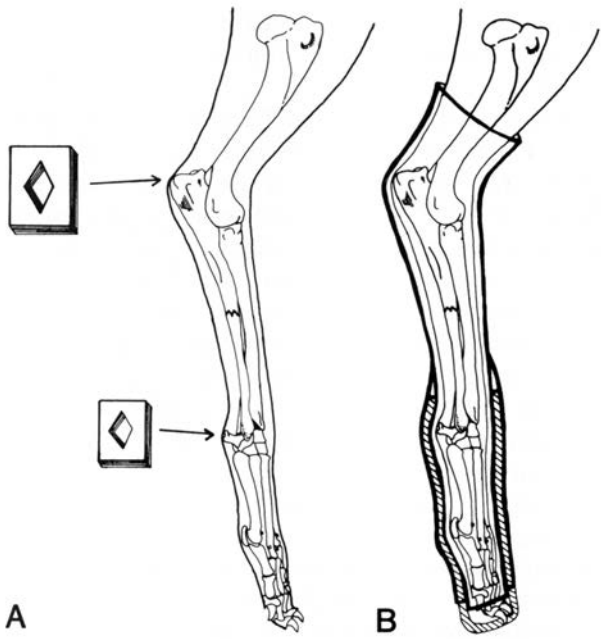


Figure 57-4. Isolated ulnar and radial diaphyseal fractures can be treated with external coaptation. **A.** Cut-out "donut" pads are applied over accessory carpal bone and the olecranon to relieve pressure from the cast. **B.** A walking bar incorporated into the distal aspect of the cast prevents damage to the dorsal surface of the protruding toes.

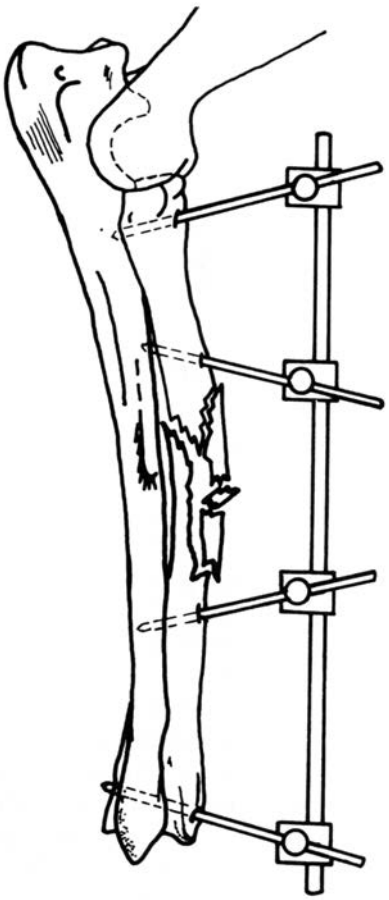


Figure 57-5. A severely comminuted isolated radial fracture stabilized with a Type I external fixator.

Isolated ulnar diaphyseal fractures resulting from gunshot wounds can be treated with a cast, provided no extensive open wounds are present. Such fractures usually do not require rigid fixation because the radius is the major weight-bearing bone. The limb can be immobilized temporarily in a Robert Jones bandage until any swelling subsides or the open wounds begin to heal before applying a cast.

Radial and Ulnar Styloid Fractures

The radial and ulnar styloid processes serve as the origins of the medial and lateral collateral ligaments of the antebrachio-carpal joint. The styloid processes also extend distal to the proximal row of carpal bones, thus providing a buttress for medial and lateral stability. Because carpal instability results

from fracture of one or both styloid processes, internal fixation of these fractures is required.

The styloid processes are exposed by incising directly over the process taking care to avoid iatrogenic laceration of the collateral ligaments. Fixation of radial styloid fractures usually is accomplished with tension band wire or lag screws (Figure 57-6A-C). It may not be possible to place two pins into the distal ulna in small dogs; therefore, ulnar styloid fractures may not be completely rotationally stable (Figure 57-6D and E).

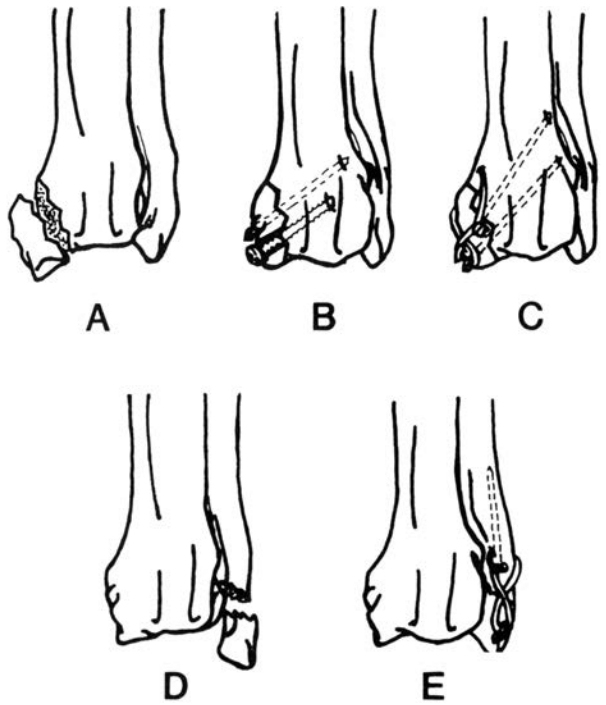


Figure 57-6. A radial styloid fracture **A.** can be repaired with a lag screw and Kirschner wire (to prevent rotation of the fragment) if the fragment is large enough **B.** or with two Kirschner wires and a tension band wire **C.** An ulnar styloid fracture **D.** can be repaired with a pin and tension band wire **E.**

Because uncomplicated healing of these fractures is necessary to prevent carpal instability, supplemental external coaptation is necessary. A fiberglass half-cast or Mason metasplint provides satisfactory support. External coaptation can be discontinued after 6 to 8 weeks. The animal's exercise should be restricted until fracture healing is complete.

Radial Head Fractures

Radial head fractures, which are uncommon, may or may not involve the articular surface. If the articular surface is involved, perfect reduction and rigid fixation are required to minimize secondary arthritis and joint stiffness.

The radial head is most easily approached through a lateral skin incision. A fascial incision is made between the common and lateral digital extensor muscles near their origin. These muscles are separated to expose the supinator muscle, deep branch of the radial nerve, branches of the dorsal interosseous artery, and part of the radius. One should protect the radial nerve during the surgical procedure. Incision of the supinator muscle along its insertion on the radius exposes the lateral collateral ligament annular ligament and joint capsule. The annular ligament and joint capsule are incised along the cranial border of the collateral ligament thus exposing the radial head. After the fracture is repaired, the joint capsule and annular ligament are re-apposed. The supinator muscle may be sutured to the radial periosteum. The remainder of the closure is routine.

Extra-articular radial head fractures can be repaired with a T-plate or crossed Kirschner wires (Figure 57-7A and B). The latter method is used in cats and small dogs in which T-plate fixation often is not feasible. Intra-articular radial head fractures can be repaired with lag screws or divergent Kirschner wires, depending on the size of the fragment. Lag screw fixation is ideal because it provides interfragmentary compression. A small Kirschner wire should be used in conjunction with the lag screw to counteract rotation of the fragment around the screw (Figure 57-7C). If the fragment is too small for lag screw fixation, then multiple divergent Kirschner wires can be used. Because

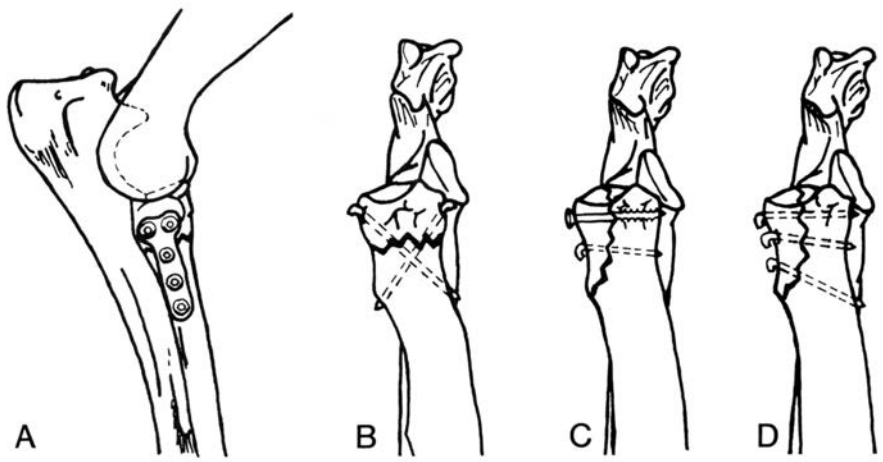


Figure 57-7. After reduction, an extra-articular radial head fracture can be stabilized with a small T-plate **A.** or crossed Kirschner wires **B.** in the case of small animals. Intra-articular radial head fractures are stabilized with a cancellous screw placed in lag fashion and a Kirschner wire to counteract rotation **C.** or with multiple Kirschner wires placed a divergent angles **D.**

interfragmentary compression is not achieved with Kirschner wires, the fracture should be reduced and compressed as much as possible with a bone clamp before the Kirschner wires are placed. At least two, and preferably more, Kirschner wires should be driven at maximally divergent angles across the fracture and through the opposite cortex (Figure 57-7D). The divergence of the wires prevents the fragment from loosening and sliding along the wires.

Preventing the animal from bearing weight on the radial head for several weeks postoperatively may be advisable, depending on the stability of the repair. This goal may be accomplished by placing the limb in a carpal flexion bandage, Velpeau bandage, or cast.

Salvage procedures such as elbow joint arthrodesis or excision of the radial head can be considered for treatment of severely comminuted radial head fractures.

Combined Radioulnar Diaphyseal Fractures

Most fractures of the antebrachium involve both the radius and ulna, and many of these fractures occur in the middle or distal third of the diaphysis. These fractures can be managed in several ways, depending on the fracture type, patient, client cooperation, facilities available, and the surgeon's capabilities. The methods of managing these fractures include closed reduction and external coaptation, open reduction and bone plating, open reduction and pinning, and closed or open reduction and external skeletal fixation. Each method is described here.

Closed Reduction and External Coaptation

Some combined fractures of the radius and ulna can be managed adequately with external coaptation after closed reduction. This method should be reserved for treatment of incomplete or transverse midshaft fractures in young, medium-sized dogs and in cats. External coaptation of radial and ulnar fractures should be avoided in toy breeds and in large, active dogs. There is a high incidence of delayed union or nonunion in distal radial and ulnar fractures in toy breeds treated with external coaptation. This may be due, in part, to a decreased interosseous blood supply in the distal radius of toy breed dogs compared to large breed dogs. Bone plates and screws should be used to treat radius and ulnar fractures in toy breed dogs.

When performing closed reduction of transverse midshaft radial and ulnar fractures, reduction is considered adequate only when a 50% or more purchase is achieved. The limb should not have a varus or valgus angulation when it is cast. (See the earlier discussion of isolated ulnar or radial diaphyseal fractures for guidelines and complications of external coaptation.)

Open Reduction and Bone Plating

The radius is an ideal bone to plate because the approach to it is straightforward, its cranial surface is the tension side of the bone, and little bending is required to contour the plate properly to the bone. Open reduction and bone plating are the treatments of choice for combined radioulnar fractures in toy breeds, in large or giant breeds, and in animals with multiple limb fractures. In toy breeds, distal radial and ulnar fractures seem to have an unusually high incidence of delayed or nonunion when treated conservatively; plating these fractures provides the rigid fixation necessary for healing. Properly applied bone plates are better than other methods of fracture repair in withstanding the tremendous stresses placed on fracture repairs by active large and giant breed dogs. Similarly, the rigid fixation provided by bone plates permits earlier return to function in the patient with multiple limb fractures than when more conservative treatment methods are used.

Usually, only the radius needs to be plated, although plating both the radius and ulna may be advisable in large or active dogs. The radius is exposed through a craniomedial approach; the ulna can be exposed through a caudal or caudolateral approach if it is to be plated also. The most proximal and distal aspects of the radius are more difficult to expose than the diaphysis because of proximal muscular insertions and tightly adherent extensor tendons distally. The plate is applied to the cranial surface of the radius and, if necessary, the caudolateral surface of the ulna (Figure 57-8A). One must be certain that a plate applied to the radius is beneath the extensor tendons. Failure to do so results in entrapment of the extensor tendons and limited function of the carpus or digits.

With proximal radial fractures, screws can be placed through the radial plate into the ulna. This procedure may increase

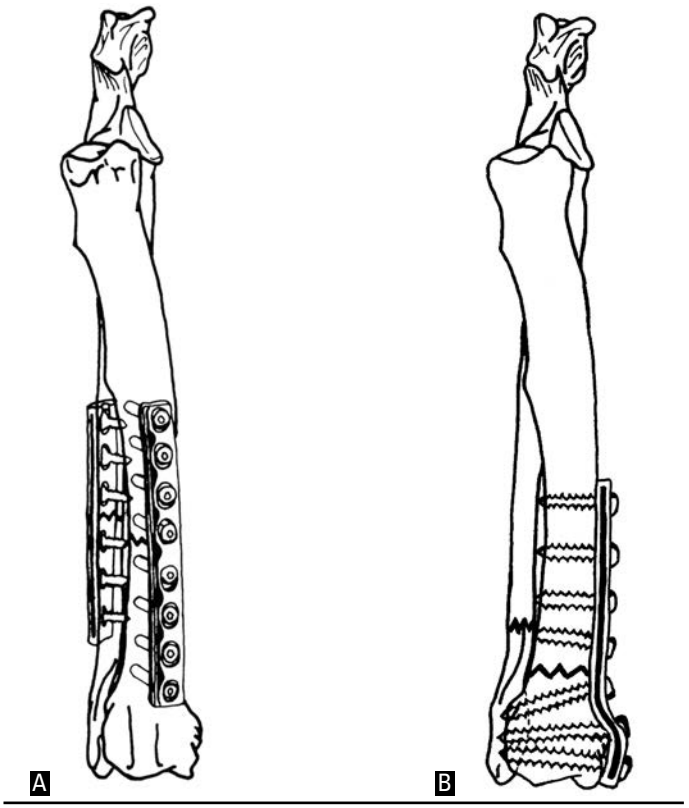


Figure 57-8. Combined radius and ulnar diaphyseal fractures repaired with two bone plates **A.** Usually, only the radius needs to be plated except in very large dogs or in dogs with multiple limbs fractured. When dealing with distal radial and ulnar fractures, a bone plate can be applied to the medial aspect of the radius thus facilitating the placement of more screws into the distal fragment **B.**

fracture stability, but it prevents supination and pronation of the antebrachium. Therefore this technique should be used only when there is a short proximal segment and additional screw purchase is warranted. Screws should never be placed through the radius into the ulna in a growing animal because doing so causes the animal to develop an angular limb deformity.

Plating the medial aspect of the radius is advised for treating distal radial and ulnar fractures where three screws cannot be placed into the distal fracture segment using a dorsally applied bone plate (Figure 57-8B). Because the plate can be applied along the radial styloid process, additional screw purchase can be achieved in the distal radial epiphysis. Additionally, the screws engage the thicker medial and lateral radial cortices, and the extensor tendons are avoided. Generally, a narrower plate is chosen for the medial radius compared to the plate that would be chosen for the dorsal radius. The radius is narrower in a craniocaudal direction than it is mediolaterally, therefore accurate aiming of the screws is necessary to capture the entire width of the radius. Care must be used to avoid placing the most distal screw into the antebrachiocarpal joint.

A cancellous bone graft is recommended for comminuted fractures and for fractures in older animals. The proximal humerus is a convenient site to harvest cancellous bone for radial and ulnar fractures. The cancellous graft can be placed around the fracture site as it is removed from the humerus, or the graft can be put into a stainless steel bowl until enough cancellous bone has been harvested. The fracture site should not be lavaged after the graft has been placed.

A padded bandage is applied to the limb after wound closure. The bandage is applied snugly from the toes to the midshaft of the humerus. The bandage minimizes postoperative swelling of the limb and keeps the incision clean. The bandage can be removed in 48 hours. The dog's activity should be restricted to leash walks only for 10 to 14 weeks postoperatively. Although not routinely done, the plate may be removed 10 to 12 months after the fracture has healed.

Open Reduction and Intramedullary Pinning

The radius is not as amenable to intramedullary pinning as the other major long bones for several reasons. Because the radius is relatively straight and both ends are completely covered with articular cartilage, retrograde pin placement causes the pin to enter either the elbow or the carpal joint. The oval cross-sectional shape of the medullary cavity limits the size of the pin that can be used. Furthermore, many toy breed dogs do not have a distinct medullary cavity in the radius, making it difficult or even impossible to pin. A single medullary pin does not provide stable fixation of a radial fracture even if the ulna is also pinned. Therefore, treating radial fractures with an intramedullary pin is not advised and should be avoided.

Pinning of the ulna may be performed in conjuction with other types of radial fracture fixation (e.g., bone plate and screws, external fixator) to facilitate alignment of the ulna. One may wish to use this auxiliary fixation in large or active dogs. Retrograde placement of the pin is more easily accomplished than normograde placement. It is advisable to insert the pin into the proximal ulnar fragment before stabilizing the radial fracture if one wishes to use retrograde placement. The pin should be aimed toward the caudal ulnar cortex to avoid the pin exiting the ulna through the dorsal aspect of the anconeal process. If normograde placement is chosen, the pin is inserted at the medial aspect of the olecranon and directed slightly laterally to insure the pin enters the medullary canal.

Closed or Open Reduction and External Skeletal Fixation

External skeletal fixation is a versatile and useful method of managing many combined radioulnar fractures. An external fixator can be applied after open or closed fracture reduction. If open reduction is chosen, the approach should be limited in length to what is necessary to see the fracture site. I prefer to use a limited craniomedial approach. The open approach offers the advantages of seeing the fracture during reduction and allowing application of a cancellous bone graft. However, open reduction also has disadvantages of causing further trauma to the blood supply of the fracture fragments and exposing the fracture to the outside environment.

Several different external fixator configurations are applicable to the radius. Stable transverse or short oblique fractures in medium-sized dogs can be treated with a Type 1-a fixator consisting of four half- pins and a single connecting bar (Figure 57-9C). A similar configuration with six pins and a single connecting bar is used for similar fractures in larger dogs (Figure 57-9D). The fixator is applied on the cranial or craniomedial aspect of the radius. Driving the pins in a true medial to lateral direction across the radius is difficult and may result in iatrogenic fracture because of the oval shape of the radius. If one chooses to apply a Type II fixator, smaller diameter pins should be used in the proximal portion of the radius to minimize the risk of iatrogenic fracture.

Depending on the system used, the pins must be inserted in a particular order during application of an external fixator with only one connecting bar. The fracture is reduced, and the most proximal and distal pins are inserted first. These pins should be inserted as far away from the fracture as possible and at a 45 to 60° angle to the long axis of the bone (Figure 57-9A) if smooth pins are used. If positive profile threaded pins are used, they should be applied perpendicular to the long axis of the bone. A connecting bar with four clamps is attached, and the two outermost clamps are tightened on the pins. The middle two pins are placed through the clamps and then are driven into the bone (Figure 57-9B). These pins should be 1 to 2 cm from the fracture. The greatest biomechanical stability is achieved when there is maximal distance between the two pins on each side of the fracture (Figure 57-9C). All clamps are then completely tightened, and postoperative radiographs are obtained. Minor adjustments in fracture reduction can be made if the clamps are loosened. Because use of a single connecting bar precludes major adjustments in fracture reduction once all the pins have been placed, one should reduce the fracture properly before applying the external fixator.

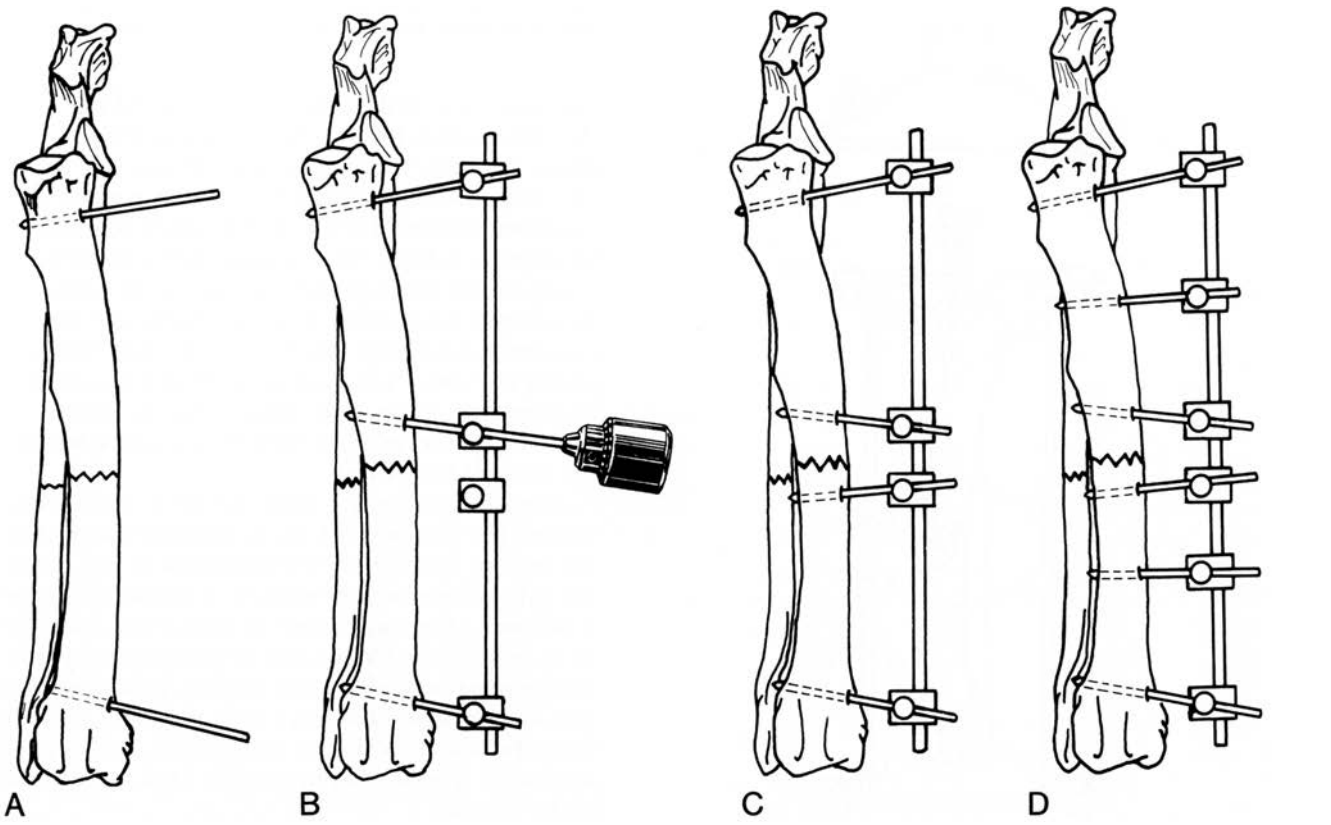


Figure 57-9. External skeletal fixation of combined radial and ulnar diaphyseal fractures. **A.** Insertion of most the distal and most proximal pins. **B.** Attachment of t he connecting bar with clamps and placement of middle two pins. **C.** Completed four-pin, single-bar (Type I) fixator in place. **D.** Six-pin single-bar fixator in place.

A six-pin, single-connecting bar fixator is applied similarly to a four-pin, single-bar fixator. Six clamps are placed on the bar instead of four. The middle pins on either side of the fracture are placed last (See Figure 57-9D).

A quadrilateral frame (Type I-b) external fixator is useful for unstable comminuted fractures and open fractures with missing bone fragments (Figure 57-10). This configuration is also particularly useful for proximal or distal fractures in which one segment is short. A quadrilateral frame allows pin fixation in two planes, thus providing stable fixation of short fragments that would not be possible with other configurations. A quadrilateral frame, like other external fixators, can be applied after open or closed reduction. If reduction is not possible (i.e., if cortical fragments are missing), the bone is anatomically aligned before the fixator is applied. The first row of pins is applied from the craniomedial aspect of the radius toward the caudolateral aspect in the same way as described for a four-pin, single-bar fixator. Once the first row of pins is placed and the connecting bar is applied, the second row of pins is placed. The second row of pins is placed identically to the first, except it is applied from the craniolateral aspect of the radius toward the caudomedial aspect. The second connecting bar is then applied. The two rows of pins are connected to each other by applying a connecting bar to the two most proximal and another to the two most distal pins (Figure 57-11). Alternatively, a diagonal connection can be made (i.e. from the most proximal pin on the lateral side to the most distal pin on the medial side) which has been shown to be stronger than the proximal and distal connections previously described.

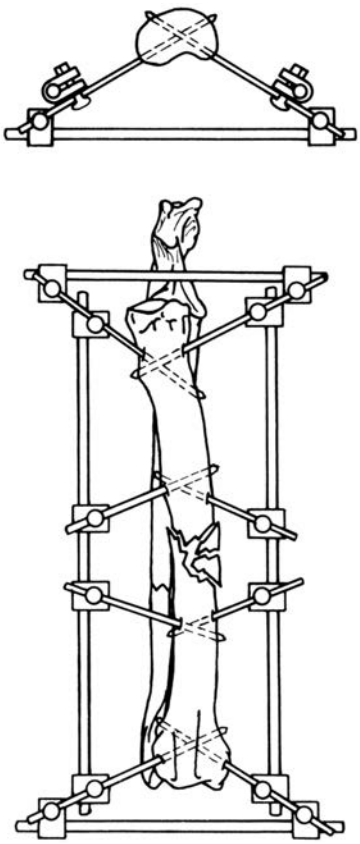


Figure 57-10. A quadrilateral frame (Type IB) external fixator is useful for unstable comminuted radial and ulnar fractures, especially those that occur in the distal third of the diaphysis.



Figure 57-11. Proximal and distal radial physeal fractures can be stabilized with two small Kirschner wires. External coaptation may also be necessary, especially with distal physeal fractures.

Other fixator configurations may be used depending on the nature of the fracture. Generally, the more unstable the fracture or the longer the expected healing time, the more stable the configuration should be. Positive profile threaded pins provide greater bone holding power and are less likely to loosen prematurely. Pre-drilling technique is recommended with these pins. Some of the newer systems allow placement of threaded pins through the clamps and permit clamps to be tightened on the pins after they have been inserted into the bone. These systems provide the flexibility of adding additional pins after the connecting bar and initial clamps have been applied. Regardless of the configuration chosen, the points of the pins should protrude slightly beyond the second cortex. The pins should be driven by hand or with a low-speed power drill. The clamps should not touch the skin; rather, they should be approximately 1cm above the skin. The pins are cut off near the clamps after any necessary adjustments have been made.

Circular ring fixators may be used to stabilize radius and ulnar fractures. These devices require some preoperative assembly of the rings to facilitate application during surgery, and may require more time to apply than conventional external fixators. Ring fixators offer the advantage of placing small wires (e.g., 1.6 mm diameter) through the fracture fragments. These wires are attached to the rings and tension is applied which dramatically increases the stiffness of the wires. Therefore these small wires can be used instead of larger pins (see Chapter 53 – Circular External Skeletal Fixation). Using small wires allows one to stabilize short bone fragments that occur with distal radial fractures because they do not require as much bone length as larger pins. I believe circular ring fixators offer the greatest advantage when attempting to repair fractures with one main fragment is very short. Hybrid fixators utilizing a ring and wires to capture the short segment and linear fixator elements to immobilize the long segment have also been used successfully (see Chapter 53 – Circular External Skeletal Fixation).

Post-operative placement of a compression bandage is helpful. The bandage helps to minimize postoperative swelling and is left on for 48 hours. The fixator is wrapped with cotton and elastic tape after the compression bandage has been removed. This wrap covers any sharp pins and prevents the fixator from catching on carpet and similar objects. The client should limit the animal's exercise to leash walks until the fracture has healed.

Fixation pins may loosen before a fracture has healed. The likelihood of this complication depends on the type of fracture, the configuration of the fixator, the number and type of fixation pins used and the techniques used to place them, the animal's age, and the amount of activity the animal is allowed. One may choose to replace the loose pins or to remove the fixator and use external coaptation for the remainder of fracture healing. In certain cases, one may be able to remove only the loose pins and leave the rest of the fixator undisturbed. This can only be done if at least two pins remain fixed on each side of the fracture.

Generally, an external fixator can be removed without anesthesia or even sedation. The clamps and connecting bars are loosened and removed. Smooth fixation pins can be pulled out by hand or with a pair of pliers. Positive profile threaded fixation pins must be un-screwed from the bone with a hand chuck or power drill. The small amount of hemorrhage that usually occurs from the pin holes can be controlled with a light pressure bandage. The animal's activity should be restricted for several weeks after removal of the fixator while re- modeling of the holes in the bone begins.

Radial Physeal Fracture-Separations

Fracture-separation through either radial physis is uncommon. Such fractures occur through the zone of hypertrophied cartilage. The animal's owner should always be warned that premature physeal closure and angular limb deformity may follow such a fracture. If premature physeal closure does occur, it usually happens within 2 weeks of the fracture.

Closed reduction of a radial physeal fracture and external coaptation should be attempted first. If closed reduction fails, open reduction should be performed. The fracture can be stabilized with small Kirschner wires (See Figure 57-11). The wires are driven from the epiphysis across the physis and into the metaphysis. To minimize premature physeal closure, the wires should be as parallel to one another as possible and as perpendicular to the physis as possible. Some form of external coaptation is advisable for 2 weeks, especially for distal physeal fractures. These fractures usually heal within 3 weeks. The pins should be removed if possible.

Suggested Readings

Boltz WH, Chiguet C, Niederer PG: Der fixateur externe (Rohrsystern) Stabilitatspriifung. *AO Bulletin,* Friihling, 1978.

Boudrieau RJ: *Textbook of small animal surgery.* Philadelphia. WB Saunders, 2003, 1953.

Brinker WO, Hohn RB, Prieur WD: *Manual of internal fixation in small animals*. New York: Springer-Verlag, 1984.

Brinker WO, Piermattei DL, Flo GL: *Handbook of small animal orthopedics and fracture treatment*. Philadelphia: WB Saunders, 1997, 321.

Brinker WO, Verstraete MC, Soutas-Little RW: Stiffness studies on various configurations and types of external fixators. *JAm Anim Hosp Assoc* 21:801, 1985.

Dieterich HF: Repair of a lateral radial head luxation by radial head ostectomy. *Vet Med Small Anim Clin* 68:671, 1973.

Egger EL: *Textbook of small animal surgery.* Philadelphia: WB Saunders, 1985, 1736.

Egger EL: Static strength of six external skeletal fixation configurations. *Vet Surg* 12:130, 1983.

Johnson AL, Kneller SK, Weigel RM: Radial and tibial fracture repair with external skeletal fixation. *Vet Surg* 18:367, 1989.

Lewis DD, Radash RM, Beale BS, Stallings JT, et al: Initial clinical experience with the IMEX circular external skeletal fixation system. Part I. Use in fractures and arthrodeses. *Vet Comp Orthop Traumatol* 12:108, 1999.

Phillips JR: A survey of bone fractures in the dog and cat. *J Small Anim Pract* 20:661, 1979.

Piermattei DL, Johnson KA: *An atlas of surgical approaches to the bones of the dog and cat.* Philadelphia: WB Saunders, 2004.

Putnam RW, Archibald J: Excision of canine radial head. *Mod Vet Pract* 49:32, 1968.

Sardinas JC, Montavon PM: Use of a medial bone plate for repair of radius and ulna fractures in dogs and cats. *Vet Surg* 26:108. 1997.

Wallace MK, Boudrieau RJ, Hyodo K, Torzilli PA: Mechanical evaluation of three methods of plating distal radial osteotomies. *Vet Surg* 21:99, 1992.

Welch JA, Boudrieau RJ, Dejardin LM, Spodnick GJ: The itraosseous blood supply of the canine radius: implications for healing of distal fractures in small dogs. *Vet Surg* 26:57, 1997.

Correction of Radial and Ulnar Growth Deformities Resulting from Premature Physeal Closure

Dominique J. Griffon and Ann L. Johnson

Introduction

The most common angular deformities in dogs affect the antebrachium and represent 0.74% of all skeletal diseases in dogs. Among these, angular deformities attributed to crushing injuries (Salter V fractures) of the distal ulnar growth plate have been well described. This type of injury may result in external rotation, radius valgus, cranial bowing of the radius, radio-ulnar incongruence, and limb shortening. Retained cartilage core, hypertrophic osteodystrophy, nutritional disorders, asymmetrical crushing injuries (Salter VI) and other fractures of the growth plates can also result in premature physeal closure of the antebrachium. Scientific documentation of the effects of angular deformity and limb shortening on limb function and secondary degenerative joint disease is limited. However, surgical correction has traditionally been recommended in cases with elbow dysplasia, more than 10 degrees of angulation, and / or more than 20% limb length discrepancy. The management of growth deformities of the antebrachium is based on consideration of the following factors:

1. Presence of a unifocal or bifocal (resulting in translation of the limb) deformity
2. Three-dimensional (rotation, medio-lateral and craniocaudal planes) assessment of the severity of the angular deformity
3. Point of maximum deformation
4. Limb length discrepancy (actual and expected)
5. Growth potential of the affected limb and the contralateral limb
6. Congruence of the elbow joint

Careful patient selection and thorough pre-operative planning are crucial to optimize treatment outcome. Physical examination is essential to evaluate the overall function of the limb and evaluate joints for pain on manipulation, crepitation, effusion and range of motion. Rotational deformity is easier to measure on physical examination than radiographs, by comparing the planes of flexion and extension of adjacent joints. Planning requires a minimum of two orthogonal radiographic views including the elbow and the carpus of the affected limb. Similar radiographs of the contralateral antebrachium are useful as a reference. Additional radiographs and/or computed tomography of the forelimb are indicated to evaluate the elbow for any evidence of dysplasia.

Ulnar Ostectomy in the Immature Dog

The purpose of this technique is to release the constraint created by the ulna on the remaining growth of the radius in immature dogs. Postoperative increase in radial length and correction of the angular deformity correlate with the growth potential in the radial physes. Owners should be warned that any rotational deformity will most likely persist and that additional surgical correction may be warranted at skeletal maturity. Ulnar ostectomy is always coupled with procedures to prevent premature union of the ulnar segments, such as the insertion of a fat graft.

The dog is placed in lateral recumbency, with the affected forelimb and ipsilateral flank prepared for aseptic surgery. A lateral approach to the distal ulna starts with a skin incision extending over the mid to distal ulna. Subcutaneous tissue is incised and the lateral digital extensor muscle is separated from the extensor carpi ulnaris muscle. Fascia and surrounding soft tissues are dissected to expose a segment of ulna carefully insuring that all periosteum, with its osteogenic potential, remains with the segment of bone to be resected. Depending on the size of the dog, a one to three centimeter segment of the ulna is resected using bone cutters or an oscillating bone saw cooled with a saline flush. The segment of bone and associated periosteum are removed (Figure 57-12). If the interosseous artery is disrupted during the ostectomy, effective hemostasis must be achieved.

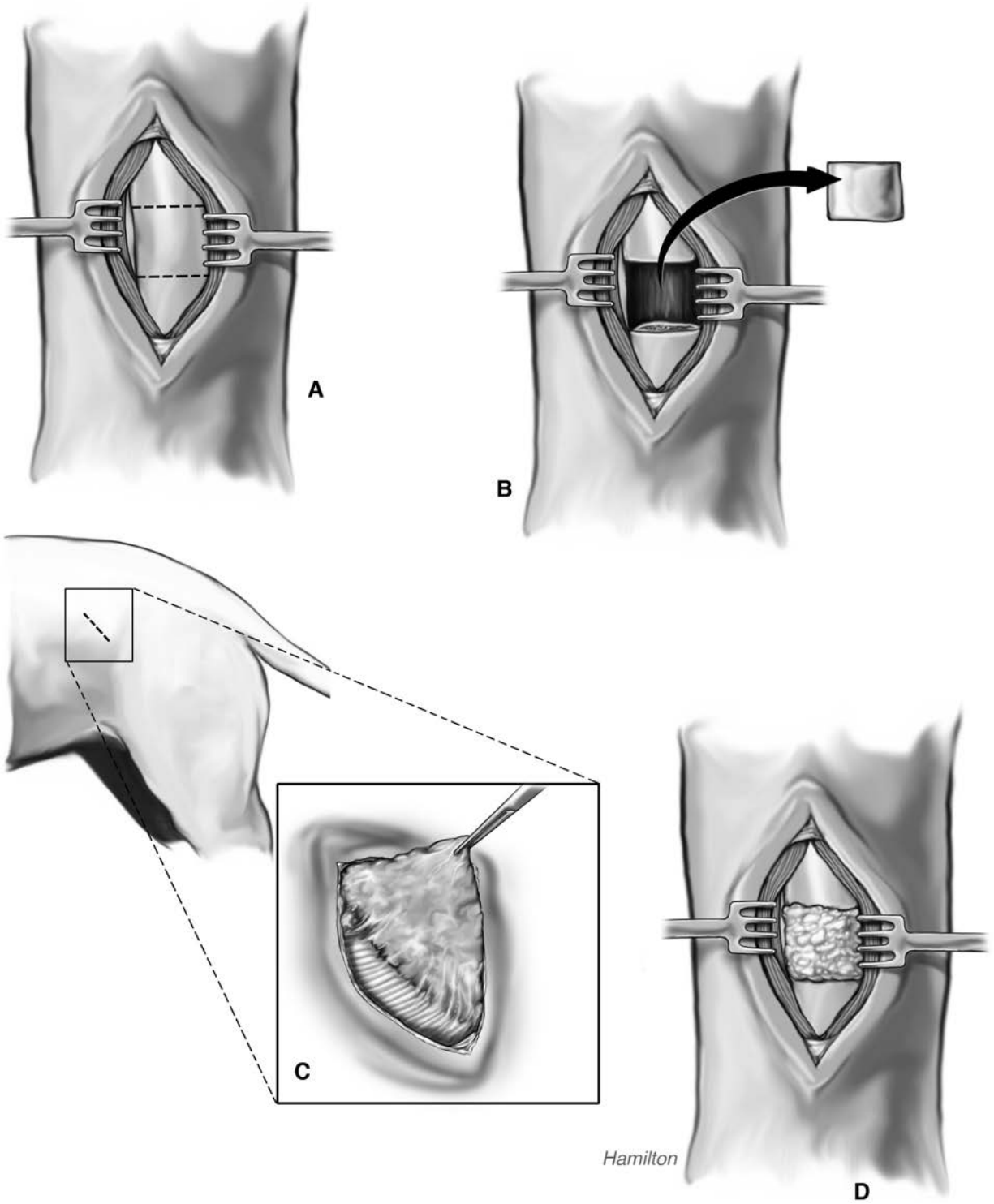


Figure 57-12. Distal ulnectomy in the immature dog. **A.** The distal ulna is exposed. An ostectomy is performed just proximal to the distal physis. **B.** A 1- to 3- cm section of bone and surrounding periosteum is removed. **C.** A large piece of fat is atraumatically harvested from the flank. **D.** The fat is inserted in the ostectomy gap and the fascia closed.

Bone wax may be applied directly over the proximal and distal ends of the osteotomized bone to prevent premature healing of the ulna. While this procedure effectively inhibits bone formation and development of a synostosis, it is associated with a risk of foreign body reaction. Other surgeons have recommended suturing the periosteum covering the resected segment of ulna over each end of the osteotomized bone. However, the procedure most commonly used to prevent premature healing of the ulna consists of interposing a fat graft in the ulnar defect. A 2 to 3 centimeter skin incision is made in the ipsilateral flank area, exposing the subcutaneous fat. A large single piece of fat is sharply dissected free and placed in the ostectomy gap (See Figure 57-12). Hemostasis is achieved at the donor site and the subcutaneous tissue and skin are sutured. The transplanted fat is secured in the ostectomy gap by suturing adjacent soft tissues. The subcutaneous tissues and skin are closed in a routine fashion.

Post operative radiographs are obtained to document the location and length of the ostectomy gap. A soft padded bandage is placed for 2-4 days after surgery to prevent seroma formation. A splint is recommended to protect the limb for 2 weeks if bilateral procedures are done. The dog is released to the owners with instructions to limit activity. Monthly radiographs are indicated until skeletal maturity, to allow serial evaluation of radial growth, correction of the angular deformity and persistance of the ostectomy gap. Restoration of the normal configuration of the elbow due to the release of the proximal ulna may be noted. Union of the ulna prior to skeletal maturity may require reoperation. A corrective osteotomy of the radius may be indicated if angular deformity remains clinical at maturity.

The ostectomy should be performed in the distal ulna just proximal to the physis to effectively relieve the restraints on the radial growth plate without affecting the stability of the elbow or carpus. Failure to remove all of the periosteum at the ostectomy site will result in premature bone bridging of the ostectomy gap. Meticulous apposition of soft tissues and obliteration of dead space minimizes the risks of herniation of the fat graft (potentially leading to dehiscence and premature union of the ulna) and seroma formation at the donor site. Postoperative splint support for two weeks is important with bilateral ostectomies to prevent motion at the ostectomy gap and displacement of the fat graft. However, splinting an immature dog often leads to laxity of the flexor tendons and hyperextension of the carpus. Therefore careful attention must be paid to removing the splint at the appropriate time.

Radial Ostectomy in the Immature Dog

The goals of treatment are to allow unrestricted growth of the normal physes of the radius and ulna, and to restore and maintain elbow congruity. This procedure is indicated in immature dogs with premature closure of the proximal or distal radial growth plate and active ulnar physes.

The animal is treated with a middiaphyseal ostectomy of the radius coupled with the placement of a free autogenous fat graft in the defect to prevent bone union (Figure 57-13A and B). Release of the tension on the proximal and distal radius will

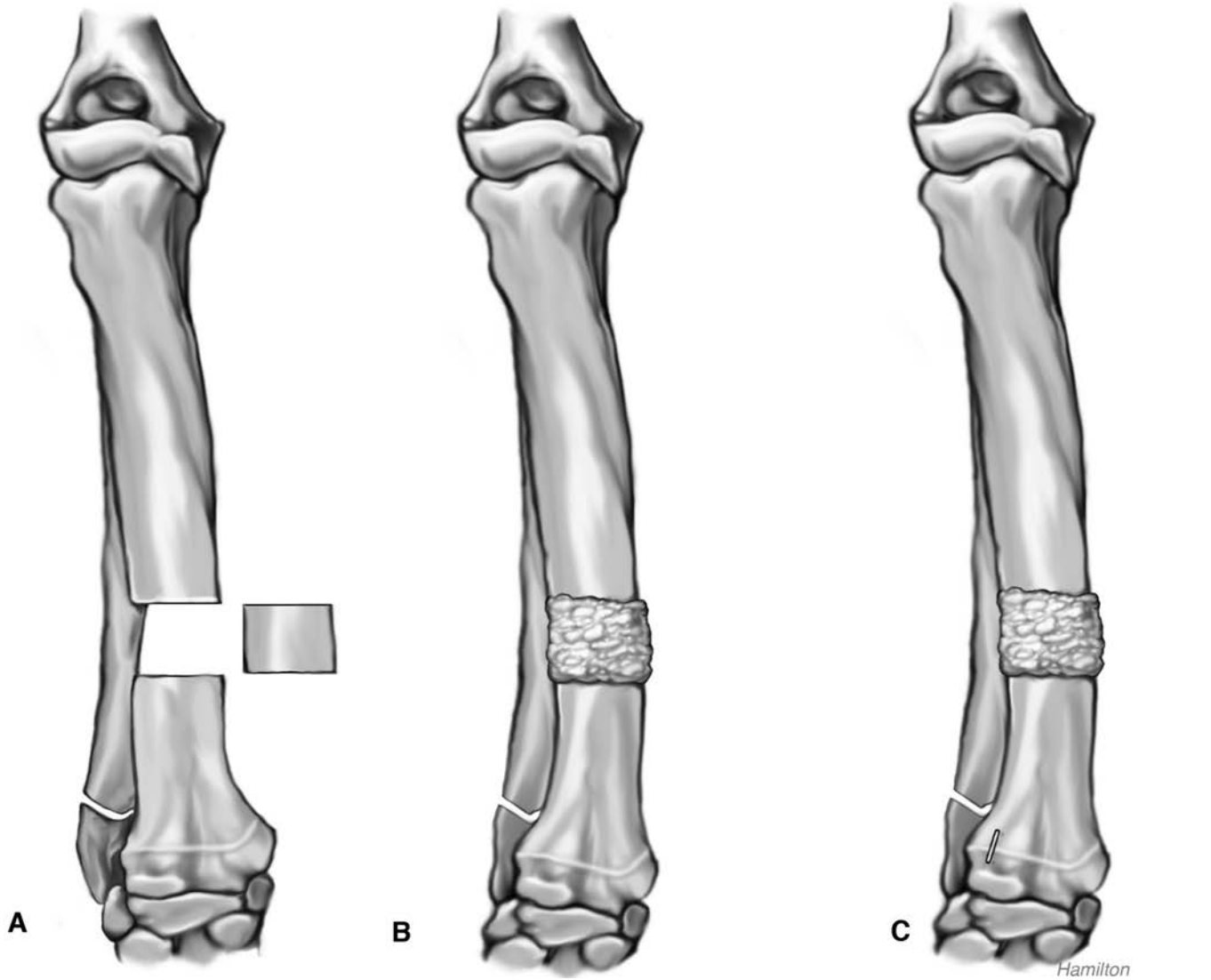


Figure 57-13. Radial ostectomy in the immature dog. **A.** A 1- to 2- cm segment of radius is resected. **B.** A large piece of fat is placed in the ostectomy gap. **C.** If this technique is used to treat an incomplete, premature closure of the distal radial growth plate, staples are placed across the functional portion of the growth plate to prevent future interference.

usually allow the adjacent joints to reestablish normal position. A postoperative splint is applied for three to four weeks once surgical swelling has decreased (24 to 48 hours after surgery), as the radius is the primary weight bearing bone in the distal forelimb. The limb should be splinted in a slight flexion and varus, to minimize post-immobilization laxity of the carpus. The dog is released to the owners with instructions to limit activity. Monthly radiographs are indicated until skeletal maturity, to allow serial evaluation of radial growth, correction of the angular deformity and persistance of the ostectomy gap. Thickening and cranial bowing of the ulna commonly occurs in response to the increased mechanical loading of the bone. A second surgical procedure to reunite the radial segments by bridging the ostectomy gap with autogenous cancellous bone graft once the dog has reached skeletal maturity is therefore rarely indicated.

Radial ostectomy can also be considered in dogs with asymmetrical closure of the radial growth plate secondary to retained cartilage core or Salter VI fracture. In these cases, the active portion of the affected growth plate may be stapled to prevent any further deviation of the radial segment and interference with the ostectomy site (Figure 57-13C). Partial closure of the distal radial growth plate has also been treated by resection of the bone bridging the physis and placement of a fat graft. Whereas this option may decrease the risk of postoperative fracture and compensatory changes in the ulna, identifying the margins of diseased growth plate may require advanced imaging and is technically challenging. Complications include incomplete resection of the bone bridge and collateral damage to remaining growth plate resulting in failure to correct the deformity.

Closing Wedge Osteotomy and Plate Fixation in the Mature Dog

A closing wedge osteotomy can be used to treat an angular deformity of a long bone that is not significantly shortened, as this procedure will result in loss of bone length. This procedure results in cortical apposition if no rotational correction is required.

Preoperative planning is based on radiographs of the affected and contralateral control radius and ulna, including the adjacent joints. The radiographs of the affected radius are studied to determine the location of the point of greatest curvature of the radius and to evaluate the anatomy of the adjacent elbow and carpus. The affected limb is compared to the control limb to determine the discrepancy in length. The plane of angulation may be calculated based on the deviations measured on lateral and cranio-caudal projections. It may also be directly determined on a radiograph which best shows the angle of the deformity. Lines are drawn parallel to the proximal and distal joint surfaces to determine the angle of deformity of a radius (Figure 57-14). A line is then drawn perpendicular to the proximal line and centered within the proximal diaphysis. A similar line extends from the distal line, centered within the distal diaphysis. The intersection of these lines identifies the location of the osteotomy. At the osteotomy site, lines are drawn parallel to the proximal and distal joint lines. These lines intersect to form the wedge to be removed. The base of the wedge is at the convex surface of the deformity. The distance between the osteotomy line and the

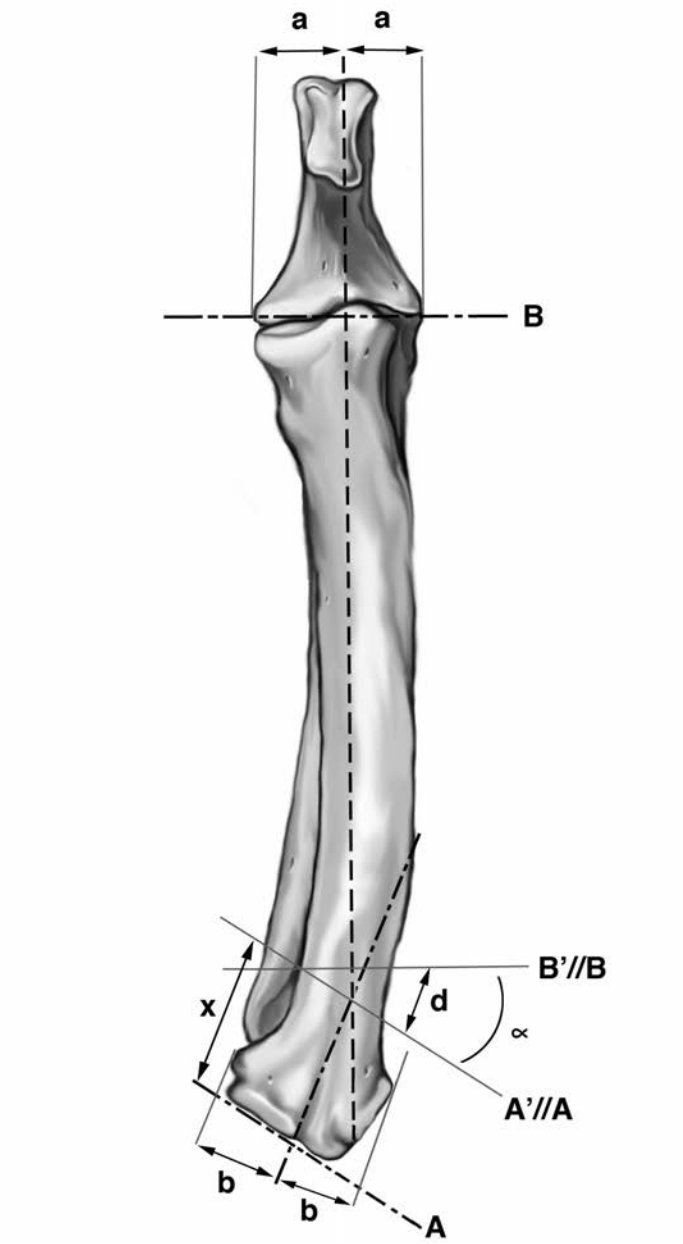


Figure 57-14. Preoperative planning of a closing wedge osteotomy to correct a radius valgus. Lines *A* and *B* are parallel to the distal and proximal radial articular surfaces, respectively. The axis of the proximal and distal radius is drawn perpendicular to the closest joint surface and originating in the center of the bone. The point of intersection of these axes locates the site of maximum deformation of the bone. A line *A'* is drawn from that point, in a direction parallel to the distal joint surface (Line *A*), representing the distal osteotomy. The point of intersection of this line with the concave surface of the bone corresponds to the origin of the distal osteotomy. The distance between this point and the carpal joint *(x)* can be used as an intra-operative landmark. A second line *(B')* extends from the origin of the distal osteotomy on the concave aspect of the radius in a direction parallel to the elbow joint (line *B*). This line represents the proximal osteotomy. The angle between lines *A'* and *B'* *(α)* corresponds to the amplitude of angulation. The distance between these two lines *(d)* may be measured along the convex surface of the radius to provide an intraoperative landmark for the proximal osteotomy. The section of bone comprised between lines *A'* and *B'* represents the wedge of bone that should be removed in order to correct the deformity.

carpal joint, and the width of the wedge to be removed on the convex side of the radius are measured and corrected for radiographic magnification (115%). A template of the selected plate can be used to verify that the bone stock between the osteotomy and the joint will allow screws to purchase six cortices. If necessary, the location of the wedge may be moved slightly proximally to secure a plate. However, moving the osteotomy site away from the area of greatest curvature results in a translational deformity. The dog is placed in dorsal recumbency, with the affected limb prepared for aseptic surgery and hanging from the ceiling. A sterile hook connects the distal extremity of the limb to a hook fixed to the limb, to allow aseptic, intra-operative manipulation of the limb. Draping the contralateral limb (if normal) in the surgical field allows intra-operative comparison, which is especially helpful in chondrodystrophic breeds. Kirschner wires are placed parallel to the proximal joint and parallel to the distal joint. A small needle may be inserted in the carpal joint as a landmark. The proximal and distal osteotomies should be parallel to the proximal and distal Kirschner wires, respectively. The distal osteotomy is located as close as possible to the point of maximum deformation, at the predetermined distance from the carpal joint. The proximal osteotomy should intersect the distal osteotomy at the convex surface of the bone, creating a bone wedge of a similar size to the preoperative plan. (Figure 57-15). The bone wedge is removed and may be morsellised to use as an autogenous graft. An ulnar ostectomy is performed via a separate lateral approach to the bone. Removing a small segment of ulna prevents interference of the ulna during manipulation of the radius and provides additional bone graft. The major segments of the radius are reduced and rotational alignment verified and corrected, if needed. Bone segments are stabilized with a compression plate. Correction of any rotational deformity will affect cortical apposition and complicate plate contouring, since the distal radius is not cylindrical.

Postoperative radiographs are indicated to evaluate correction of the deformity and implant placement. Postoperative care is similar to the management of a plated fracture. Bone healing should occur within 6 to 12 weeks.



Figure 57-15. Closed corrective osteotomy in the mature dog. The distal osteotomy is performed from a distance *(x)* from the carpal joint determined on pre-operative radiographs. This osteotomy should be parallel to the distal articular surface. The proximal osteotomy is started at a predetermined distance (distanced on Figure 57-14) on the convex surface and aimed toward the distal aspect of the opposite cortex. The wedge of radius removed is morsellised and used as a graft. An ulnar ostectomy is performed prior to reduction of the radius and plate fixation.

Open Corrective Osteotomy and External Fixation (Linear or Hybrid) in the Mature Dog

This procedure combines an oblique osteotomy of the radius and a transverse osteotomy of the distal ulna to correct angular and rotational deformities while preserving pre-existing limb length. This technique is therefore preferred in mature dogs with minor limb length discrepancy, especially if morbidity would result from shortening of the limb secondary to a closed wedge osteotomy. External fixation is a versatile method of stabilization of the osteotomy, which allows additional postoperative correction if necessary. Hybrid fixators add further versatility to this technique, especially when osteotomies are located close to a joint. These advantages facilitate the correction of angular deformities in multiple planes, and avoid the technical difficulties associated with plate contouring. However, the owners must be willing to comply with the post-operative care of external fixators. In addition, type II linear fixators are not very effective at correcting the cranio-caudal component of antebrachial deformities, most likely because this plane is perpendicular to that of the fixator.

The dog is placed in dorsal recumbency with the affected limb prepared for aseptic surgery and securely suspended from the ceiling. A sterile hook connects the distal extremity of the limb to a hook fixed to the limb, to allow aseptic, intra-operative manipulation of the limb. The contralateral limb may be included in the surgical field for comparison. In addition, a donor site for cancellous bone (usually the proximal humerus of the affected forelimb) should be prepared for aseptic surgery and draped off if the surgeon plans to fill the open osteotomy site with an autogenous bone graft.

Small needles may be placed in the carpal and elbow joints as landmarks. The lateral head of the radius is palpated, the skin incised and the bone exposed by blunt dissection of the subcutaneous tissues and grid dissection of the muscle. Small Hohmann retractors may be placed on the cranial and caudal cortices of the radius to facilitate placement of the pin in the center of the bone. Using predrilling technique, a centrally-threaded positive profile fixation pin is placed through the proximal radius from the lateral aspect. The pin should be parallel to the proximal radial articular surface and should be within the lateral transverse plane of the proximal radius. The lateral aspect of the distal radius is palpated and the ulnar styloid process is identified. Using predrilling technique, a centrally-threaded positive profile fixation is placed through the distal radius, starting cranially to the ulnar styloid process, from the lateral aspect. The pin should be parallel to the distal radial articular surface and should be within the lateral transverse plane of the distal radius.(Figure 57-16) A lateral approach is made to the distal ulna (see ulnar ostectomy) and a transverse osteotomy is performed with an osteotome or oscillating saw. Intraoperative radiography or fluoroscopy may be used to verify acceptable placement of the pins in relation to the joints. A skin incision is made over the cranio-medial aspect of the distal radius at its point of greatest curvature. Dissection through the subcutaneous tissues exposes the radial diaphysis. An oblique osteotomy of the radius is made at the point of greatest curvature using an osteotome or an oscillating bone saw. The osteotomy line should be directed parallel to the distal radial articular surface (See Figure 57-16). The operating table is lowered so the weight of the animal is suspended from the ceiling. The weight of the animal distracts the distal radius and helps to align the proximal and distal joint surfaces parallel to each other. The proximal and distal transfixation pins are aligned parallel to each other and in the same transverse plane which should eliminate any angular or rotational deformity. Connecting rods with two to six single fixation clamps on the medial rod are connected to the transfixation pins on the lateral and medial aspect of the limb. Additional fixation half-pins are driven through the unused single clamps and into the medial aspect of the radius, penetrating both cortices. One to two additional pins should be placed in each radial segment (See Figure 57-16). Placing these pins on the medial aspect of the radius allows post-operative destabilization and conversion of the type II external fixator to a type Ia. Autogenous cancellous or allogeneic bone (demineralized bone matrix) is placed at the radial osteotomy site. The wounds are closed by suturing the subcutaneous tissue and skin separately.

A circular ring and fixation wires may be used to secure the distal radial segment instead of threaded pins (Figure 57-17).

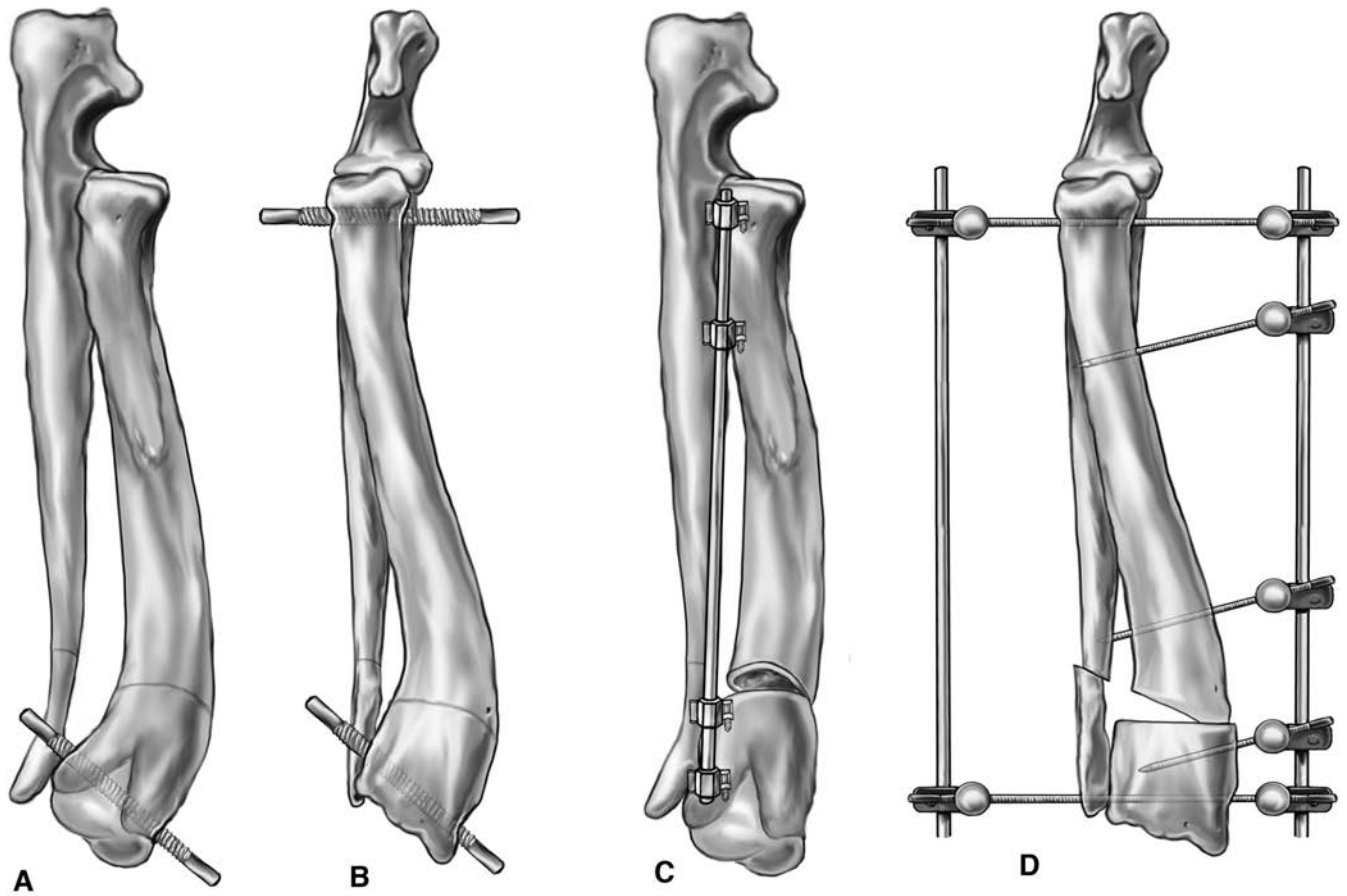


Figure 57-16. Open corrective osteotomy and linear external fixation in the mature dog. **A** and **B**. The proximal pin should parallel the proximal radial articular surface and should be within the lateral transverse plane of the proximal radius. The distal pin should parallel the distal radial articular surface and should be within the lateral transverse plane of the distal radius. An oblique osteotomy of the radius is made at the point of greatest curvature with an osteotome or an oscillating saw, directing the osteotomy line parallel to the distal radial articular surface. A transverse osteotomy of the ulna is performed. **C** and **D**. After the osteotomy, the radius is aligned so the proximal and distal transfixation pins parallel each other and are in the same transverse plane, and the remainder of the type II external fixator frame is constructed.

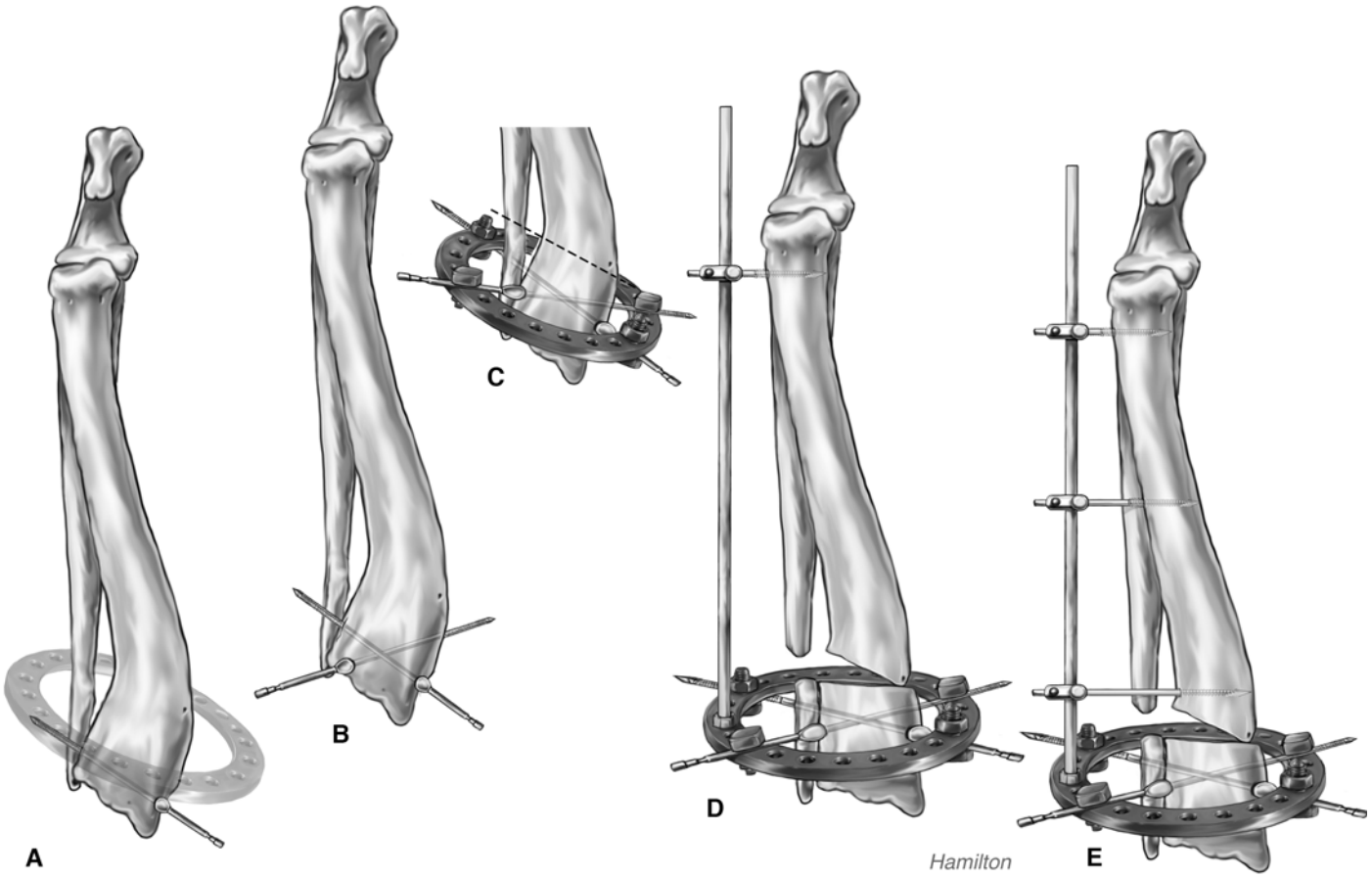


Figure 57-17. Open corrective osteotomy and hybrid external fixation in the mature dog. **A.** A ring is passed around the limb, with a diameter allowing a space of one to two cm between the inner edge of the ring and the skin of the distal antebrachium. An olive wire should be placed parallel to the distal radial articular surface and should be within the lateral transverse plane of the distal radius. This wire can then be used as a reference to correct the alignment of the limb, and as the most distal point of fixation. **B.** The most distal wire is secured to the bottom of the ring and a second olive wire is inserted from the proximal aspect of the ring. This wire should cross the first wire through the center of the radius and be inserted in a safe corridor, at a 60 to 90 degree angle from the first wire. The proximal reference wire should parallel the proximal radial articular surface and should be within the lateral transverse plane of the proximal radius. **C.** An oblique osteotomy of the radius is made at the point of greatest curvature with an osteotome or an oscillating saw, directing the osteotomy line parallel to the distal radial articular surface. A transverse osteotomy of the ulna or an ulnectomy is performed. If the distal radial segment is too short to accommodate a second ring, a drop wire (not shown) is added to the distal ring. **D.** The radius is aligned so the proximal and distal reference wires parallel each other and are in the same transverse plane. A connecting rod is placed on the ring and connected to an end-threaded pin positioned in the proximal radius through a stab incision. The proximal reference wire is removed.

Hybrid fixation is especially relevant for adequate fixation of a short segment of bone in dogs with a point of maximum angulation located very distally along the radius. In these cases, the osteotomy site may need to be displaced proximally to allow placement of at least two threaded pins in the distal segment, thereby creating a translation of the radial segments during correction of the deformity. Use of a circular ring and fixation wires to capture the distal segment requires less bone stock and allows optimal placement of the osteotomy. The dog is placed in dorsal recumbency with the affected limb prepared for aseptic surgery and securely suspended from the ceiling. A sterile hook connects the distal extremity of the limb to a hook fixed to the limb, to allow aseptic, intra-operative manipulation of the limb. The procedure starts with the placement of the distal ring around the limb (See Figure 57-17). The most distal wire is inserted parallel to the plane of the distal radial articular surface to serve as a reference. This wire may be used as the most distal element of fixation and fixed to the bottom of the ring. The second wire is inserted from the proximal aspect of the ring, at a 60 to 90° angle from the first wire. Both wires are secured to the ring and tensioned appropriately. Another wire is placed distal and parallel to the elbow joint to serve as reference. An osteotomy of the radius and ulna are performed as described above. The operating table is lowered so that the weight of the animal distracts the distal radius and helps to align the proximal and distal joint surfaces parallel to each other. The proximal and distal references are aligned parallel to each other and in the same transverse plane to eliminate any angular or rotational deformity. A hybrid rod is attached to the ring with a pair of nuts and an SK single fixation clamp applied to the rod is used to secure a threaded half pin placed in the most proximal, medial or cranio-medial aspect of the radius. Limb alignment and range of motion are checked prior to application of additional fixation pins to the proximal segment to complete the hybrid fixator. The positioning of wires and rod (thereby determining the plane of the most proximal pin) on the distal ring should be planned

to allow insertion of a drop wire, providing a third element of fixation in the distal segment (See Figure 57-17). Clamps and fixation pins are added to stabilize the proximal segment and form a Type I-a hybrid construct. A type I-b construct may be preferred, especially in cases with cranio-caudal angulation. In these cases, the hybrid rod placed cranially should be short enough to allow flexion of the elbow. Olive wires may be used for better control of the distal radius, especially if cranio-caudal correction is attempted and/or if only two wires are placed in the short segment of bone.

Postoperative radiographs are obtained to document radial alignment and implant position. The limb is bandaged with gauze sponges wedged between the apparatus and the skin to minimize soft tissue swelling. As postoperative swelling decreases, the limb may be left unbandaged. A light wrap around the rods and rings minimizes the risk of catching the fixation on surrounding objects after discharge from the hospital. Owners are instructed to confine their dog, limit activity to leash walking and clean the pin tracts daily. Weekly rechecks should be scheduled initially, to monitor pin tracts, remove sutures (at 2 weeks) and change the bandage around the frame. Radiogaphic evaluation of healing of the osteotomy is indicated every 4 to 6 weeks. The fixator is removed when the osteotomy site is bridged with bone.

Suspending the limb from the ceiling during the osteotomy aids the surgeon in aligning the limb, and apparently decreases the amount of postoperative swelling because of the minimal manipulation needed to support the limb during correction and fixation. It is important to make the radial osteotomy cut parallel to the distal radial joint surface not only in the lateral to medial plane but also in the cranial to caudal plane to enable correction of a severe cranial bowing deformity. External fixation of the osteotomy is useful for several reasons. The proximal and distal transfixation wires serve as external landmarks to help align the bone after osteotomy. Additional manipulations can be easily made after the surgical procedure if the surgeon is not satisfied with the corrections. The rigidity of the fixator can be altered to fit the animal and the stage of healing of the osteotomy. Finally, removal of the fixation after bone healing is simple and generally requires only sedation. The disadvantages of external fixation lie in the aftercare which the owner must perform, and the damage the external fixator can do to the dog's surrounding environment.

Correction of Angular Deformity and Continuous Distraction with a Circular External Fixator

Circular fixators are indicated as treatment for adult dogs that have a limb length discrepancy of at least 20%, or immature dogs with anticipated extensive growth. Circular fixators can be effectively used to simultaneously correct angular deformities and length discrepancies. It is also indicated to treat dogs with complex deformities such as 1) bifocal angulations, resulting in a translation of the limb, or 2) significant cranio-caudal and rotational deformities. Although the circular fixator can be used to treat dogs with varus/valgus deformities, there are simpler techniques that are equally as effective using plate or standard external fixation. However, the advantage of the circular fixator in treating angular deformities consists in its flexibility in allowing correction of the deformity and length discrepancies simultaneously. The disadvantages of the circular fixator in correcting deformities are the intensive and sometimes lengthy learning curve for the surgeon, the detailed preoperative planning, and the need for regular postoperative monitoring of the distraction process. Length deficit, rotational, craniocaudal and mediolateral angulations are determined as previously described (see pre-operative planning in closing wedge osteotomy and Figure 57-14).

The simplest method described to treat angular deformities with circular external fixators (CEFs) consists of an acute correction of the angulation and rotation, followed by a linear distraction. The procedure starts by placing the most proximal and distal rings parallel to the plane of the proximal and distal joint surfaces of the radius, respectively. The radial osteotomy is then performed at the point of maximum curvature, parallel to the carpal joint. The periosteum should be incised along with the cortex to allow manipulation of the bone, but care is taken to avoid stripping this layer. The ostectomy of the ulna can be achieved through the same incision, or via a lateral approach to the ulna. The antebrachial deformity is corrected by aligning the proximal and distal rings (Figure 57-18). Additional fixation is added to the short segment using a second ring and fixation wires (preferably) or a drop wire, depending on the bone stock available. Another ring is placed in the proximal segment and connecting rods are added between these rings. Linear motors connect the ring immediately proximal to the osteotomy to the ring immediately distal to the osteotomy to enable postoperative lengthening of the bone.

Limb alignment and implant position are confirmed on postoperative radiographs. The limb is bandaged with gauze sponges wedged between the apparatus and the skin to minimize soft tissue swelling. As postoperative swelling decreases, the limb may be left unbandaged. A light wrap around the rods and rings minimizes the risk of catching the fixation on surrounding objects after discharge from the hospital. A delay, or latency period, is recommended after surgery, before distraction is initiated. This allows local cellular and vascular responses to occur in order to facilitate optimal distraction osteogenesis. The recommended latency period varies from 1 to 3 days for immature animals to 5 to 7 days for adult animals. Early distraction may cause diminished callus production while unduly delayed distraction may allow premature consolidation. For the same reasons, distraction is started at a rate of 1 to 2 mm daily, divided into two to four increments. Physiotherapy and pain medications are indicated until the dog is bearing full weight on the limb. Low-impact exercise is essential to encourage use of the limb and stimulate formation of regenerate bone. Owners are shown how to turn the linear motors in order to provide a rate of distraction adjusted to the age and size of the dog. For example, the distraction rate may be increased to 2 mm daily in large dogs, less than 6 months of age, who have undergone an osteotomy of the radial metaphysis. Daily cleaning of the skin with 0.05 percent chlorhexidine solution and application of a triple antibiotic ointment around the wire-skin interface minimize the risk of wire tract infection.

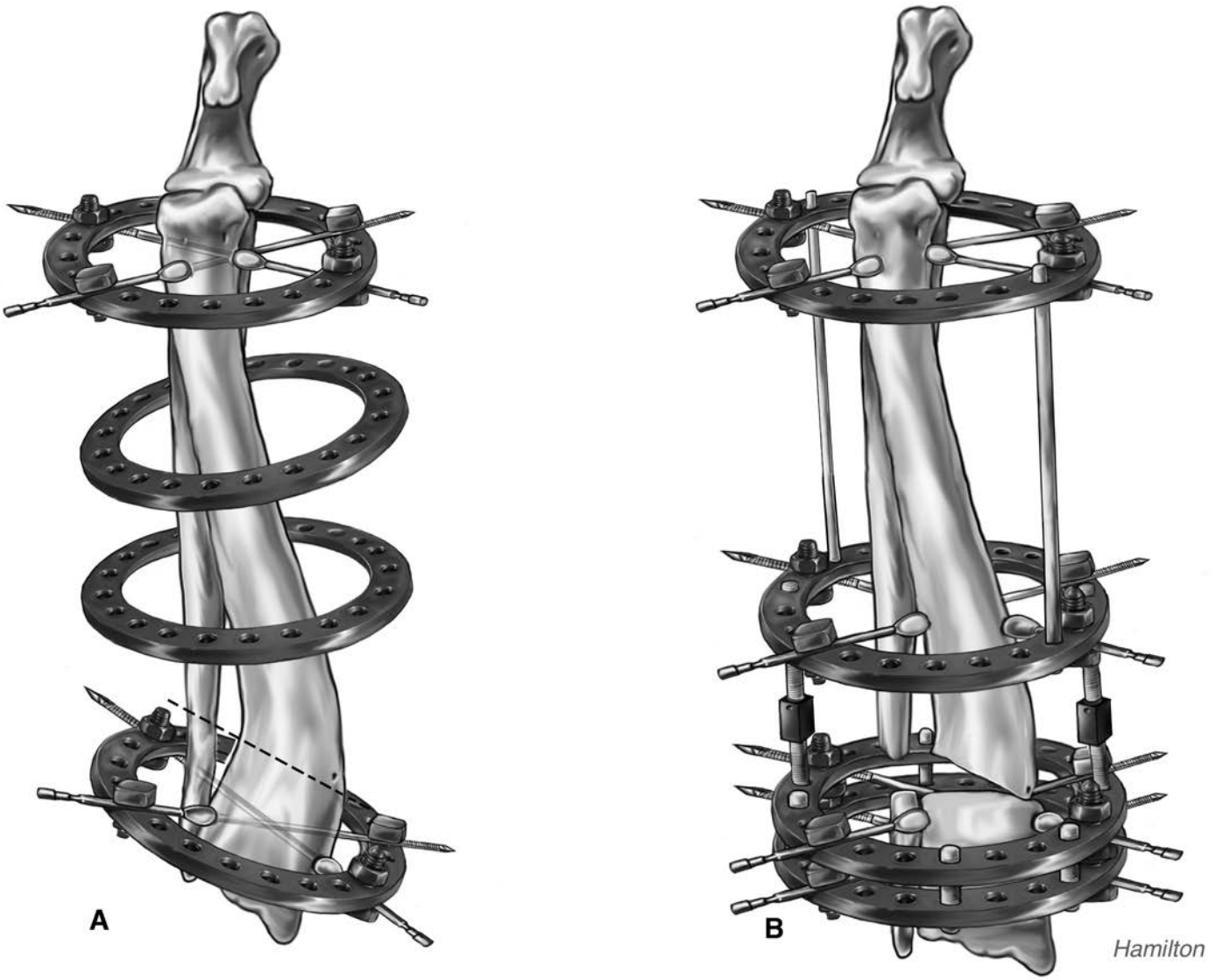


Figure 57-18. Correction of an angular deformity and limb shortening with standard circular ring fixators. **A.** The proximal and distal rings should be parallel to the proximal and distal radial articular surfaces, respectively. Two wires are tensioned on each side of the corresponding ring, crossing each other in the center of the bone and at an angle of at least 45° from each other, avoiding neurovascular structures. A second ring is added on each side of the anticipated osteotomy, so that each segment of radius will be immobilized with two rings. Alternatively olive wires and a drop wire may be used to control a short segment of radius. An oblique osteotomy of the radius is made at the point of greatest curvature with an osteotome or an oscillating saw, directing the osteotomy line parallel to the distal radial articular surface. A partial ulnectomy is performed. **B.** Rotation and angulation are acutely corrected by aligning the rings placed in the proximal and distal radial segments. Linear motors connect the rings placed on either side of the radial osteotomy to allow post-operative distraction of the bone.

Use of the limb, range of motion of the carpus and radiographs are re-evaluated every seven to ten days. Because planned and actual adjustments routinely differ by 25%, the distraction regimen is adjusted based on serial radiographs. Contracture of the flexor muscles is a common complication, leading to decreased range of motion of the carpus and reluctance to use the limb. This complication is more likely in dogs requiring more than 10 percent lengthening and is best managed by decreasing the distraction rate (to 0.5 mm daily), pain medications and aggressive physical therapy. When the distraction is complete, the frame is left in place until the gap has completely filled with new bone, typically three to five weeks after distraction has stopped. CEFs are removed under sedation and exercise is limited to low-impact activity for three weeks thereafter.

This standard circular fixator is a relatively simple technique to allow lengthening of the bone if there is no angular deformity, or if the deformity is mild and can be corrected as a one-stage procedure. However, it requires complete transection of the periosteum and limits contact between the proximal and distal radial segments. The resulting gap increases the stress placed on the frame, may slow bone healing, and increases postoperative morbidity. Complications requiring a second surgery have been described in 29 to 67% of cases, with good to excellent results reported in 68% of dogs treated with this method. To address these limitations, another strategy consists of placing hinged external fixators to gradually correct the angular deformity and length deficit. The positioning of the hinges is critical to the outcome and requires careful pre-operative planning to determine the direction and amplitude of the oblique deformity.

The frame is assembled before surgery so that the rings are placed at an angle to each other corresponding to the amount of deformity. Hinges are levelled with the origin of the deformity. Their axis (line joining these hinges) should be perpendicular to the direction of the deformity and tangential to the bone at the origin of the angulation. The angular motor is placed on a third connecting bar in the plane of deformity and on the concave side of the deformity. Positioning olive wires against the concave surface of the bone prevents translation of the radius during angular correction. Acute, intra-operative correction of any torsional deformity simplifies the design of the frame. As the angulation is corrected, an opening wedge of regenerate bone is formed, resulting in an overall gain of length equal to half of the length gained on the concave surface of the bone. Hinge fixation is also indicated in the treatment of bifocal deformities, where bone lengthening and correction occur at two osteotomy sites, effectively doubling the rate of distraction.

Suggested Readings

Johnson AL: Corrective osteotomies. In: Johnson AL, Houlton JEF, Vannini R Eds: AO Principles of Fracture Management in the Dog and Cat. New York: Thieme, 2005, p374.

LatteY: Anomalies de croissance et leur traitement par fixateurs externes classiques. In Latte Y, Meynard JA Eds : Manuel de Fixation Externe. Paris : Editions PMCAC, 1997, p191.

LatteY: Traitement des anomalies de croissance par fixateurs externes circulaire. In Latte Y, Meynard JA Eds : Manuel de Fixation Externe. Paris :Editions PMCAC, 1997, p 466.

Marcellin-Little DJ, Ferretti A, Roe SC, et al.: Hinged Ilizarov external fixation for correction of antebrachial deformities. Vet Surg; 27:231, 1998.

Marcellin-Little DJ: Treating bone deformities with circular external skeletal fixation. Comp Cont Ed 21:481, 1999.

Lewis DD, Radasch RM, Beale BS, et al.: Initial clinical experience with the IMEX TM circular external skeletal fixation system, Part II: Use in bone lengthening and correction of angular and rotational deformities. Vet Comp Orthop Traumatol, 12:118, 1999.

Quinn MK, Ehrhart N, Johnson AL, et al.: Realignment of the radius in canine antebrachial growth deformities treated with corrective osteotomy and bilateral (Type II) external fixation. Vet Surg; 29:558, 2000.

Toombs JP: Acute correction of distal antebrachial growth deformities with hybrid ESF. Small Animal Hybrid Circular ESF Course, American College of Veterinary Surgeons Symposium, Washington DC, October 11, 2003.

Dismukes DI, Fox DB, Tomlinson JL, Essman SC: Use of radiographic measures and three-dimensional computed tomographic imaging in surgical correction of an antebrachial deformity in a dog.J Am Vet Med Assoc, 232(1):68-73, 2008.

Fox DB, Tomlinson JL, Cook JL, Breshears LM. Principles of uniapical and biapical radial deformity correction using dome osteotomies and the center of rotation of angulation methodology in dogs. Vet Surg, 35(1):67-77, 2006.

Crosse KR, Worth AJ. Computer-assisted surgical correction of an antebrachial deformity in a dog. Vet Comp Orthop Traumatol, 23(5):354-61, 2010.

Chapter 58

Carpus, Metacarpus, and Phalanges

Classification and Treatment of Injuries to the Accessory Carpal Bone

Kenneth A Johnson

Introduction

The accessory carpal bone seems more prone to injury than the other carpal bones, perhaps because it is such an integral component of the palmar support structure that prevents hyper-extension during full weight bearing. Fractures of this bone are commonly in the region of ligamentous insertions (sprain avulsion fractures), and frequently they involve the articular cartilage surface on the dorsal end of the bone that forms part of the accessory-ulnar carpal joint. Most fractures of this bone occur in racing greyhounds.[1,2] Similar types of fractures are seen occasionally in dogs of other breeds, and these fractures may be due to trauma, landing awkwardly on the limb, stepping in a hole while running, and falling from heights. Swelling, instability, and pain are common features of carpal injuries, but the diagnosis and classification of fractures are made from radiographs. Fractures can usually be visualized in mediolateral radiographic views with the carpus in full extension or slightly flexed. Additional information about the type and extent of the fracture can be obtained from the dorsopalmar radiographic view. Luxation of the accessory carpal bone, without any fracturing of the bone, can also result from severe trauma in sporting dogs.[3]

Fracture Classification

These fractures have been classified into five types, on the basis of their radiologic and pathologic features (Figure 58-1).[1,4,5]

Type 1

Injuries are avulsion of bone in the region of the insertion of the accessory-ulnar ligament. Fracture fragments may be large slabs or multiple comminuted chips that are best appreciated on the mediolateral radiographic views. These fractures involve the distal margin of the articular surface, and this feature, combined with disruption of the ligamentous support, leads to instability, subluxation, cartilage damage, and secondary osteoarthritis. Chronic fractures often do not proceed to bony union, and the bone fragments become surrounded by proliferative bone and fibrous tissue.

Type I fractures are further defined as being palmarolateral (type 1A) or palmaromedial (type 1B).[4,6] The type IA fracture of the palmaorolateral prominence may be visualized on a dorsolateral palmaromedial oblique radiographic view.

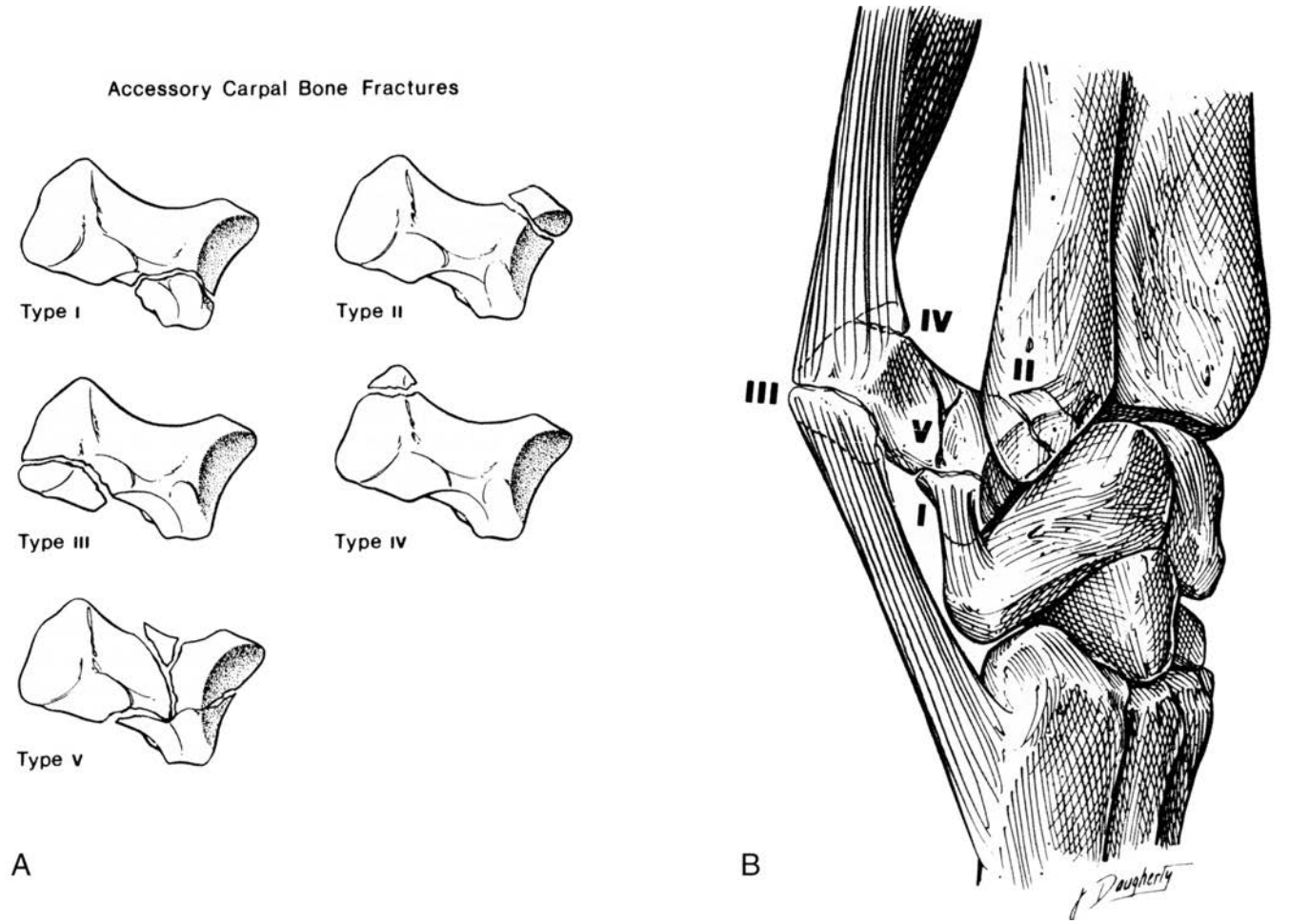


Figure 58-1. Classification scheme of accessory carpal bone fractures, depicted on the right bone. (From Johnson KA and Piras A: Fractures on the carpus. In Johnson AL, Houlton JEF, Vannini R, eds.: AO Principles of Fracture Management in the Dog and Cat. Davos Platz: AO Publishing: 341, 2005.)

Type II

Injuries are avulsion fractures of the proximal margin of the articular surface and involve bone at the insertion of the palmar ulnocarpal and radial carpal ligaments that connect to the caudomedial surface of the distal ulna and the caudal surface of the distal radius. They are often associated with a type I injury. Like type I injuries, they allow subluxation, and articular cartilage damage and secondary osteoarthritis are sequelae.

Type III

Injuries are avulsion fractures of the distal surface of the palmar end of the bone, at the origin of the two large accessory-metacarpal ligaments that connect to metacarpal bones IV and V. Such injuries disrupt the stay apparatus provided by the accessory-metacarpal ligaments that normally counteract carpal hyperextension during full weight- bearing.

Type IV

Injuries are strain-avulsion fractures of bone from the proximal surface of the palmar end of the bone, at the tendon of insertion of the flexor carpi ulnaris muscle. Bone fragments are distracted proximally by the flexor tendon. The fracture may be an apophyseal avulsion in dogs up to 5 months of age.

Type V

Injuries include all other fractures of the carpal body, and these fractures may be comminuted or intra-articular. Fractures may be in a longitudinal, sagittal, or transverse plane, dividing the bone into two or more fragments.

Treatment and Prognosis of Fractures

Screw Fixation

Open reduction and internal fixation with screws are indicated in certain type I, II, and III injuries with large, noncomminuted bone fragments (Figure 58-2).[7,8] The aims of treatment are restoration of ligamentous integrity and the prevention of subluxation and secondary osteoarthritis. Dogs are positioned in lateral recumbency with the affected limb uppermost for surgery. A skin incision, 5cm long, is made palmarolateral to the carpus.[9] The palmar carpal retinacular fascia is incised to expose the accessory carpal bone and supporting ligaments. The abductor digiti quinti muscle is elevated and is retracted medially from the accessory-metacarpal IV and V ligaments. A lateral arthrotomy of the accessory-ulnar joint is performed to allow inspection of the articular cartilage surface and accurate reduction in type I and II injuries. Small pointed AO/ASIF forceps are used to maintain reduction (Figure 58-3). Lag screw fixation is with 1.5 or 2.0 mm cortical screws (Figure 58-4). If

the fragment is thin, countersinking is not performed. The drill hole should be measured and tapped completely to minimize the risk of screw breakage, an occasional problem with 1.5 mm screws.

The internal fixation is protected with a palmar fiberglass slab splint for 4 to 6 weeks after surgery. Initially, the carpus is immobilized in slight flexion, but then it is moved progressively to a more extended position. Radiographs are taken at 6 and 12 weeks postoperatively to monitor fracture healing.

One study of 12 greyhounds with fractures treated by internal fixation found that 10 returned to racing, and five of those won one or more races.[7] Animals with type I and II fractures are expected to have a worse prognosis because these fractures are intra-articular, but further studies are needed. Although internal fixation of these fractures seems more logical, this operation is technically demanding, and some fracture fragments are simply too small to permit screw fixation, so excision becomes unavoidable.

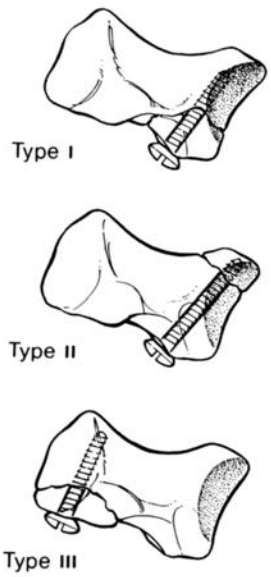


Figure 58-2. Screw fixation of fracture types I, II, and III. (From Johnson KA, Dee JF, Piermattei DL Screw fixation of accessory carpal bone fractures in racing greyhounds: 12 cases (1981 -1986). J Am Vet Med Assoc 1989;194:1618-1625.)

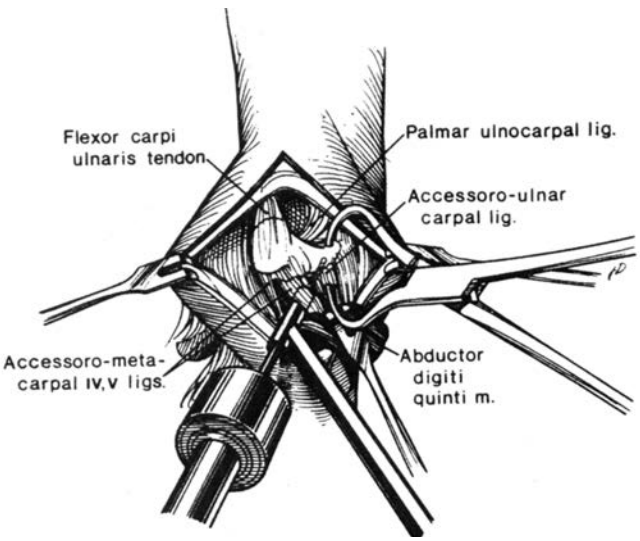


Figure 58-3. Reduction of a type I fracture with pointed reduction forceps and drilling a I. I hole for screw fixation. (From Johnson KA, DeeJF, Piermattei DL Screw fixation of accessory carpal bone fractures in racing greyhounds: 12 cases (1981-1986). J Am Vet Med Assoc 1989; 194:1618-1625.)

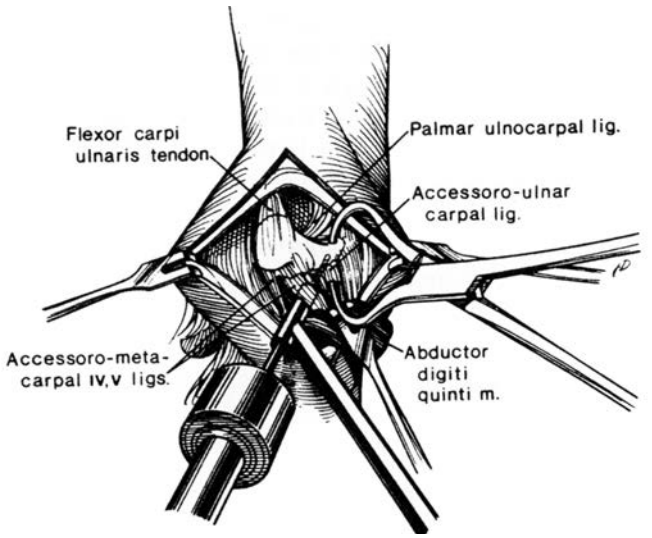


Figure 58-4. Fixation of a type I fracture with a 1.5-mm cortical screw. (From Johnson KA, Dee JF, Piermattei DL. Screw fixation of accessory carpal bone fractures in racing greyhounds: 12 cases (1981 -1986). J Am Vet Med Assoc 1989; 194:1618-1625.)

Fragment Excision

Removal of avulsed fracture fragments is an alternative treatment for type I and II fractures. Access for fragment excision is a limited lateral approach, similar to that used for lag screw fixation. Fragments are usually found attached to the accessory-ulnar ligament of the joint capsule, and they are excised with a No. 11 or 15 scalpel blade.

No attempt is made to suture the damaged ligament or capsule after fragment excision, and healing proceeds by fibroplasia. Without surgical treatment, type I and II fractures do not naturally heal by bony union, and often they damage the articular cartilage on the ulnar carpal bone. When internal fixation is not possible, fragment excision perhaps may be preferable to nonsurgical management, but further studies are needed. One study in Scotland found that, of 19 racing greyhounds that had type I fragments removed, 13 returned to race and nine won races. Of the other six, three became sound but were unable to race, whereas the other three remained lame.[10]

External Coaptation

For comminuted fractures that are not amenable to internal fixation and for minimally displaced fractures in young dogs, immobilization of the carpus in flexion is indicated. Malunion of the fracture may be well tolerated unless the fracture is intra-articular.

Partial Arthrodesis

Animals with hyperextension injuries confined to the accessory-ulnar joint frequently have concurrent type I and II fractures of

the accessory carpal bone. A partial carpal arthrodesis of this joint may stabilize the carpus while preserving motion in the antebrachiocarpal joint.[11] The surgical approach is similar to that used for fracture repair by internal fixation. After the joint is opened, articular cartilage is removed, the space is bone grafted, and a lag screw is placed in a palmarodorsal direction from the accessory carpal bone into the ulnar carpal bone. Additional support is provided by a cerclage wire from the palmar pole of the bone, down to the fifth metacarpal bone.

References

1. Johnson KA: Accessory carpal bone fractures in the racing greyhound: Classification and pathology. Vet Surgery 17:60, 1987.

2. Johnson KA, Dee JF, Piermattei DL: Screw fixation of accessory carpal bone fractures in racing greyhounds Twelve cases (1981 1986). J Am Vet Med Assoc 194:1618, 1989.

3. Guilliard MJ: Accessory carpal bone displacement in two dogs. J Small Anim Pract 42:603, 2001.

4. Johnson KA and Piras A (2005) Fractures on the carpus. In Johnson AL, Houlton JEF, Vannini R, eds.: AO Principles of Fracture Management in the Dog and Cat. Davos Platz: AO Publishing, 2005, p 341.

5. Chico AC: Characteristics of accessory carpal bone fractures: 25 cases. Proceedings 12th European Society of Veterinary Orthopaedics and Traumatology, Munich, 2004.

6. Boemo CM: Fracture of the accessory carpal lateral articular prominence in a racing ground. Aust Vet Pract 24:70, 1994.

7. Johnson KA, Piermattei DL, Davis PE, et al.: Characteristics of accessory carpal bone fractures in 50 racing greyhounds. Vet Comp Orthop Traumatol; 2:104, 1988.

8. Johnson KA: Carpal injuries. In Bloomberg MS, Dee JF, Taylor RA, editors. Canine Sports Medicine and Surgery. Philadelphia: WB Saunders 1998, p 100.

9. Piermattei DL and Johnson KA: An Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat. Fourth edition. Philadelphia: Saunders, 2004.

10. Chico AC: Accessory carpal bone fracture in greyhounds: assessment of prognostic indicators and outcome following surgical management by fragment removal. M Vet Med thesis, University of Glasgow, 1992.

11. Lenehan TM, Tarvin GB: Carpal accessorioulnar joint fusion in a dog. J Am Vet Med Assoc 194:1598, 1989.

Surgical Treatment of Injuries to the Antebrachial Carpal Joint and Carpus

Alessandro Piras and Jon F. Dee

Introduction

The carpus is a complex joint composed of seven bones arranged in a proximal row of three bones and a distal row of four bones. The radial carpal bone is the medial bone of the proximal row. It is the largest of the carpal bones and articulates with the radius. The lateral bone of the proximal row is the ulnar carpal bone and articulates with the ulna and with the radius. The accessory carpal bone is located on the palmaro lateral aspect of the proximal row and articulates with the ulnar carpal bone and with the ulna styloid process. The four carpal bones of the distal row are named from medial to lateral as I, II, III, and IV.

Three joint levels are present: the antebrachiocarpal joint between the distal end of the radius and ulna and the proximal row of carpal bones, contributing 70% of the carpal motion; the middle carpal joint is between the proximal and distal row of carpal bones and contributes 25% of total carpal motion; and the carpo-metacarpal joint between the distal row of carpal bones and the bases of the metacarpal bones that contributes only 5%.

The carpal joint is a complex ginglymus joint that allows movements of extension, flexion, internal and external rotation, a few degrees of valgus, varus and a few millimeters of translation in the palmaro dorsal direction. Several ligaments join the various bones at different levels. The dorsal ligaments are quite thin and join the adjacent bones individually, the palmar ligaments are thicker and are in part embedded in the robust palmar fibrocartilage that attaches to the palmar aspect of the carpal bones and to the bases of the metacarpal bones (with the exception of the accessory carpal bone). This structure provides a strong support to the palmar aspect of the carpal joint and is constantly under tension. The collateral ligaments are strong, especially the medial ligament that is constantly under tension due to a normal five degrees of carpal valgus that is present. Unlike the tarsus, the collateral ligaments span only one joint level. The joint capsule separates the antebrachiocarpal joint from the middle carpal and carpo-metacarpal joints, creating two separated compartments. The types of carpal injuries include sprain, hyperextension, luxation and fracture.

Clinical Examination

Carpal fractures are usually avulsion fractures of ligaments (origin or insertion) and tendon insertions or the result of the combination of shearing and compressive forces acting on the bones during hyperextension. Most of these fractures are intra articular with few exceptions.

The clinical examination consists of palpation to localize pain, soft tissue swelling, crepitus and joint instability. The range of motion of the joint should be tested in flexion and extension. Additional maneuvers include internal or external rotation of the carpal joint while in extension or 90 degrees of flexion. Cranial translation is evaluated with the carpus in 90 degrees of flexion. Both are useful tests for an accurate evaluation of joint stability. In cases in which carpal damage is suspected, but the injury cannot be localized, it is useful to apply a well padded compressive bandage, supported by a palmar meta-splint, prescribe an anti-inflammatory and rest. After two or three days, re-examine the patient, the decrease in soft tissue swelling will facilitate the examination.

Radiographic Examination

Radiographic examination of the carpus starts with routine views. However, due to its anatomical complexity, injuries may be obscured by the superimposition of the different bony structures. In order to make or confirm the diagnosis of a suspected injury, supplemental or additional radiographic views are often required.

Additional radiographic views often consist of special projections such as flexed or extended oblique views and stress views.

Stress projections, are views taken during "the application of controlled force to a joint to demonstrate abnormal spatial relationship between two or more of its components"(Farrow 1982). Stress views can be obtained by application of shear, traction, wedge and rotatory maneuvers. When ligamentous injuries are suspected, stress views are invaluable in demonstrating the presence of subluxation, joint instability, or in evaluating the location and size of avulsed fragments.

A variation of stress views are; the weight bearing views, taken with the dog in standing position and the x-ray beam in horizontal position in respect to the weight bearing limb. Adequately exposed radiographs are essential and high detail screens, such as rare earths and mammography mono-emulsion films are recommended to achieve fine detail. Whenever doubts about the radiographic anatomy exist it is helpful to x-ray the contra-lateral normal limb for comparison. In cases of hairline or incomplete fractures is useful to repeat the x-ray in a week so that osteolysis can highlight the fracture line.

Routine Projections

Medio-Lateral (ML) views and Dorso-Palmar (DP) views

Additional Projections

Dorso-Lateral Palmaro-Medial Oblique 45 degrees (DLPMO);
Dorso-Medial Palmaro-Lateral Oblique 45 degrees (DMPLO);
Medio-Lateral Flex (ML-Flex): this view is helpful to evaluate the dorsal articular margin of the radius, the dorsal surface of the radial carpal bone and the articular surface of the accessory carpal bone.

Stress Views

Hyperextended ML views are very useful to evaluate palmar instability, subluxation of the radial carpal bone, subluxation of the proximal carpal joint, subluxation and luxation of the carpo-metacarpal joints and fractures affecting the accessory carpal bone.

DP views with application of lateral or medial stress: very helpful views in case of suspected collateral instability, damage to the collateral ligaments with avulsed fragments from the styloid process, subluxation of the second carpal bone, carpo metacarpal collateral instability.

Dedicated Views

Specific radiographic views are sometimes necessary to critically evaluate some of the carpal bones or the dorsal articular margin of the radius and the ulnar styloid.
Palmaro-Lateral Dorso-Medial hyper flexed oblique view (PLDM-Flex)
Palmaro-Medial Dorso-Lateral hyper flexed oblique view (PMD-Flex). (Figure 58-5A, B, and Figure 58-6).

Skyline or tangential views are invaluable for a complete evaluation of the dorsal aspect of the radius. This view, with other views, can confirm the presence of a fracture or chip affecting this region. Incomplete fractures and small chips can sometimes be detected only with the aid of this view (Figure 58-7, and Figure 58-8A and B).

Treatment Principles

Complex fractures of the carpal bones are associated with ligament damage, severe comminution, and variable degrees of subluxation. Therefore, careful preoperative planning should consider the type of fracture in relation to the age, breed and the expected level of physical activity of the dog, the level of expertise of the surgeon and the availability of mini implants; after reviewing these considerations, arthrodesis may be the best choice. Open reduction and internal fixation is the treatment of choice to achieve results compatible with normal joint function. Carpal fractures are usually treated with K wires and tension-band wiring, or lag screw fixation. In case of non surgical treatment, as for any other intra-articular fracture, the development of osteoarthritis due to fracture instability is expected.

Fractures of the Radial Carpal Bone (RCB)

Fractures of the body of the RCB are uncommon injuries and are

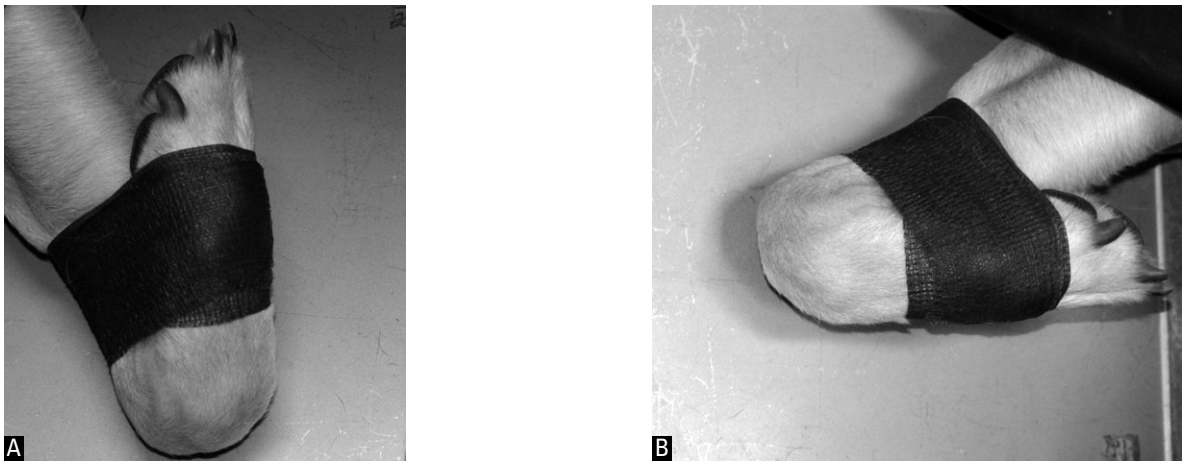


Figure 58-5. A. and **B.** PLDM- Flex **A.** PMDL-Flex **B.** The carpus is in direct contact with the x-ray cassette. Position the limb at an angle that may vary from 30 to 45 degrees.

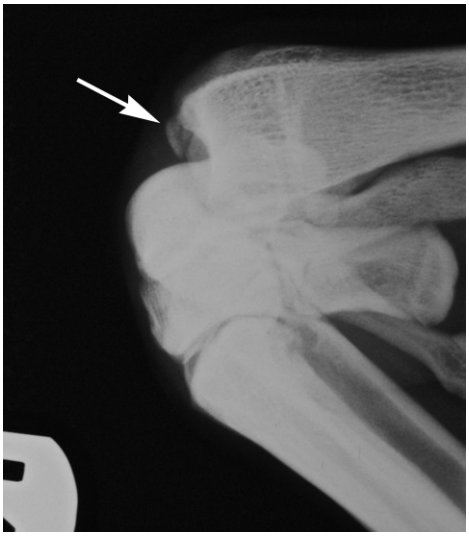


Figure 58-6. PLDM-Flex view showing a chip fracture of the dorsal articular margin of the radius (white arrow).



Figure 58-7. Lock the wrist at the maximum degree of flexion that is possible and secure it with a strip of tape. With the dorsal aspect of the distal row of carpal bones in direct contact with the x-ray cassette, position the beam tangent to the dorsal articular margin of the distal radius with an angle that can vary between 40 to 60 degrees. Two or three views are obtained at different angles to allow a complete study of the region.

usually caused by compressive forces during hyperextension of the carpal joint. Different types of fractures have been identified: midbody saggital, saggital oblique (this fracture can be either complete with displacement or a hair-line fracture), comminuted or "Y" shaped composed generally of three fragments; and fracture of the dorsal margin (usually a small chip) (Figure 58-9).

Midbody fractures are often incomplete and have been described in racing Greyhounds. Some authors suggest that these fractures are more common in the right leg (Dee, personal communication: 6 cases) but insufficient numbers exist to completely define this type of predisposition. Overall, the clinical signs are variable. With complete fractures, the dog is lame and often non-weight bearing on the limb. Joint swelling, pain upon palpation, crepitation, and decreased range of motion in flexion is usually present. With hairline fractures, the diagnosis can be very difficult as this type of injury is subtle, showing minimal clinical signs, minimal joint effusion, and pain only on forced flexion. Radiographic examination consists of Dorso-Palmar (DP) and Medio-Lateral (ML) views. In addition to the routine views, PMDL-Flex, PLDM-Flex, Dorso-Palmar oblique, and Skyline views are recommended.

With incomplete fractures, the fracture line may not be detectable for several weeks, until bone resorption creates some widening at the fracture line. These fractures are intra-articular and are treated with open reduction and internal fixation. According to the type, the fracture can be approached surgically either with a standard dorsal or a palmaro-medial approach or a combination of the two.

Midbody fractures are accurately reduced and stabilized with lag screws, generally 1.5, 2.0 or 2.7 mm cortical, inserted from the palmaro-medial aspect of the bone in an oblique dorso-lateral direction. Accurate countersinking of the screw head and precise measurement of the screw length are vital to avoid interference of the implant with adjacent bones or soft tissues (Figure 58-10).

Some authors suggest that "Y" shaped fractures of the RCB that occur without a history of trauma share a common etiopathogenesis. Considering that the two main fracture lines recognized on radiographs and CT scan correspond approximately to

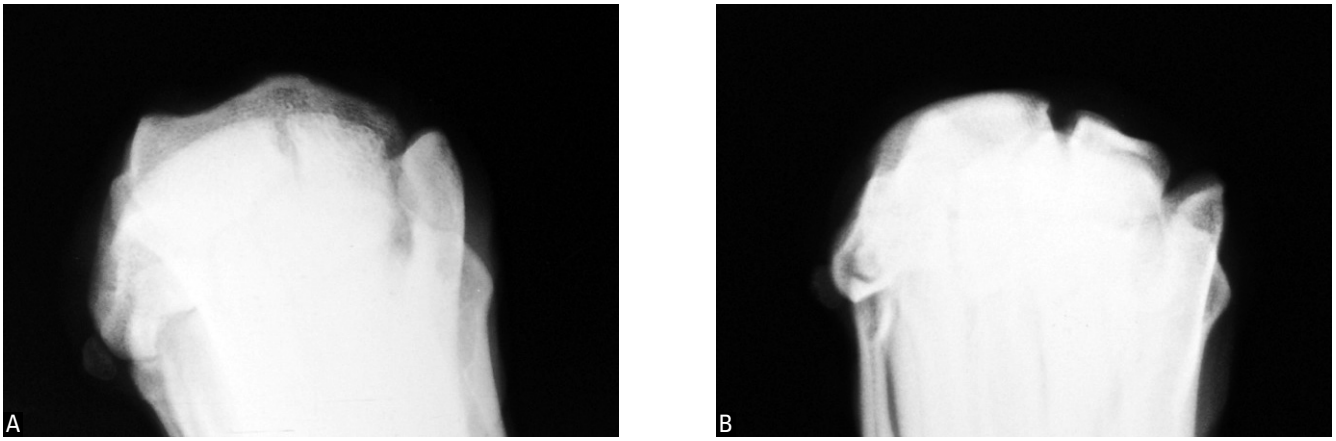


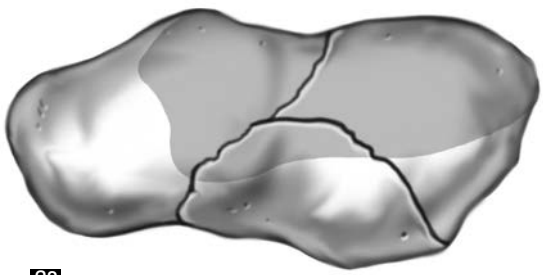
Figure 58-8. A. Skyline view at 60 degrees shows the contour of the dorsal articular margin of the radius and the articular portion of the ulnar styloid. **B.** 40 degree skyline view shows the dorsal surface of the radial carpal bone and the ulna carpal bone.













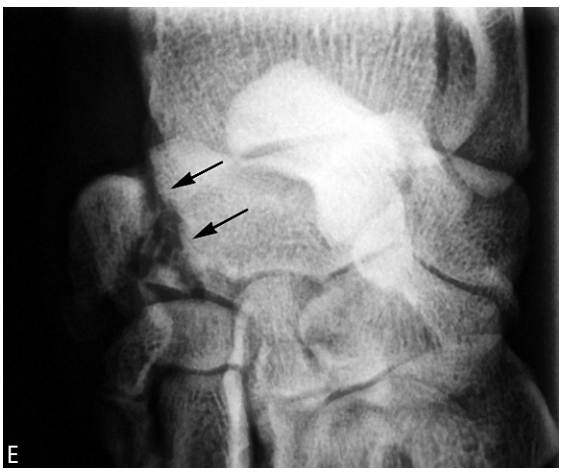


Figure 58-9. Different types of fractures of the radial carpal bone: **A.** saggital oblique; **B.** hair-line fracture); **C1, C2.** comminuted or "Y" shaped generally composed of three fragments, **C3**. This schematic of the left radial carpal bone illustrates the typical pattern of a three piece fracture; **D.** chip fracture of the dorsal aspect of the bone; **E.** fracture of the palmar process.

the fusion planes of the three ossification centers of the bone, it has been hypothesized that an incomplete fusion of these areas predisposes to this injury. According to these authors, the breeds most commonly represented are the Boxer, Labrador Retriever, English Setter, English Springer Spaniel and Pointer. These breeds often present with bilateral involvement. In acute cases, an attempt at fixation can be made using two 1.5 or 2.0 mm lag screws inserted from the dorsal fragment to engage the medial and the lateral fragments (Figure 58-11). Due to the nature of these fractures they tend to respond poorly to internal fixation. The fragments are prone to non-union with resulting implant failure and subsequent osteoarthritis. In most of the cases, these fractures are best managed with pan-carpal arthrodesis.

Fracture of the palmar process has been described as a sprain avulsion of the palmar radial carpo-metacarpal ligament. This injury is treated with open reduction and internal fixation using lag screws or K-wire and tension band wire techniques (Figure 58-12).

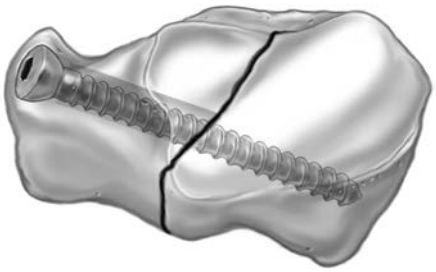


Figure 58-10. A midbody fracture of a left radial carpal bone is repaired with a 2.7 mm cortical screw, inserted from the palmaro-medial aspect of the bone in an oblique palmar-lateral direction. The head of the screw is countersunk and the screw is just a few millimetres shorter than the measured length to avoid protruding from the bone.

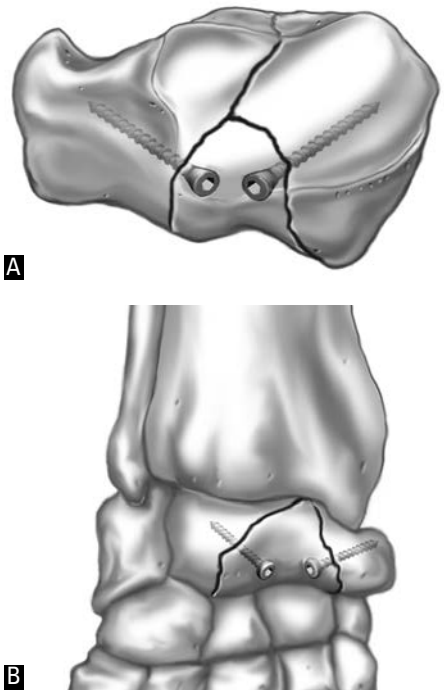


Figure 58-11. A. and **B.** A three fragment fracture is repaired using two 2.0 mm lag screws inserted from the dorsal fragment to engage the medial and the lateral fragments. The screws heads are well countersunk.

Dorsal RCB chip fractures are extremely common in racing Greyhounds consisting in most cases of a small chip. They are likely the result of impingement of the distal dorsal margin of the radius over the RCB during hyperextension of the joint. The history is variable with the trainer reporting poor performance and the dog "checking" and running wide in the turns. Lameness, when present, usually appears following intense exercise and tends to disappear within 12 hours. Clinical examination usually reveals pain with flexion. Joint effusion can be minimal to absent. Direct finger pressure on the dorsal aspect of the carpus does not necessarily elicit a pain response. Diagnostic radiographic views are usually the medio-lateral and medio-lateral oblique. In many cases, skyline views are of invaluable help to define three dimensionally the fragment location, thus decreasing the size of the surgical approach and the surgical time. With small chip fractures surgical removal is the treatment of choice. Larger slabs can be reduced and stabilized with 1.0 or 1.5 mm screws applied in a lag fashion, while insuring that the screw head is well countersunk.

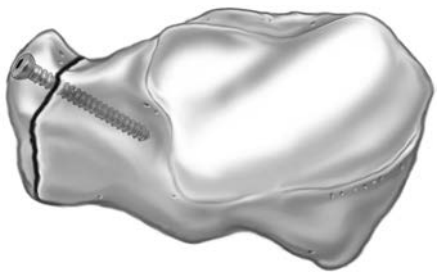


Figure 58-12. A fracture of the palmar process is repaired with a 1.5 mm lag screw inserted in a palmar lateral direction. The head of the screw is deeply countersunk in the palmar process of the bone.

Fractures Of The Other Carpal Bones

Ulnar Carpal Bone

Complete fractures are very rare, however they have been observed in conjunction with other carpal fractures and luxations, as well as an isolated fracture. Fractures affecting the palmar component are quite difficult to diagnose with routine radiographic views. In addition to routine views the PMDL- Flex view offers an excellent visualization of the palmar aspect of the bone (Figure 58-13). Treatment consists of stabilization of the fragment with a lag screw inserted in palmaro dorsal direction.

Dorsal chip fractures are more common and are often detected as an incidental finding. They share the same etiopathogenesis, diagnostic approach and treatment as the RCB dorsal chip.

Second and Third Carpal Bones

These uncommon and isolated fractures usually consist of a very small chip or a dorsal slab. In addition to routine radiographic views, ML-Flex, Semi Flex views and either standard and/or oblique are recommended.

Treatment consists of surgical excision of the small chips and lag screw fixation for larger dorsal slabs.



Figure 58-13. The Palmaro-Medial Dorso-Lateral-Flex view offers an excellent visualization of a fracture of the palmar aspect of the ulnar carpal bone.

Post Operative Considerations

Following surgical repair of the fracture, the carpus is supported with a padded bandage and a palmar splint from 2 to 4 weeks according to the severity of the injury. Restricted and controlled activities are maintained until radiographic signs of healing are evident. Avoid prolonged immobilization of the carpus and promote early physiotherapy. In case of chip removal apply a light padded bandage to decrease postoperative swelling. The bandage is usually removed after a week and physiotherapy is started after 2 weeks.

Fractures of the Distal Radius and Ulna

Fractures of the Radial Styloid

These are uncommon intra-articular fractures. They are avulsion sprain fractures of the origin of the short radial collateral ligament. Normally the short radial collateral ligament provides medial stability for the antebrachiocarpal joint in both flexion and extension. This ligament has two components originating on a tubercle on the styloid process and inserting respectively on the medial (straight portion) and palmaro-medial (oblique portion) aspects of the radial carpal bone.

Clinical signs include variable degrees of lameness according to the severity of the injury, soft tissue swelling (usually diffuse around the carpal region), and pain upon palpation and manipulation of the area.

Treatment Principles

These fractures are treated by open reduction, accurate anatomical realignment and internal fixation. The surgical exposure is made with a longitudinal incision directly over the styloid process. In case of a larger fragment, a dorsal approach to the carpal joint can be combined to evaluate the quality of fracture reduction.

Several fixation techniques have been described, including K wires with a figure-of- eight tension band wire for the small fragments, or multiple divergent K wires or lag screws and anti rotational K wires for larger fragments. Very small fragments can be excised (Figure 58-14A, B, Figure 58-15 and Figure 58-16).

When inserting K wires, it is always advisable, in order to achieve better stability, to drive them from the fragment across the metaphyseal bone into the far cortex.

Fractures of the Ulnar Styloid

The ulnar styloid process, in association with the radial styloid, buttresses the proximal carpal bones. The short ulnar collateral ligament, the radio-ulnar ligament, and the palmar ulno-carpal ligament, originate on the ulnar styloid, providing lateral and palmar stability for the joint. Fractures of the ulnar styloid can be divided into two types: fractures affecting the proximal portion of the styloid, (usually 1 to 3 cm from its distal end) and fractures of the distal portion characterized by a small avulsed fragment.

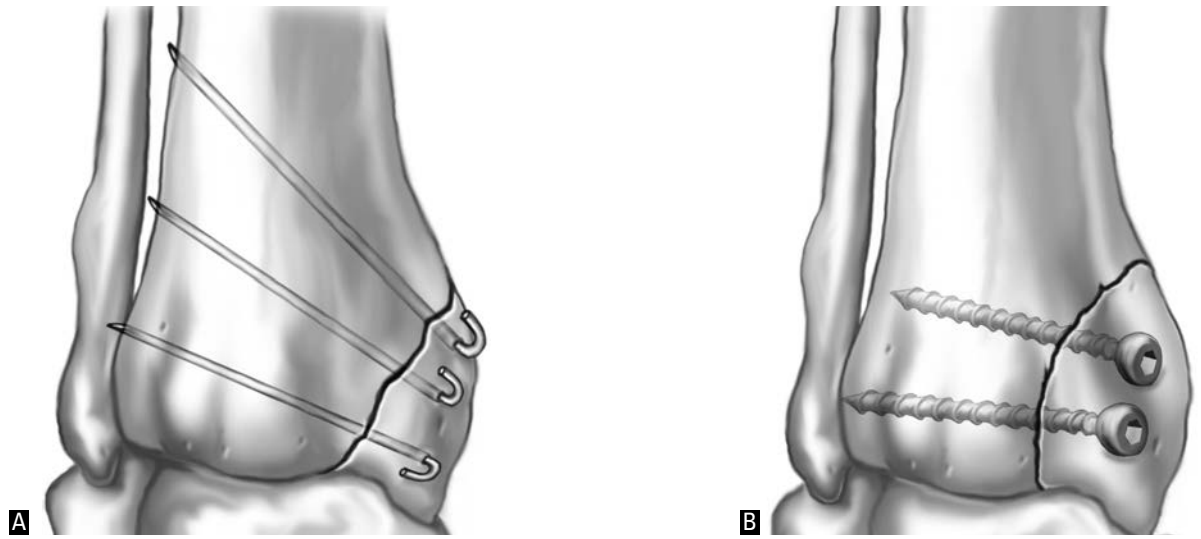


Figure 58-14. A. A fracture of the radial styloid process is repaired with three divergent K wires. This form of repair can be acceptable in small patients but does not guarantee a stable fixation. **B.** The same type of fracture repaired with two lag screws provides superior stability and a better prognosis.

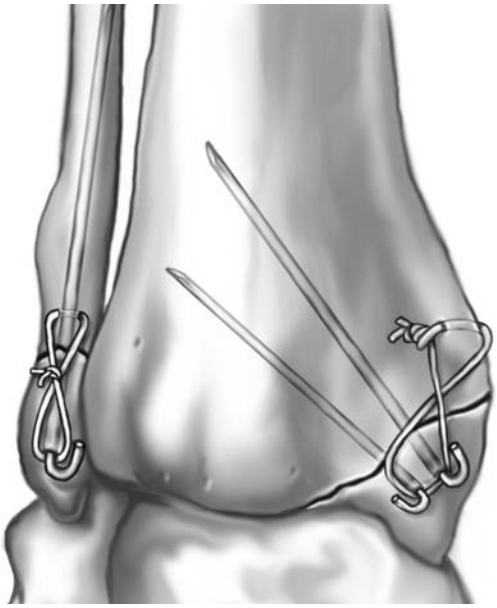


Figure 58-15. A fracture of the radial styloid process is repaired with two K wires and a figure- of- eight tension band wire. A fracture of the ulnar styloid is repaired with a similar technique.

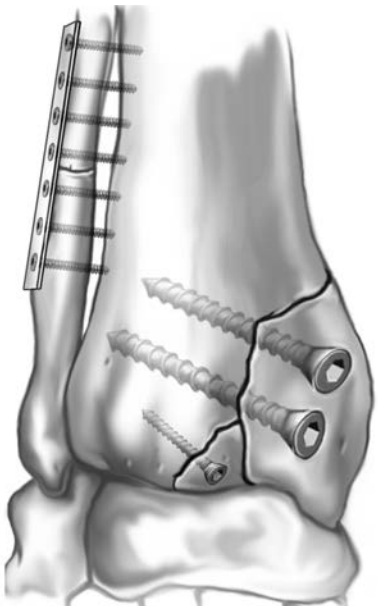


Figure 58-16. A comminuted fracture of the radial styloid is repaired with two lag screws, the small dorsal fragment is repaired with a 1.5 mm lag screw. An extra articular fracture of the distal ulna is repaired with a Veterinary Cuttable Plate applied on the lateral aspect of the bone. Care should be taken to avoid excessive protrusion of the screw tips.

Ulnar styloid fractures are not necessarily intra-articular and if incomplete, can be treated conservatively with external coaptation. Complete fractures can be associated with antebrachiocarpal subluxation, luxation of the radial carpal bone, or accompanied by fracture of the radial styloid; in any case they require open reduction and internal fixation.

Technique of choice is generally K wires with a figure-of-eight tension band wire for distal fractures and IM pinning or a small lateral plate (2.0/2.7 mm VCP or DCP) for more proximal fractures (See Figures 58-15 and 58-16).

Post Operative Considerations

A post operative bandage is recommended to support the repair of styloid fractures, with restricted and controlled activity maintained until radiographic signs of healing are evident. Implants are left in situ unless they become loose or are irritating the soft tissues.

Fractures of the Dorsal Articular Margin of the Distal Radius

Fractures of the distal articular radius can involve the central or lateral portions of the articular surface. As with any other intra articular fracture, open reduction and rigid, "gap free" internal fixation is preferred. This fracture of the dorsal articular margin of the radius was first described in racing Greyhounds by Ferguson (1986). Although not common in the pet population, it has been described in sporting breeds. The following information on this injury is focused on the racing Greyhound. This fracture is most commonly located at the origin of the dorsal radiocarpal ligament that joins the dorsal articular margin of the radius with the ulna carpal, is probably caused by a combination of compressive and torsional forces during hyperextension of the carpal joint. The history can be subtle; usually the trainer reports the dog "checking" in the turns and running wide. The lameness affects the dog for the first 24/36 hours after a trial or race but the dog is weight bearing. Generally, after a few days the dog seems to be normal but is lame again after a gallop or a trial. The clinical examination reveals pain in flexion, as well as on internal or external rotation of the carpus. Cranial translation with the joint at 90 degrees of flexion elicits a pain response. Swelling is not a constant finding and identifying the lesion by the application of direct pressure does not necessarily evoke a pain response. Radiographic examination consists of multiple views including standard and oblique views. Some authors describe the straight medio-lateral as the best diagnostic view. The radiographic findings of 150 cases have been compared to determine the location and type of injury and the sensitivity of standard lateral, dorso palmar and oblique views compared with skyline (tangential) views. The results of this unpublished study suggest that there are four types of lesions that can be described and that the skyline view is, in some cases, the only diagnostic view allowing identification and location of the injury. When available, CT scan is the tool of choice due to its superior diagnostic sensitivity. On the basis of the radiographic and surgical findings, four main lesion patterns are recognized. The first type consists of chondromalacia and erosion in the area of the origin of the dorsal radio-carpal ligament. The second type is an incomplete mono-cortical fracture, usually perpendicular to the dorsal articular margin, entering the joint for a few millimeters. The third type is a fracture avulsion of the origin of the radio-carpal ligament consisting of one fragment, or multiple small fragments, ranging from 2 to 6 mm in size. The fourth type is a dorsal slab fracture, which is usually complete and non-displaced, varying in size from 1 cm to a large slab (Figure 58-17A, B, C, and D). The fracture is exposed with a small incision made, between the extensor carpi radialis and the common digital extensor tendon. Surgical removal of small fragments by curettage and/or lag screw fixation of larger or incomplete fractures, offers the best prognosis (Figure 58-18 and Figure 58-19). Removing the small

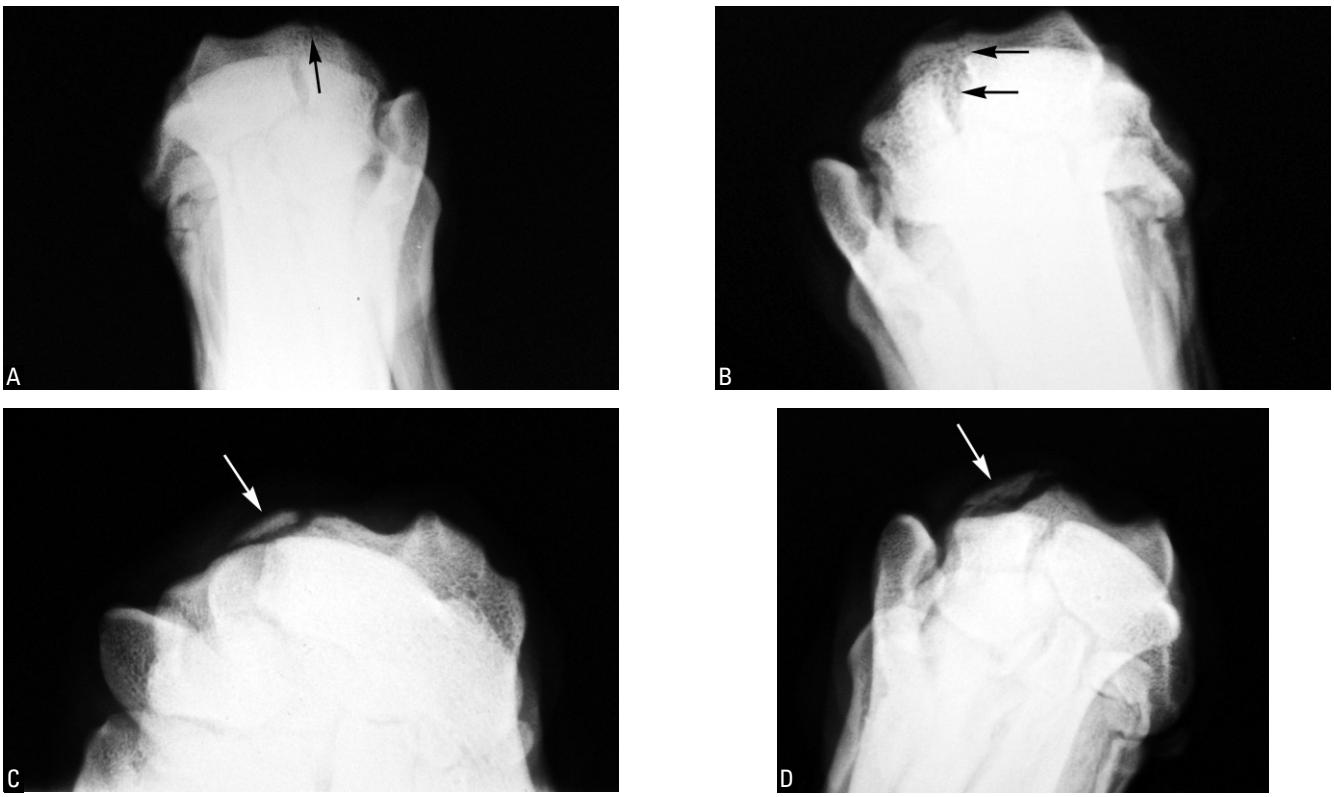


Figure 58-17. A. Type I: chondromalacia and erosion at the origin of the dorsal radio-carpal ligament that appears usually thickened and partially damaged. A skyline view illustrates the erosion of the dorsal articular margin. **B.** Type II: An incomplete mono-cortical fracture line, usually perpendicular to the dorsal articular margin. It enters the joint for a few millimeters. A skyline view of this lesion is shown with an arrow pointing to the fracture line. **C.** Type III is a fracture avulsion of the origin of the dorsal radio-carpal ligament consisting of one fragment as shown by this skyline view. **D.** Type IV is a dorsal slab fracture, usually complete and non-displaced. Skyline view of the same lesion.

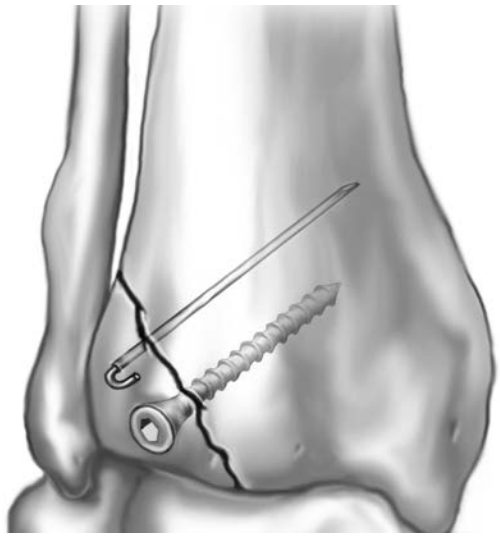


Figure 58-18. A fracture of the dorsal articular margin of the radius is repaired with a 2.0 mm lag screw and a K wire. The head of the screw is well countersunk. In case the K wire is interfering with soft tissue it can be cut flush to the bone surface.

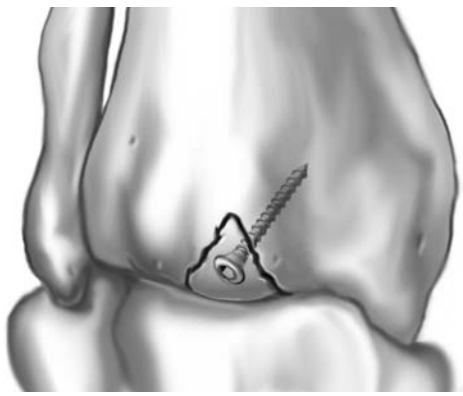


Figure 58-19. A chip fracture of the dorsal articular margin is repaired with a 1.5 mm lag screw. Aggressive countersinking should be avoided to prevent splitting of the small fragment.

fragments creates damage to the dorsal radio-carpal ligament that heals by formation of fibrous tissue. The involvement of this small ligament in the etiopathogenesis of this type of fracture and its role in the joint's stability is yet to be clarified.

Post Operative Considerations

After the surgery a light bandage is applied on the carpus for 10 days. After suture removal, a light bandage is reapplied for another 15 days and light exercise and physiotherapy are encouraged. The dog is expected to restart training between 6 and 10 weeks after surgery.

Suggested Readings

Johnson KA: Carpal Injuries. In: Canine Sports Medicine and Surgery. Bloomberg MS, Dee JF, and Taylor RA eds. W.B. Saunders Company, 1998, 100-119.

Johnson KA, Piras A: Fractures of the Carpus. In: AO Principles of Fracture Management in the Dog and Cat. Johnson AL, Houlton JEF, and Vannini R eds. AO Publishing 2005, 341-348.

Li A, Bennett D, Gibbs C, Carmichael S, et al: Radial carpal bone fractures in 15 dogs. JSAP 41(2):74, 2000.

Tomlin JL, Pead MJ, Langley-Hobbs SJ, et al: Radial carpal bone fracture in dogs. JAAHA 37(2):173, 2001.

Boemo CM: Chip fractures of the dorsal carpus in the racing greyhound: 38 cases. Aus Vet Practit 23:139, 1993.

Partial Carpal Arthrodesis

Thomas Van Gundy

The purpose of partial carpal arthrodesis is to provide a bony union across the carpometacarpal, middle carpal, and intercarpal joints. Indications for this procedure include luxation, subluxation (e.g., hyperextension injury), chronic instability resulting in degenerative joint disease, intra-articular nonunion, and arthritis (septic or immune-mediated) not responsive to medical treatment. The antebrachiocarpal joint must be stable and pain free. Stability is assessed by palpation and stress radiography. Instability and subluxation of the accessory-ulnar carpal joint complicate partial carpal arthrodesis, making pancarpal arthrodesis the procedure of choice.

The animal is placed in dorsal recumbency. The limb is prepared for surgery. Proper use of a temporary tourniquet fashioned of wide Penrose drain or elastic bandage material facilitates the surgical procedure. Access to the joints involved is gained through a cranial approach. The skin incision is offset, to avoid overlying bone plates directly. The middle carpal, intercarpal, and carpometacarpal joints are opened with full carpal flexion, and the cartilage surfaces removed using an air-powered bur and rongeurs. The joints are then lavaged thoroughly and are placed in extension (neutral alignment of carpal and metacarpal bones) and stabilized. Preferred stabilization uses a cranially applied T or L plate with screws in the radial carpal, intercarpal (if possible), and metacarpal bones. A single plate overlies the proximal third or fourth metacarpal bone (Figure 58-20). Larger dogs may have two opposite-angle L plates applied, allowing screw purchase in the radial and ulnar carpal bones and both central metacarpal bones (Figure 58-21). Proper plate and screw placement is crucial to avoid impingement of screws or plates on the antebrachiocarpal joint. Cancellous bone graft harvested from the ipsilateral humerus is liberally packed into all joints to be fused, and overlying tissues are closed in a routine manner. An alternative method of fixation uses intramedullary Kirschner wires placed in retrograde fashion from the distal dorsal surfaces of the second, third, fourth, and fifth metacarpal bones, seating into the radial and ulnar carpal bones (Figure 58-22).

Postoperative radiographs (including stress views) determine implant placement and the need for further implant removal if antebrachiocarpal joint impingement is noted. Postoperative management includes 6 weeks in a cast or splint and implant removal at the time of bony fusion if clinically indicated.



Figure 58-20. A T plate is applied to the dorsal aspect of the left carpus with two bone screws seated in the radial carpal bone, one in carpal bone III and two in the proximal aspect of metacarpal III.

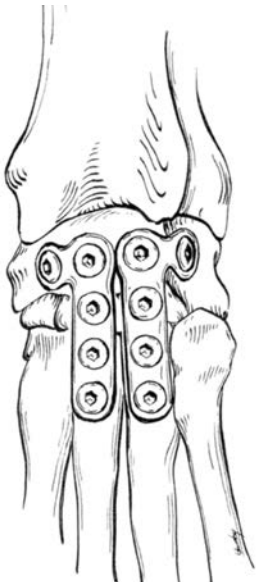


Figure 58-21. Paired 2.7-mm L plates are applied to the dorsal aspect of the left carpus. With this technique, two carpal bones are secured with screws, and the lateral plate spans the radial and ulna carpal bones. A total of four screws may purchase in metacarpal bone.

Proper patient selection and procedure are paramount for success. Insufficient evaluation of a pathologic antebrachiocarpal joint may allow progressive hyperextension and may require subsequent pancar-pal arthrodesis. Careful radiographic comparison of the accessory-ulnar carpal bone articulation with normal stress radiographs is helpful. Proper placement of implants can be facilitated by careful antebrachiocarpal joint arthrotomy to visualize radial and ulnar carpal bone geometry. Persistent lameness may require re-evaluation of implant placement or of antebrachiocarpal joint disease.

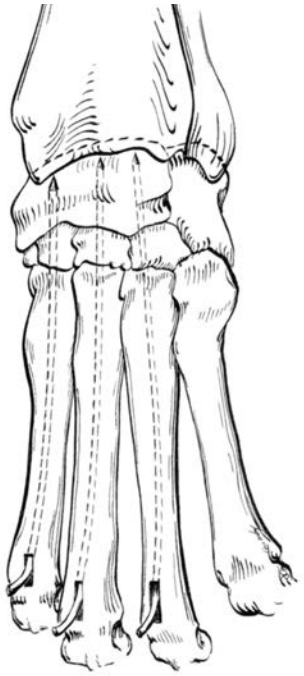


Figure 58-22. Kirschner wires are used with this technique by retrograde placement. The wires are started from an extra-articular position just proximal to the metacarpophalangeal joint. The points of the Kirschner wires extend to just below radial carpal bone articular cartilege.

Pancarpal Arthrodesis

Arnold S. Lesser

Indications

The primary indication for pancarpal arthrodesis is irreparable damage to the articular surfaces of the antebrachiocarpal joint or the soft tissues around the joint that causes intractable pain and loss of limb function. This damage may be from trauma, infection or arthritis. Examples of trauma would be highly comminuted fractures of the articular surface or fracture luxations with significant soft tissue and or bone loss where a primary repair would still be unstable. Severe cartilage damage can also result from chronic osteoarthritis, infection from septic arthritis or open, infected fracture luxations. Rheumatoid arthritis, seen mostly in small breeds, causes severe ligamentous instability that does not respond well to soft tissue repairs. Pancarpal arthrodesis is effective in these cases but the disease may affect multiple joints. Partial carpal arthrodesis is sufficient in those cases with hyperextension injuries where the antebrachiocarpal joint is not damaged.

There are other less common indications for pancarpal arthrodesis. It is used to increase purchase for a plate in the fore leg with atrophic nonunions of the radius and ulna in miniature breeds, and limb salvage procedures for Osteosarcoma treatment. In both of these cases there is not enough distal radius to anchor a plate. Arthrodesis allows the plate or External Skeletal Fixator to extend down to the metacarpal bones. Radial paralysis and mild brachial plexus injuries can be treated with a pancarpal arthrodesis. Pure radial paralysis is rare. There are other treatments such as muscle transfers, but pancarpal arthrodesis to keep the paw in the proper orientation is one alternative. These animals may still bear weight on the side of the paw and a protective boot may be necessary. In Brachial plexus injuries the patient must be able to extend the elbow in order to make the procedure worthwhile. Fusing the carpus in severe brachial plexus injuries with a nonfunctional elbow will not have any benefit.

Procedure

In a pancarpal arthrodesis, the antebrachiocarpal, middle carpal, and carpometacarpal joints are included. It has been reported that fusing only the antebrachiocarpal joint and not the distal joints will lead to degenerative joint disease of the latter due to excessive stress. All the cartilage in these joints must be removed with a power burr or curette. The fascia, joint capsule and intercarpal ligaments must be incised to expose the cartilage. With a dorsal approach the cephalic and accessory cephalic veins and the common digital extensor tendons must be retracted but the extensor carpi radialis and abductor pollicus longus tendons can be sacrificed to expose the intercarpal and carpometacarpal joints. Some form of graft material should be placed between the denuded joint surfaces. Autogenous cancellous chips are the best but there are now numerous choices from freeze dried, decalcified, cancellous allograft to artificial Ca Phosphate substitutes. The carpus is fixed in 5 to15 degrees of dorsiflexion to place the foot in a more natural weight bearing position.

Plate fixation is the most commonly used method although external fixators and even cross pins have been advocated. Both plates and external skeletal fixation are acceptable methods of providing

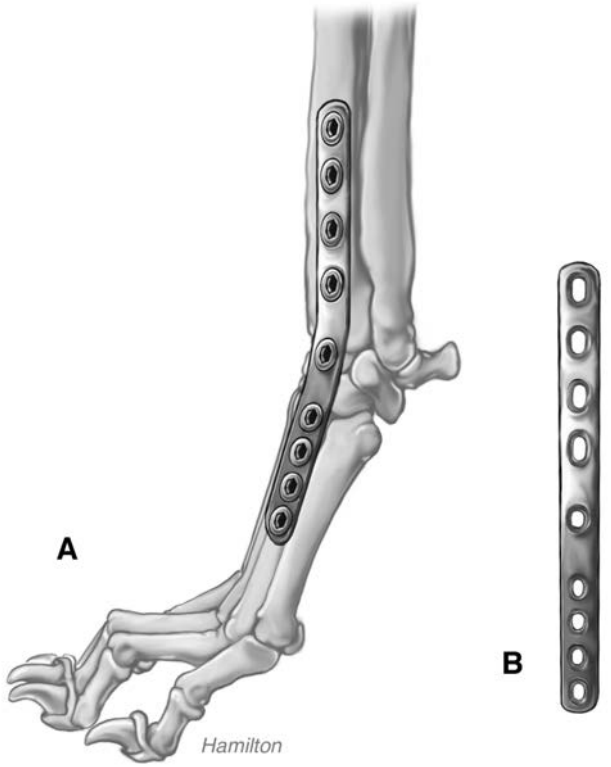


Figure 58-23. A. The preferred method of pancarpal arthrodesis is a plate with at least 3 to 4 screws in the radius, 1 in the radial carpal bone, and 3 more in the third or fourth metacarpal bone. The carpus is placed in 5 to 15 degrees of extension. **B.** Newer plats allow downsizing of screws to be placed in the metacarpals.

stable long term fixation. External fixators have an advantage in type III open fractures or at the site of an infection. No metal is buried and it is possible to treat the open wounds around the fixation. A type II, or rarely, a type III ESF can be used. Ring fixators and hybrids are also an effective choice in these situations. In clean, uncomplicated cases plates are usually the preferred implant and are better tolerated during the long periods required for arthrodesis. DCP plates also have the advantage of applying compression across multiple joint surfaces. The plate is placed dorsally (Figure 58-24) in most cases. The plate can also be placed ventrally, which is the tension band side, although this approach is much more difficult and involved (Figure 58-25). There is also a recent report in which the plate is placed on the medial aspect of the radius and carpus. This placement removes the plate from the compression side of the fixation. The newer locking plates can be contoured in four directions allowing the 10 to 15 degtrees of dorsiflexion with a medial plate. By far the most commonly used position is dorsal. Three or four screws are placed in the radius, one in the radiocarpal bone to pull it up to the plate, and at least 3 in the 3rd or 4th metacarpal bone. Depending upon how the plate lays on the radius and intrercarpals it may line up on either the 3rd or 4th metacarpal. Some newer plates taper down distally permitting the use of smaller screws for the metacarpal bones For example a 3.5 mm screw and plate over the radius and radiocarpal bone and 2.7 mm screws for the metacarpal bone. Others allow placement of screws in both the 3rd and 4th metacarpals.

A cast is usually added to plate fixation since there is no worry about joint stiffness and it adds a measure of safety. The cast can be left on until radiographic signs of fusion are seen, or removed at the discretion of the surgeon in a smaller quieter patient. The plates are rarely removed but fractures at the end of the plate are a concern in large active patients.

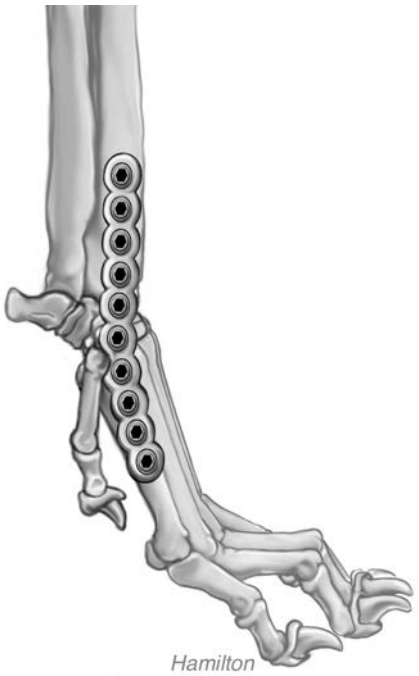


Figure 58-24. Placing the plate on the medial side but allowing 5 to 15 degrees of extension requires a plate to be contoured in two planes. The newer locking plates allow this.

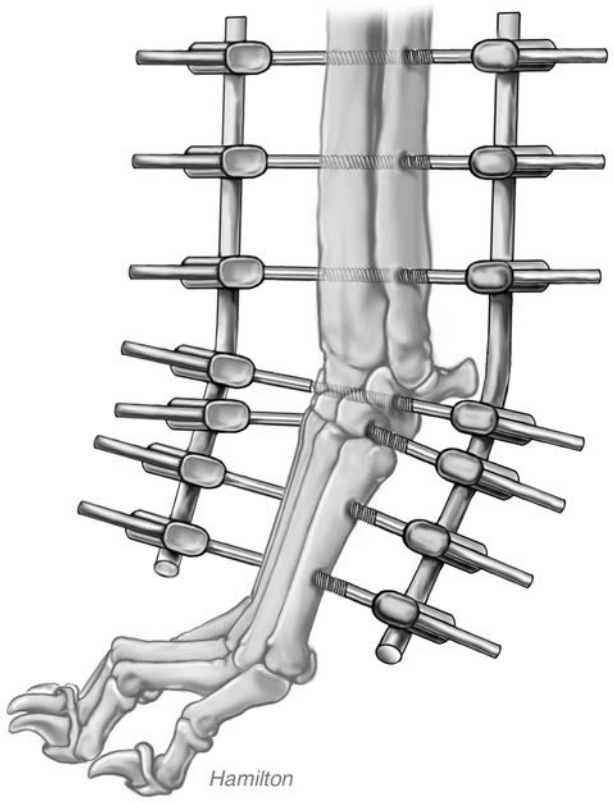


Figure 58-25. External skeletal fixators, ring fixators or hybrids work well as an alternative to plates especially in the presence of infection or major soft tissue damage.

Suggested Readings

Chambers JN, Bjorling DE: Palmar surface plating for arthrodesis of the canine carpus. J Am Anim Hosp Assoc 18:1875. 1982.

Ehrhart, N: Longitudinal Bone Transport for Treatment of Primary Bone Tumors in Dogs: Technique Description and Outcome in 9 Dogs. Vet Surg. 34: 24-34, 2005.

Gambardella PC, Griffiths RC: Treatment of hyperextension injuries of the canine carpus. Comp Cont Educ 4:127.1982.

Johnson KA: Carpal arthrodesis in dogs. Aust Vet J 1 56:515.1980.

Johnson KA, Bellenger CB: The effects of autologous bone grafting on bone healing after carpal arthrodesis in the dog. Vet Rec 107:126. 1980.

Repair of Fractures Involving Metabones and Phalanges

Alessandro Piras and Jon F. Dee

Introduction

Metacarpal and metatarsal fractures are a common injury in small animals. Although they can occur from direct trauma or from a collision against a stationary object, other causes are recognized. Entrapment of the paw while leverage is applied to the area or a fall can cause the fractures. Fractures caused by falls usually have associated hyperextension injuries.

In a retrospective study of 37 cases of meta-bone fractures, metatarsal fractures were over represented (Muir 1997). Fractures of one metacarpal or metatarsal bone occurred in 24% of the dogs, two meta-bones were involved in 16% of the cases, three meta-bones in 19% and four meta-bones in 41% of the cases. Fractures of the metacarpal/tarsal bones are classified according to their anatomical location: fractures of the proximal end (base), fractures of the shaft, and fractures of the distal end (head).

Clinical Examination

The degree of lameness that is observed increases as the severity of the injury increases. Isolated non-displaced fractures affecting the II or the V meta-bones, can cause a mild lameness that tends to resolve in 48 to 72 hours. Fractures affecting the III and IV bones or multiple bones are generally accompanied by severe non-weight bearing lameness. Clinical signs in acute cases include: swelling, and pain on digital palpation. With complete fractures, crepitus and deformity are usually also detectable.

Radiographic Examination

A complete radiographic assessment should include dorso-palmar/plantar and lateral views. Isolated metacarpal\tarsal views are not possible. Dorso-palmar/plantar 15° oblique views and lateral 45° oblique views (Figures 58-26, 58-27 and 58-28). are often necessary to isolate individual bones or to evaluate complex multiple fractures.



Figure 58-26. Dorso-palmar/plantar 15° oblique positioning.

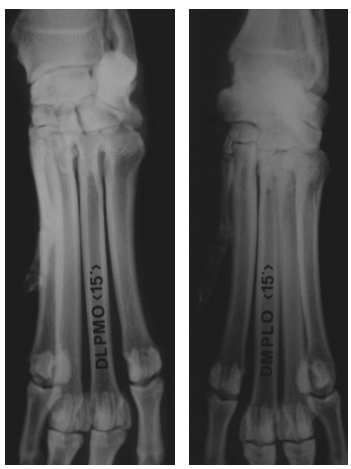


Figure 58-27. Dorso lateral – Palmaro medial (15°) oblique and Dorso medial – Palmaro lateral (15°) oblique view.



Figure 58-28. Plantaro-Dorsal view shows how difficult it can be to highlight a fracture of MTV in contrast to the oblique view.

Preoperative Considerations

The application of a modified Robert Jones bandage supported by a meta-splint for 24 to 48 hours prior to surgery will dramatically decrease swelling and facilitate fracture reduction. Application of a stockinette will enhance skin retraction and sterility. Judicious use of a tourniquet will decrease bleeding.

Surgical Approachs

(Figure 58-29A, B and C)

Fractures of the Base

Basilar fractures usually involve the second and the fifth meta-bones. These uncommon fractures are usually avulsions of ligament or tendon insertions and may be associated with some degree of varus/valgus deviation of the foot. Conservative treatment is considered for non-displaced, stable fractures. In the case of unstable fractures the fragment tends to displace due to the pulling action of the ligament or tendon; the risk of

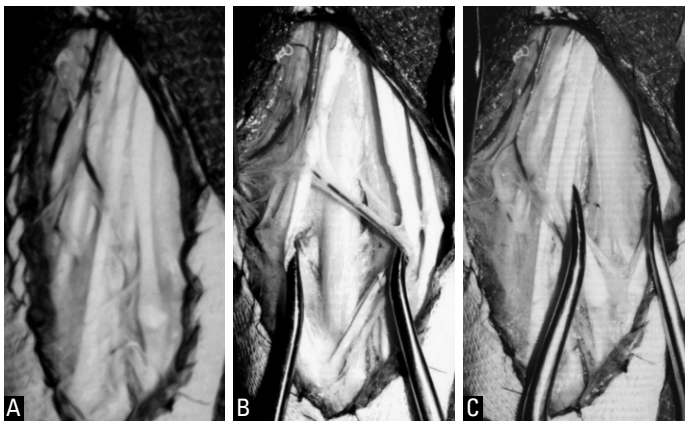


Figure 58-29. A. The skin is retracted and sutured to the stockinette. The deeper structures are visible, especially the dorsal common digital veins and the tendons of the common digital extensor muscle. **B.** The tendons are elevated and retracted together with the vascular structures to expose the fracture. **C.** Medial or lateral retraction of tendons allows exposure of the metabones.

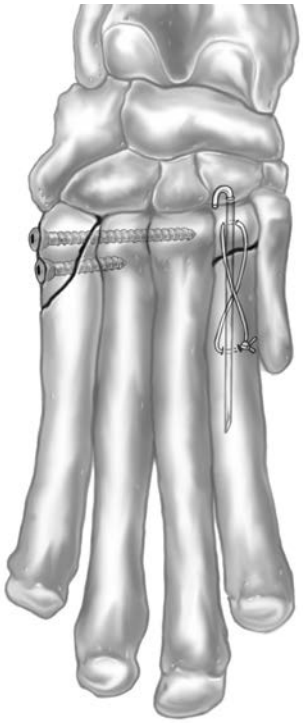


Figure 58-30. Fracture of the base of the II metacarpal bone treated with a small K wire and a figure-of-eight tension band wire. Fracture of the base of the V metacarpal bone treated with two lag screws. The heads of the screws are countersunk. The screws can be inserted to engage one or two adjacent metacarpal bones.

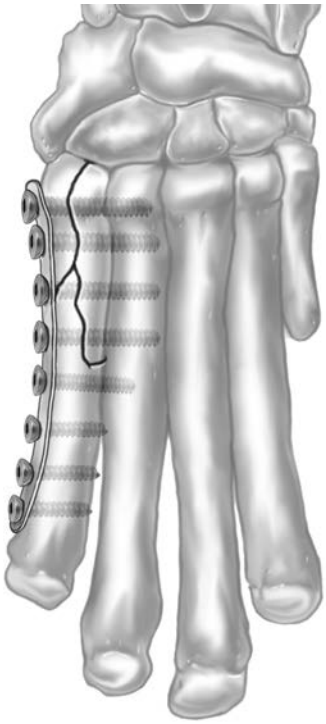


Figure 58-31. Comminuted fracture of the base and shaft of the V metacarpal bone treated with a Veterinary Cuttable Plate (Synthes Ltd. USA, Paoli, PA), applied on the lateral aspect of the bone. The first four screws are applied in lag fashion.

mal-union and consequent angular deviation justifies open reduction and internal fixation as the treatment of choice in these cases.

Fixation can be achieved with a small K wire and a figure-of-eight tension band wire or with multiple 1.5 mm or 2.0 mm lag screws (Figure 58-30). The most proximal screws are usually inserted to engage the proximal cortex of the adjacent meta-bone. Comminuted fractures of the base can be repaired with a small plate (Figure 58-31). A careful clinical and radiographic examination with stressed views is necessary to assess complex and multiple basilar fractures, as they can be associated with a hyperextension injury, resulting in palmar/plantar and lateral or medial instability. These complex injuries are best treated with carpal arthrodesis.

Fractures of the Shaft

Metacarpal/tarsal fractures can be treated either conservatively or surgically: Displacement of shaft fractures is limited by the surrounding soft tissue structures and by the support of the adjacent meta-bones. Transverse fractures of one or two metacarpal/tarsal bones, if located in the proximal and middle third tend to be stable, and can be treated with closed reduction and external coaptation. The meta-bones tend to spread in their distal third and less adjacent support is present, so fractures located in the distal portion of the shaft tend to displace, and are more difficult to maintain in a reduced position with conservative treatment.

Internal fixation of shaft fractures is usually indicated when there are more than two metacarpal/tarsal fractures in the same leg, when the two weight-bearing bones (third and fourth) are fractured, or when there is significant displacement or shortening. In large breed dogs and athletic or working dogs, fractures of even a single bone are ideally treated with internal fixation in order to achieve the best functional results.

Transverse Fractures

Transverse fractures often result from a direct blow. These fractures usually present with dorsal angulation and palmar/plantar displacement of the distal fragment, due to the direction of the deforming forces and the pull of the interosseous muscles and flexor tendons.

Plate application of transverse fractures assures a very stable fixation. External post-operative support needs to be maintained for a shorter period compared with other methods of internal fixation, thus speeding the functional recovery and allowing an earlier rehabilitation. The plate is applied to the dorsal aspect of metacarpal/tarsal III and IV, to the medial aspect of metacarpal/tarsal II and to lateral aspect of metacarpal/tarsal V (Figure 58-32). The Veterinary Cuttable Plate (VCP-Synthes™) is an excellent implant for repair of large patient metacarpal/tarsal fractures. These plates, available with 1.5 mm/2.0mm and 2.0 mm/2.7 mm screw holes, offer unique advantages; a thin profile plate with close screw holes and excellent mechanical properties.

Intramedullary pinning has been described as a successful method of treatment. A small size Kirschner wire (1.5 or 2.0 mm) can be

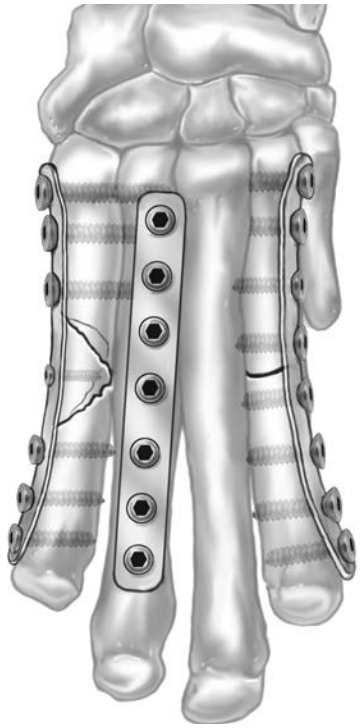


Figure 58-32. Transverse fractures of the II and IV metacarpal bones treated with medial/ lateral and dorsal plating. A comminuted fracture of the V metacarpal bone treated with a bridging plate. In this case it is possible to stabilize the large butterfly fragment with a 1.5 mm screw applied through the plate.



Figure 58-33. Transverse fractures of the III and IV metacarpal bones repaired with IM pins using the "slot" technique. A transverse fracture of the metaphysis of the V metacarpal bone repaired with two Rush pins.

inserted orthograde (normograde), starting distally, close to the dorsal attachment of the joint capsule. Reduction is achieved with a combination of traction and leverage applied with a small periosteal elevator. The pin is driven into the proximal fragment to the base of the bone. The protruding portion of the pin is cut after bending it into a hook shape. Ideally, the pin should be retracted slightly, bent into a hook and then reseated into the base in order to diminish the irritation of the pin to adjacent joint structures. A slot can be created with a high-speed burr to facilitate the insertion of the pin and the lodgement of its tip (Figure 58-33). Pre-sizing the length of the pins to the pre-operative x-ray will reduce the risk of penetration of the base and violation of the carpo-metacarpal/ tarso-metatarsal joints. Intramedullary pinning is advocated for fractures that are stable after reduction, for fractures in young non-athletic breeds and for fractures involving only one or two meta-bones.

Oblique Fractures

Oblique and spiral fractures tend to telescope--producing shortening and rotational deformity. Because these factors are difficult to control by external coaptation, the best option is open reduction and internal fixation. Most long-oblique and spiral fractures can be successfully repaired with multiple lag screws. Screws can be used as the only form of fixation if the length of the fracture is at least twice the diameter of the metacarpal/ tarsal bone and a minimum of two screws can be placed (Figure 58-34). Countersinking of the screws will improve the loading characteristics and will decrease soft tissue irritation. Whenever required, the repair can be supported with a neutralization plate. This is especially valid for fractures involving the III or IV meta-bones. Multiple cerclage wiring has been described

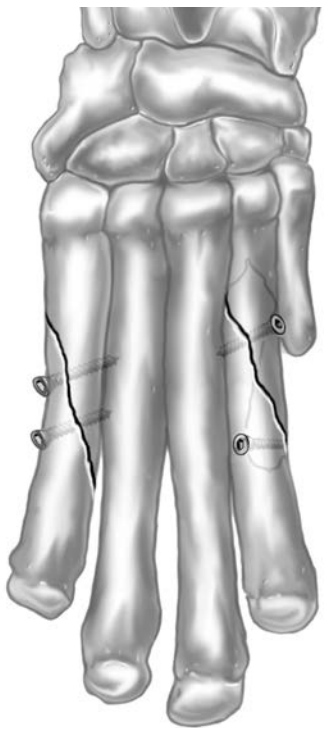


Figure 58-34. Two oblique shaft fractures repaired with lag screws. In involvement of the III or IV meta-bones it is possible to reinforce the repair by adding a neutralizing plate.

as a successful alternative to screw application; however the author does not recommend this technique. Cerclage wiring in conjunction with lag screws may be useful in selected cases.

Comminuted Fractures

Reconstructable comminuted fractures are best repaired with a combination of lag screws and mini plates or VCP. Large fragments can be lagged through the plate.

For highly comminuted fractures, a biological approach is recommended. Due to the anatomical characteristics of the area, the intact meta-bones offer a natural splintage to the fractured bone, minimizing the necessity for a perfect anatomical reconstruction. The plate can simply bridge the fracture, guaranteeing axial alignment and length.

Comminuted open metabone fractures have been successfully treated using external fixation, either with linear fixators, using epoxy resin putty, or with ring fixators.

Fractures of the metaphysis, immediately proximal to the condyles, are uncommon. These fractures are usually transverse, and tend to be stable, with the proximal fragment impacted a few millimeters into the distal fragment. A mild rotational deformity may be present. Conservative treatment with external coaptation is sufficient for isolated injuries. Surgical treatment is indicated when the fracture is in combination with other metacarpal\tarsal fractures or when it is displaced and difficult to reduce. Two pins inserted in a Rush fashion medial and lateral to the condyles and driven proximally are generally sufficient for repair (See Figure 58-33). In sporting dogs, the use of a more stable fixation with mini T or L finger-plates is recommended (Figure 58-35).

Fractures of the Head

Fractures of the head are usually intra articular fractures involving the condyles and consequently the metacarpo/tarso–phalangeal joint. Closed reduction is only used for incomplete or non-displaced fractures. Surgical treatment is indicated for mono-condylar and for T or Y fractures. Internal fixation is achieved with a lag screw or with a small cerclage wire for simple fractures and with mini T or L plate for more complex fractures (See Figure 58-35).

Post Operative Treatment

After surgery, a padded bandage is applied for approximately 3 to 4 weeks or until radiographic signs of bone healing are seen. Kennel confinement is strongly recommended until bandage removal. This period is followed by 4 to 8 weeks of restricted exercise. Fractures involving multiple bones will require either a cast or a molded splint.

Conservative Treatment

A padded bandage is reinforced with a molded splint or with a fiberglass cast. Kennel confinement and rest are required until there are radiographic signs of bone healing, which occurs usually within 4 to 8 weeks.

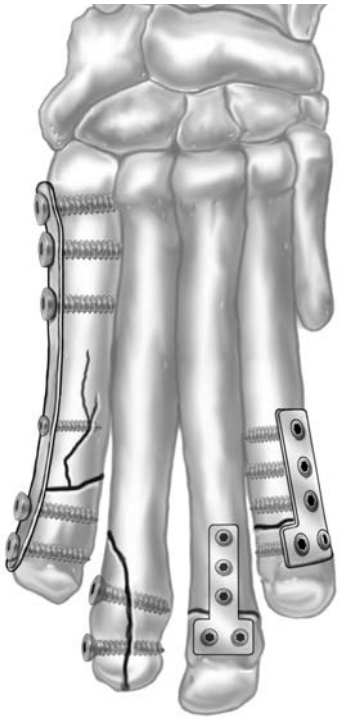


Figure 58-35. Fractures of the metaphysis of the II and III metacarpal bones. These fractures are treated with a small L plate and a small T plate. Care should be taken to avoid the joint space and to avoid allowing the screws to protrude into the sesamoids. A fracture of the head of the IV metacarpal bone is repaired with two lag screws. Excessive countersinking of the head of the most distal screw can damage the insertion of the collateral ligament and can irritate the joint capsule. A fracture of the metaphyseal area of the V metacarpal bone presents several fissures extending proximally. This fracture is repaired with a Veterinary Cuttable Plate in a bridging fashion. Two proximal and two distal screws are usually sufficient.

A retrospective study comparing the outcome of metacarpal/tarsal fractures treated conservatively versus surgically suggests that the outcome was not statistically affected by surgery or conservative treatment however this was a small non-randomized population of pet dogs, not performance nor working dogs (A. Kapatkin 2000).

Metacarpal/Tarsal Fractures in Racing Greyhounds

Metacarpal/tarsal injuries are extremely common in the racing greyhound with a high incidence in dogs between 14 and 28 months of age. Metacarpal and metatarsal fractures are, for the vast majority, fatigue or stress fractures resulting from repetitive cyclical loading as documented by (Bellenger C.R.et al 1981, Boemo 1989 & Johnson A. K. 2001). Exceptions are the traumatic fractures sustained in a fall, or following a collision against stationary objects.

Traumatic injury can involve any metacarpal bone but are usually multiple, involving two to four bones. Stress fractures almost always involve the left V and the right II metacarpal bones. Fracture of the IV left metacarpal bone can be associated with a fracture of the V left metacarpal bone, and has not been described or reported as an isolated injury. The metatarsal

bones affected by stress fractures are the left V and the right III. Greyhounds are high performance dogs and internal fixation is recommended in the majority of the cases.

Phalangeal Fractures

Introduction

Phalangeal fractures are common injuries and are often considered insignificant. As a direct consequence of this underestimation, the treatment of these injuries is not always optimal. The most common complications associated with inappropriate treatment of phalangeal fractures are: malunion with imbalance of the flexor and extensor mechanism, limited range of motion, degenerative joint disease and deformity with interference between toes.

There are a variety of factors to consider when deciding the optimal treatment. Breed, age, type of activity, owner expectations and compliance, as well as injury characteristics, pattern of the fracture, and soft tissue damage are all important when establishing a treatment plan.

The goal of the treatment of fractured phalanges is to achieve the best possible reduction and the most effective means of maintaining the reduction in order to promote bony union, early mobilization and function. This concept is particularly valid for sporting dogs in which performance is directly related to anatomical integrity and function.

Anatomy

The base of P1 articulates with the head of its corresponding metacarpal/tarsal bone at a dorsal angle slightly more than 90 degrees. In this position the first phalanx is almost parallel to the ground. P2 articulates with P1 forming a palmar/plantar angle of 135°. The superficial digital flexor tendon inserts on its proximal palmar/plantar aspect. Distally, P2 forms an obtuse dorsal angle with the shallow, sagitally concave articular surface of P3. The deep digital flexor tendon inserts on the broad palmar/plantar tubercle of P3. Each side of the tubercle is perforated transversely by a vascular bone tunnel. On the dorsal aspect of P3 there is another bony prominence, the ungual crest, which is the area of attachment of the extensor tendon and the dorsal elastic ligaments.

Clinical Examination

Variable degrees of lameness are usually present. Clinical examination reveals swelling that is often associated with crepitus and deformity of the affected phalanx. A thorough soft tissue evaluation is necessary to detect the presence of small wounds, some of which may arise from an open fracture.

Radiographic Examination

Radiologic evaluation of phalangeal injuries commences with plain radiographs. A minimum of two views taken at orthogonal angles provides information on two planes. Standard dorso palmar/plantar (DP) and lateral (L) views are the core of the radiologic assessment. DP views should include the metacarpo/tarso–phalangeal joints and the distal inter-phalangeal joints. The L view is taken with the toes spread in opposite directions with the aid of a stirrup of tape, applied on the nail of the second and fifth digit ("fan lateral") (Figure 58-36A, B). Oblique views are used to increase the sensitivity of imaging of phalangeal fractures, especially in cases of severely comminuted fractures. A lateral view with traction applied to the nail is useful to assess the shape and size of the fragments in case of a comminuted fracture of P2.

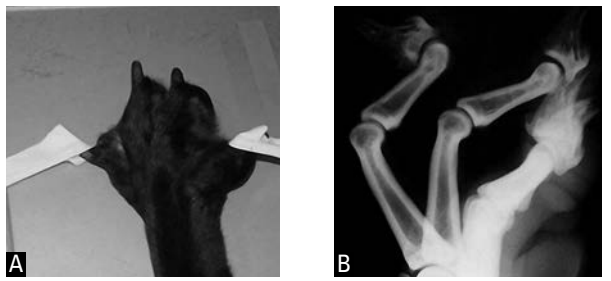


Figure 58-36. A. and **B**. The L view is taken while spreading the toes in opposite directions with the aid of a stirrup of tape, applied on the nail of the second and fifth digit ("fan lateral").

Treatment Principles

To rationalize the treatment of phalangeal fractures it is necessary to take into account the anatomical characteristics of the area as well as the functional angles of the digits. Fractures of P1 and P2 are the most common, while fractures of P3 are less frequent.

In a survey on 40 phalangeal fractures affecting racing Greyhounds (un-published data) P1 was involved in 20 cases, P2 in 14 cases and P3 in 6 cases. P1 fractures were intra-articular in 6 cases P2 in 10 cases and P3 in all of the cases. The head of P1 was involved in 3 cases, in P2 the head was involved in 9 cases and the base of P1 in 3 cases.

Fractures of the Shaft

Fractures of the shaft of P1 and P2 can vary in configuration from: transverse, oblique, spiral with or without a butterfly fragment, to comminuted. Simple, stable non-displaced fractures, especially in young dogs, can be treated by closed reduction with splinting in a functional position.

Fractures with unstable configuration are best treated with open reduction and internal fixation with lag screws (1.5 mm to 2.0 mm) and/or mini plates applied on the dorsal or lateral aspect of the phalanges. In spite of the apparent simplicity of the surgical approach, internal fixation of complex fractures can be very challenging. Careful handling of the fracture fragments with appropriate instruments and gentle traction is mandatory in order not to compromise the delicate vascular structures in this area. Failure to respect the blood supply can lead to severe complications ranging from non-union to necrosis of the toe.

Fractures of P2 tend to displace due to the pull of the flexor tendons therefore the reduction of comminuted P2 fractures can be extremely challenging. A single screw is not sufficient to withstand rotational and shear stress. Ideally a minimum of two screws should be used for oblique fractures. Unfortunately this

is not always possible due to the small size of the bones. An anti-rotational small K wire can be added to improve the stability. The screw head should be countersunk to avoid interference with the gliding tendons. When using mini plates, always try to secure two screws proximal and two screws distal to the fracture site. As this is possible only in very large breeds, one screw may be sufficient in selected cases, especially if the plate is applied in neutralization (Figures 58-37 and 58-38).

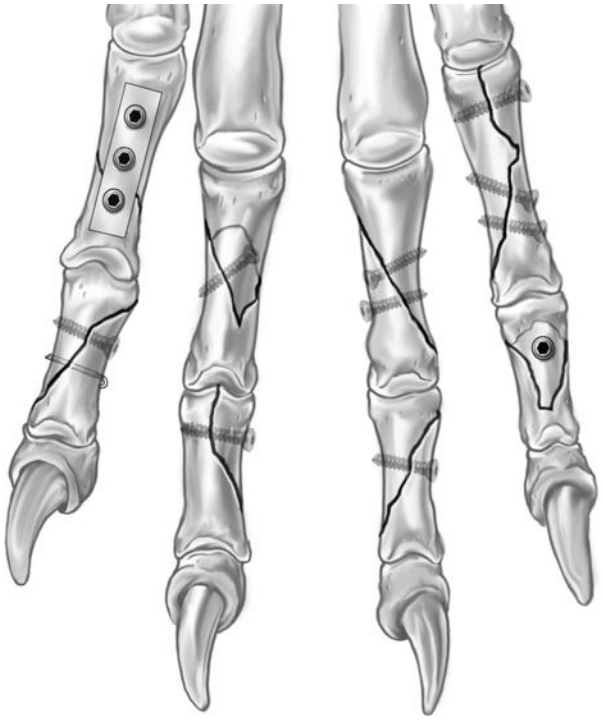


Figure 58-37. Different types of phalangeal fractures repaired with 1.5 mm lag screws. According to their shape, one or multiple screws are used. In the case of the second phalange on the left, a small K wire and a lag screw are used in combination. The protruding portion of the K wire should be bent over to prevent pin migration. A three holed mini cuttable plate is applied on the dorsal aspect of the first phalanx on the left.

Fractures of the Base and Head

Fractures of the base or of the head are articular, and almost invariably involve the insertion of a collateral ligament. Fractures of the condyles can be handled with application of lag screws or with a loop of cerclage wire unless the fragments are too small to be safely secured in place. Very small fragments can be excised, but in cases with large unstable fragments involving the joint, amputation or arthrodesis is usually necessary.

Operative Considerations

Traditionally, the lag screw technique has been the gold standard for fixation of oblique, spiral and condylar fractures. This technique, which is relatively straightforward for most long bone fractures, can be technically challenging when attempting fixation of small bones. Despite the availability of very small implants (1.0 mm to 1.5 mm to 2.0 mm) the size remains large, relative to the phalanges and the fragments to be fixed… leaving little room for error.

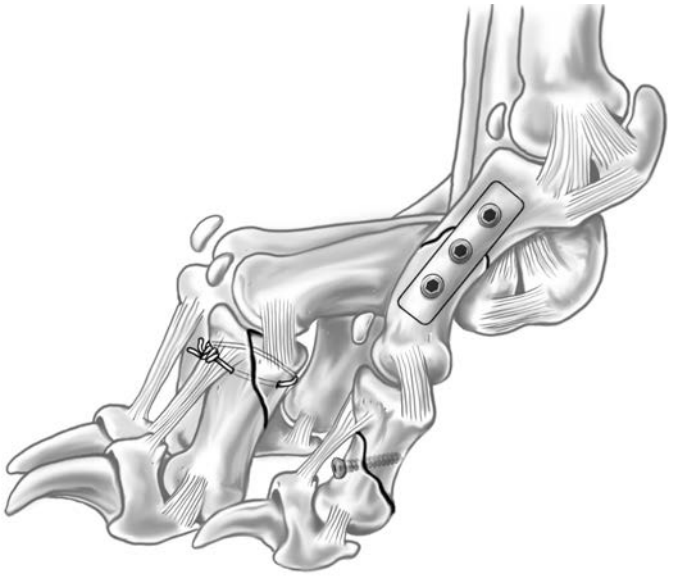


Figure 58-38. A fracture avulsion of the insertion of the superficial digital flexor tendon is repaired with a small cerclage wire. The wire is passed through two parallel, A-P bone tunnels and is tightened on the dorsal aspect of the bone. Care must be taken to bend the wire twist appropriately to avoid irritation to the extensor tendon. A three hole mini cuttable plate is applied on the lateral aspect of the first phalanx. A lag screw is applied to the second phalanx to repair an oblique fracture.

The application of bicortical (positional) self-tapping screws eliminates one surgical step and eliminates the risk of losing reduction and of splitting the fragments during the tapping process. With bicortical screws the proximal cortex is not over-drilled and the screw threads achieve purchase in both cortices while reduction and compression are maintained with bone clamps.

Open Fractures

Open fractures are often comminuted and highly contaminated with severe soft tissue damage and with devitalized bone fragments protruding through the skin. In these cases, amputation is the best choice offering a good prognosis and for sporting dogs a rapid return to performance.

Fractures of P3

Fractures of P3 can involve the joint, split the phalanx obliquely or can occasionally involve the tuberosity of insertion of the deep flexor tendon or the ungual crest. Due to the small size of P3, attempts at internal fixation are unlikely to be successful and amputation is necessary.

Post Operative Considerations

Postoperative care following surgical repair consists of a padded bandage for 3 to 4 weeks and confinement for a total of 6 to 8 weeks. The bandage can be reinforced with a palmar/plantar splint for the first 2 weeks. After bandage removal and when radiographs confirm that the bone is healed, 3 weeks of limited exercise on a lead should commence, with a gradual increase in activity until a return to full activity is attained.

In the case of amputation, a light bandage is applied for 2 weeks. As soon as the swelling decreases and the reflected digital pad is properly sealed, it is possible to gradually reintroduce the dog to exercise. For sporting dogs, the return to full training following amputation is expected by 5 to 6 weeks postoperatively. The prognosis for uncomplicated cases is usually good to excellent.

Suggested Readings

Waibl H, Mayrhofer E, Matis U, Brunnberg L and Köstlin R: Atlas of Radiographic Anatomy of the Dog, Blackwell Publishing, 2003. 82-83 & 112-113.

Brinker, Piermattei and Flo: Fractures of Carpus, Metacarpus and Phalanges in: Handbook of Small Animal Orthopedics and Fracture Repair, 3rd ed. Philadelphia: W.B. Saunders 1997, 344-389.

Boemo C M: Injuries of the Metacarpus and Metatarsus in: Canine Sports Medicine and Surgery. Bloomberg M S, Dee J F and Taylor R A. eds. W.B. Saunders 1998, 150-173.

Dee JF: Fractures of Metacarpal and Metatarsal Bones in: AO Principles of Fracture Management in the Dog and Cat. Johnson AL, Houlton JEF and Vannini R. eds. AO Publishing 2005, 361-369.

Chapter 59

Amputation of the Forelimb

William R. Daly

This topic is written based on the available literature through 2010 and does not cover the most current literature on this topic.

Introduction

Amputation of the forelimb is occasionally indicated as a primary treatment for severe traumatic injuries resulting in irreparable fracture or soft tissue injury. Other indications are severe neurological lesions such as brachial plexus avulsion, irreparable vascular occlusion, and severe congenital or acquired deformities. Amputation may also be considered as an adjunct to the treatment of neoplasia or severe infections involving the limb. With the possible exception of neoplasia, amputation should be considered a last resort "salvage" procedure, indicated only when no alternative exists that would allow the retention of a useful limb. Unfortunately, with the development of more sophisticated and expensive procedures which allow saving a limb with severe fractures or soft tissue injuries, amputation may be requested solely based on economic considerations. Because almost all animals will do extremely well with a forelimb amputation, it is better to offer amputation than resort to euthanasia because the animal owners are unable to afford the more sophisticated procedures.

Preoperative Considerations

Amputation performed at the shoulder level or above is generally preferable because a residual limb below this level serves no useful purpose and is prone to abrasions and infections from frequent trauma if the animal attempts to walk on the limb. Small dogs and cats invariably adapt well to forelimb amputation; however, some giant breed dogs may have some difficulty. If the patient is able to ambulate while carrying the affected limb, it will usually do well following forelimb amputation. It is difficult for some owners to accept the option of amputation. However, for most large breed dogs with otherwise normal bone and muscle structure, amputation is not as limiting as it would seem. Most owners and pets acclimate to amputation within a few days to two weeks. Surveys of owners who wanted to avoid amputation, but ultimately accepted that option, have revealed that 90% felt the amputation resulted in fair, good or excellent quality of life.

Forelimb amputation can be performed through or directly below the scapulohumeral joint, or the scapula may be removed with the limb. Forequarter amputation with the removal of the scapula is advantageous because major vessels and nerves are easily visualized, bone cutting instruments (oscillating saw, osteotome, or Gigli wire) are not required, and no prominent scapular spine remains behind. The procedure of choice, however, is the one that works best for each individual surgeon.

Forelimb amputation is a major procedure that should be

performed only with a thorough knowledge of the patient's physical status. Because blood loss is likely to be greater than in most major surgical procedures, the surgeon must evaluate both the hematocrit and plasma proteins pre-operatively. Anemic or hypoproteinemic patients should be treated medically, if time allows, or provisions should be made for transfusions of whole blood or plasma as the situation dictates. Balanced electrolyte solutions should be given intravenously continuously during the surgical procedure and post-operatively until the patient has recovered from anesthesia. The intravenous catheter should be large enough to allow whole blood transfusion should the need arise. In cases of amputation because of neoplasia or infection, a tourniquet may be used between the disease site and the amputation site to limit metastasis of infection or neoplasia to the general circulation.

Amputation of a limb is by necessity a painful procedure and careful consideration should be given to managing pain pre- and post-operatively. Preemptive analgesia is provided with parenterally administered narcotics and a bupivacaine brachial plexus block. If transdermal Fentanyl is used it must be applied the day before the surgery. Post-operative pain management can include narcotics, NSAIDS, and local anesthetics delivered through a "soaker catheter" placed at the time of surgery.

Regardless of the amputation method used, preliminary preparations for the surgical procedure are identical. The affected limb is clipped with a number 40 clipper blade from the carpus to the dorsal and ventral midlines. Clipping should also extend well cranially and caudally to allow adequate draping. The paw is usually covered with a gauze wrap, plastic bag or latex glove before the patient is transported to the operating room where final skin preparation is done.

Forequarter Amputation

The objective of forequarter amputation is to remove the entire pectoral limb, including the scapula, from the thorax. This procedure involves the division of all muscles, nerves and vessels that normally join the two parts. The muscles are the trapezius, rhomboideus, omotransversarius, serratus ventralis, brachiocephalicus, superficial and deep pectorals, and the latissimus dorsi.

After adequate pre-operative evaluation and preparation including the administration of pre-operative analgesics, the patient is anesthetized and is placed in lateral recumbency with the affected limb uppermost. After draping, a skin incision is made over the scapular spine beginning at the dorsal rim of the scapula and proceeding downward to the acromion. At the acromion, the incision curved cranially to cross the cranial aspect of the forelimb at the level of the greater tubercle. This incision is eventually extended to cross the medial surface of the forelimb in the axilla and to curve around the caudal aspect of the limb at the axillary fold, finally to join the lateral incision at the level of the acromion. (Figure 59-1A). The entire skin incision does not need to be completed at the beginning of the operation. The lateral incision alone allows sufficient exposure to remove all muscle insertions, and the remainder of the incision can be delayed as the final act in amputation of the limb.

After the lateral incision to the level of the greater tubercle is completed, subcutaneous dissection exposes the omotransversarius and trapezius muscles. An incision is made in these muscles to sever their attachments to the scapular spine. (See Figure 59-1A) Retraction of the trapezius muscle reveals the rhomboideus muscle which is severed as close to its attachment to the scapula as possible (Figure 59-1B). Several blood vessels that require ligation are generally encountered in the muscle bellies as they are cut. Smaller vessels may be cauterized, but vessels larger than about 1 mm diameter should be ligated with fine monofilament absorbable suture. Further lateral retraction of the scapula reveals the insertion of the serratus ventralis on the medial face of the scapula. The insertion is easily elevated with a sharp periosteal elevator, and thus the detachment of all muscles connecting the scapula to the trunk is completed (See Figure 59-1B).

At this point the vessels and nerves of the brachial plexus are easily visualized and are transected. The axillary artery and vein should be doubly ligated using a three clamp technique. Use of a transfixation suture is recommended in the axillary artery (Figure 59-1C). Nerves may be divided with either a scalpel or scissors without special treatment of the proximal severed ends. Neuroma formation is not a common problem in dogs or cats.

After division of the brachial plexus, attention is turned to the cranial portion of the limb. The brachiocephalicus muscle is transected near the greater tubercle. This is the only muscle in this procedure that is necessary to divide in mid belly, the remainder being severed at their insertions. The omocervical artery and vein are encountered near the greater tubercle and both should be ligated. The superficial and deep pectoral muscles are transected near their insertions on the greater and lesser tubercles respectively (Figure 59-1D). The cephalic vein can also be ligated and divided at this point. The last remaining muscular attachment, the latissimus dorsi, is severed from its insertion on the teres tuberosity and the medial brachial fascia. The axillary lymph node and the accessory axillary lymph node are located just under the latissimus dorsi muscle near its attachment to the humerus and can be conveniently removed, if indicated as in neoplastic disease) once this muscle has been cut (Figure 59-1E).

The amputation is completed by incising the skin of the medial surface of the brachium. A flap must be made that is sufficiently large to cover the defect caused by removal of the limb. The base of the flap must be in the axillary space and as much skin as possible is taken from the medial brachium. It is always desirable to take extra skin to allow trimming as necessary.

Once the limb has been removed, the muscle bellies are pulled together over the ends of the severed vessels and nerves of the brachial plexus. This maneuver is accomplished by inverting the severed ends of the omotransversarius, trapezius, rhomboideus and latissimus dorsi muscles over the surface of the serratus ventralis muscle with a continuous Lembert suture pattern (Figure 59-1F). The superficial and deep pectorals are then similarly inverted by suturing them to the ventral margins of the more dorsal muscles. If a "soaker" catheter is to be used for

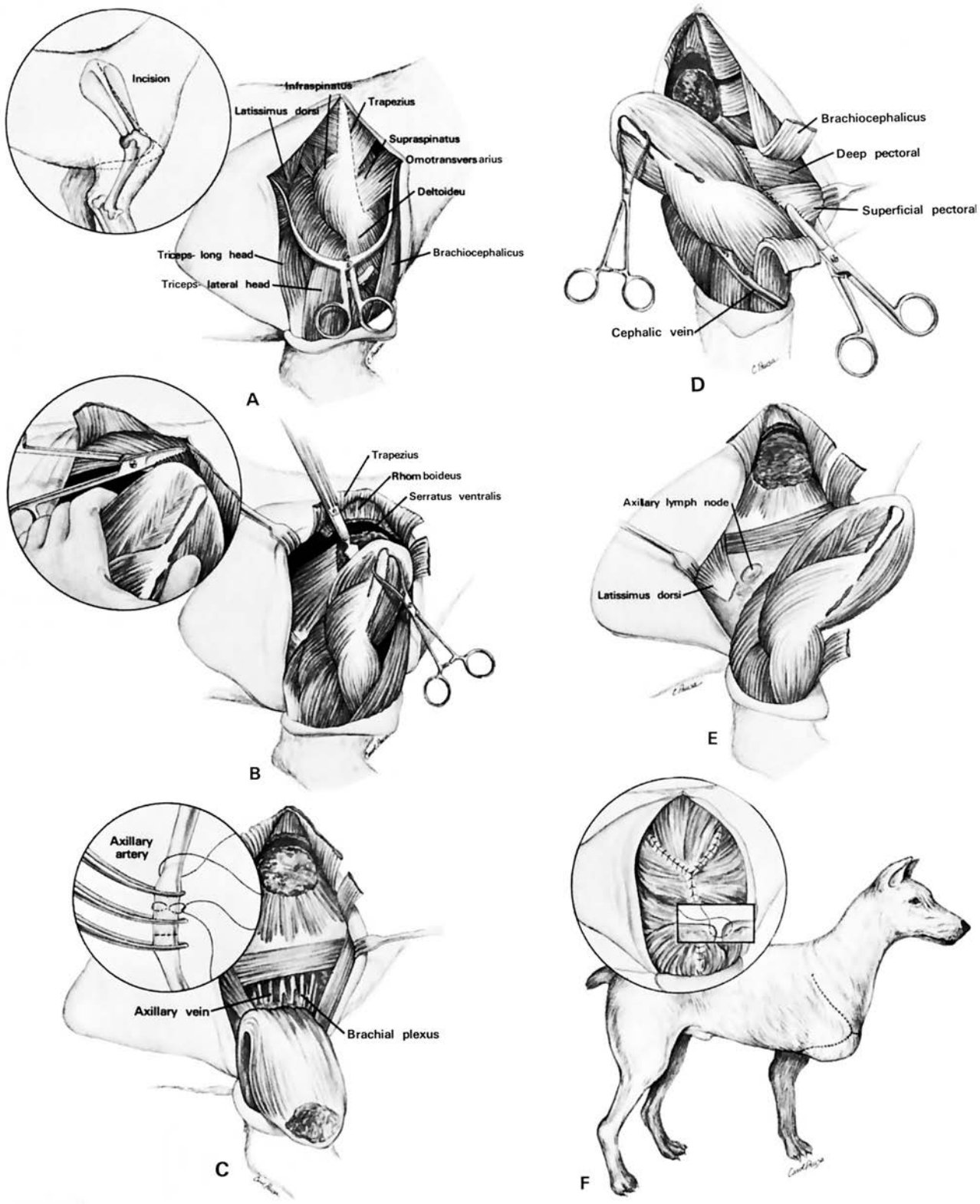


Figure 59-1. **A.** The inset demonstrates the location of the skin incision used for forequarter amputation. After the initial incision over the scapular spine, subcutaneous dissection exposes the trapezius and omotransversarius muscles, which are severed at their insertions (broken line). **B.** The inset demonstrates the rhomboideus muscle as it is severed at its insertion on the scapula. Lateral retraction of the scapula then reveals the serratus ventralis muscle which is sharply elevated from its insertion on the medial face of the scapula. **C.** Complete lateral retraction of the scapula reveals the brachial plexus. The axillary artery and vein are ligated and are severed using the three-clamp technique (inset). **D.** After transaction of the brachial plexus, the brachiocephalicus muscle is divided, and the superficial and deep pectoral muscles are trnasected near their insertions on the humerus. **E.** The final muscular attachment, the latissimus dorsi, is severed at its insertion on the humerus. The axillary lymph node may e removed at this time if indicated. **F.** After removal of the limb, the muscle bellies are inverted over the severed vessels and nerves of the brachial plexus. A Lembert suture pattern works well for this purpose (inset). Subcutaneous tissues and skin are closed routinely.

post-operative administration of local anesthetics to the surgical site, it can be placed just prior to closure of the muscle bellies. Closure of the subcutaneous muscles and skin is routine (See Figure 59-1F). If excessive skin is present, trimming should be done on the medial skin flap in order to preserve the thicker skin and hair coat present on the lateral surface of the limb.

Some veterinary surgeons place several Penrose drains into the wound before beginning closure. If placed, the drains should penetrate the skin as far ventrally as possible. If adequate attention is paid to hemostasis and atraumatic operative technique, drains are not required. In cases that will require surgical drainage, an active suction drain is a better option than the passive Penrose drains. In all cases, a light pressure bandage is used for 2 to 3 days to help prevent swelling, hematoma, and seroma formation. Post-operative pain management will be required. Most patients respond well to morphine at a dosage of 0.25 to 0.5 mg/kg SC or IM q2-6h as needed.

Forelimb Amputation by Scapulohumeral Disarticulation

Scapulohumeral disarticulation is preferred by some surgeons for forelimb amputation. Pre-operative evaluation, preparation, pain management and positioning are identical to that described for forequarter amputation.

In this procedure, the initial incision is made as a semilunar incision that begins at the point of the shoulder, extends across the mid-diaphysis of the humerus, and curves back into the axillary fold. This incision produces a large flap that is later used to cover the wound. A similar flap is then made on the medial side of the limb to ensure adequate surgical exposure for the procedure and a generous supply of skin for closure (Figure 59-2A).

The brachiocephalicus muscle is transected first just below the clavicular tendon. The cephalic vein lies in this region and must be ligated and divided. External rotation of the limb exposes the superficial and deep pectoral muscles which are divided close to their insertions on the humerus (See Figure 59-2A). Retraction of these muscles exposes the nerves and vessels of the brachial plexus, which are separated and ligated as necessary. The nerves may be cut with a scalpel or scissors. The axillary artery and vein should be doubly ligated. The axillary artery is divided distal to the point of origin of the external thoracic and lateral thoracic arteries, which arise close to the first rib.

After division of the brachial plexus, the acromial head of the deltoideus muscle is removed from its origin on the acromion process (Figure 59-2B). Distal retraction of this muscle exposes the insertions of the supraspinatus, infraspinatus and teres minor muscles, which should be transected (Figure 59-2C). The insertions of the latissimus dorsi, teres major, and cutaneous trunci muscles are next divided close to the humerus. The scapulohumeral joint capsule is then opened; total dislocation of the joint is easily accomplished once the tendons of the biceps brachii, coracobrachialis, and subscapularis muscles are severed over the joint space (Figure 59-2D). The spinous head of the deltoideus muscle is elevated from its insertion on the humerus (See Figure 59-2D). The long head of the triceps brachii muscle is then divided as distally as possible to complete the amputation. (Figure 59-2E).

The infraspinatus and supraspinatus muscles soon atrophy from disuse and loss of their nerve supply, exposing the acromion and

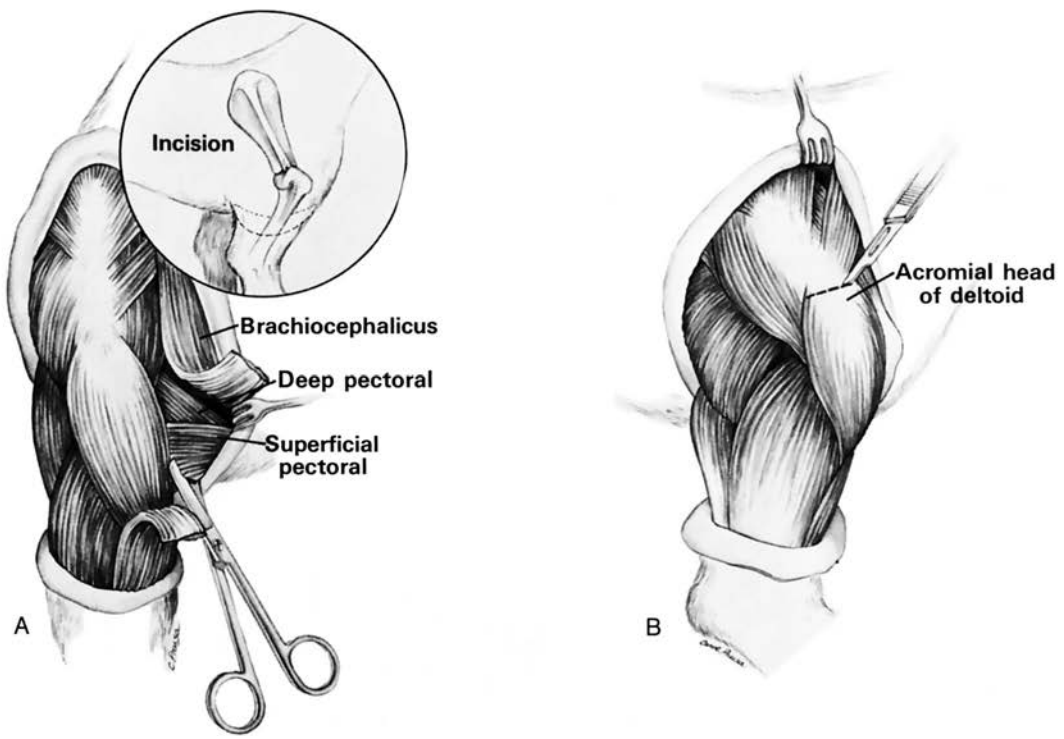


Figure 59-2. A. The inset demonstrates the location of the incision for the scapulohumeral disarticulation technique of forelimb amputation. The brachiocephalicus muscle is transected, and then the insertions of the superficial and deep pectoral muscles are exposed and divided. Retraction of these muscles exposes the brachial plexus. **B.** The acromial head of the deltoideus muscle is severed at its origin on the scapula.

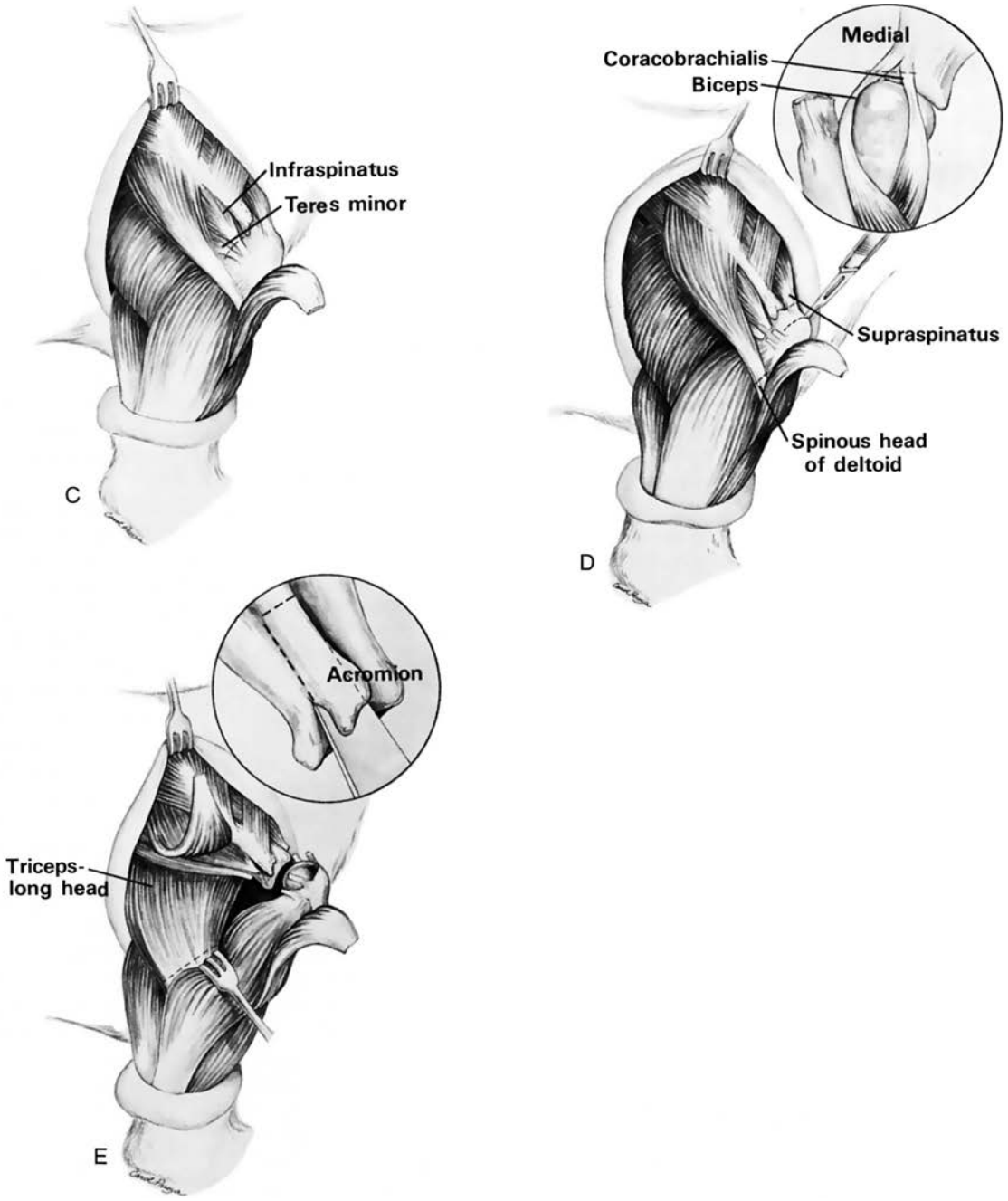


Figure 59-2. (continued). C. Retraction of the acromial head of the deltoideus muscle exposes the tendons of insertion of the infraspinatus and teres minor muscles, which are severed. **D.** The supraspinatus muscle and the spinous head of the deltoideus muscle are severed at their insertions. The joint capsule is then opened and the humerus is totally dislocated after transaction of the tendons of the biceps brachii, subscapularis and coracobrachialis muscles (inset). **E.** After division of the latissimus dorsi muscle, the long head of the triceps brachii muscle is divided as distally as possible to complete the amputation. The prominent scapular sine is removed with an osteotome (inset) for a better cosmetic effect.

spine of the scapula. A better cosmetic effect is obtained if an osteotome is used to remove the scapular spine, or at least the prominent acromion (See Figure 59-2E, inset).

Closure of the wound involves suturing the superficial and deep pectoral muscles to the latissimus dorsi , teres major, infraspinatus, supraspinatus, and brachiocephalicus muscles. During closure of the subcutaneous muscles and skin, an attempt is made to preserve as much of the lateral skin flap as possible because this skin is thicker and has a denser hair coat that produces a more cosmetic final result. Post-operative bandaging for 2 to 3 days is desirable to prevent seroma formation. Post-operative pain management is identical to that described for forequarter amputation.

Suggested Readings

Evans, H.E., Miller's Anatomy of the Dog. 3rd ed. Philadelphia: WB Saunders, 1993.

Johnson, A.L., Hulse, D.A. Other Diseases of Bones and Joints. In Fossum, T.W. ed. Small Animal Surgery. 2nd ed. St.Louis, MO, Mosby, 2002, p 1173.

Section N

Appendicular Skeleton – Pelvic Limb

Chapter 60

Sacroiliac Joint, Pelvis and Hip Joint

Repair of Sacroiliac Dislocation

Charles E. DeCamp

Introduction

Traumatic luxation of the sacroiliac joint results in displacement and laxity of the joint, variable pain, and is almost always seen with other major fractures of the pelvis and hind limbs, disabling both sides. Displacement of the ilial wing is usually cranial and dorsal, and it is not uncommon for the pelvis distal to the sacroiliac joint to be displaced medially to compromise the pelvic canal. Avoidance of severe and chronic pain, and compromise to the pelvic canal are the main indications for surgical repair of the sacroiliac joint. Fixation of the sacroiliac joint allows early weight bearing and reduction of pain, prevents complications from mal-alignment of the pelvis, and prevents potential compromise of other orthopedic repairs. The most commonly applied and effective fixation of the sacroiliac joint is deeply seated lag screws that compress and realign the joint (Figure 60-1A and B). Fixation promotes early weight bearing by reducing instability of the joint and its resultant pain.

General Considerations

There is little natural movement at the canine sacroiliac joint, but this joint does have typical anatomic structures including joint capsule, ligaments and a cartilage covered area described as the auricular surface.[1] The joint undergoes bony fusion in many dogs with age. Traumatic luxation of this joint is described with several other names including fracture-luxation and fracture-separation, all of which have identical meaning. However, sacral fracture indicates that fracture of the sacral bone is present, generally located at the site of the sacral wing. Sacral fractures are more likely to be associated with neurologic injury and have different and more complex surgical considerations. They will not be specifically discussed in this chapter.

Presentation and physical examination of a dog with sacroiliac luxation reveals the dog to be non-weight bearing on the affected side, and commonly unable to stand on either rear limb because of associated traumatic injury. The instability at the sacroiliac joint may be detected with careful digital pressure, however, local pain and swelling prevent effective palpation of this joint. Radiographic evaluation is essential to diagnose sacroiliac luxation and also fully characterizes displacement of the joint and the extent of associated pelvic or long bone injuries. The diagnosis of sacroiliac luxation is best observed on a ventrodorsal radiographic view and is seen in subtle cases as a step between the caudal sacral wing and the ilium. Those dogs with severe displacement have more instability at the joint with more severe pain. Neurologic injury with signs referable to injury of the lumbosacral trunk or to the innervation to the urinary bladder are observed infrequently, especially with severe displacement or bilateral injuries. Fortunately, neurologic injury associated with discrete sacroiliac luxation is most commonly (but not always) reversible within several weeks of the injury.

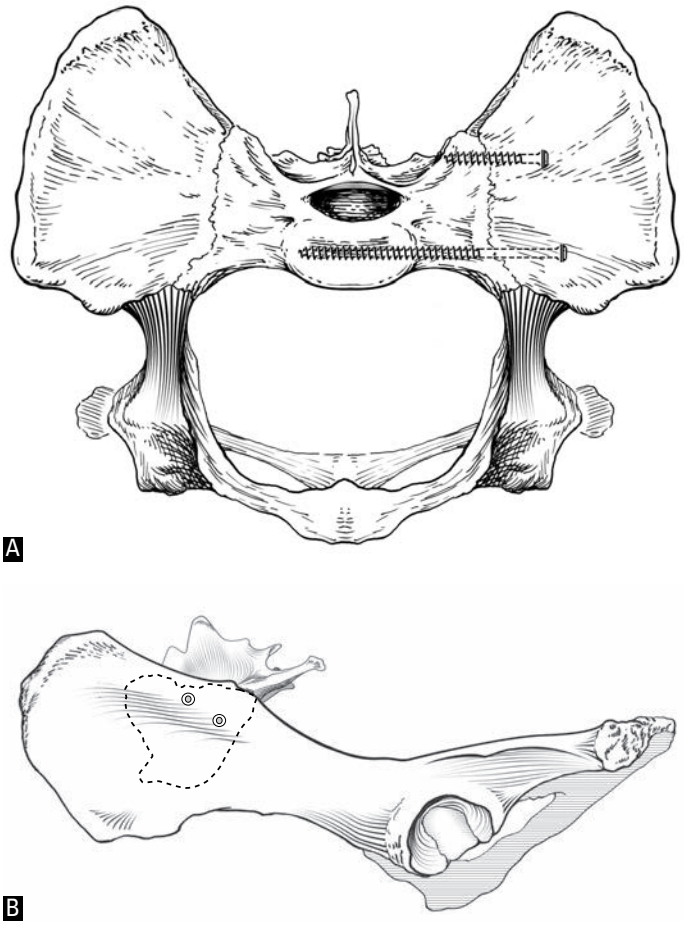


Figure 60-1. A. and **B.** Cranial and lateral views illustrate placement of one long lag screw in the sacral body and a shorter second screw placed dorsal and cranial to the first screw into the sacral wing, stopping short of the spinal canal.

Surgical Indications

Surgical stabilization of the sacroiliac joint is selected for those cases with severe pain or displacement where lack of repair may compromise the pelvic canal, the alignment of the coxofemoral joint, or the stability of other orthopedic fixations of the pelvis or long bones. Displacement of sacroiliac luxation, especially

the medial direction that could compromise the diameter of the pelvic canal, may progress in the first days post-trauma. If case selection for non-surgical care is based upon minimal displacement observed radiographically on the day of injury, additional radiographs should be taken 4 to 6 days later to ensure that the hemi-pelvis has not displaced medially to obstruct the pelvic canal.

Surgical Anatomy and Approaches

An approach to the sacroiliac joint through a dorsal incision allows access and direct visual identification of the anatomy of the sacral wing (Figure 60-2) for precise placement of lag screw fixtion for the routine sacroiliac injury.[2] A different approach is also described to the ventral aspect of the sacrum; however, it does not allow direct visualization of the sacral wing. The ventral surgical approach is useful in the uncommon circumstance when an ipsilateral ilial fracture must be repaired with a sacroiliac injury.[3]

The dorsal approach to the sacroiliac joint is completed with the dog in lateral recumbency, through an incision over the dorsal iliac spine that curves down along the cranial aspect of the ilial wing. After incisions through deep gluteal fascia and fat, the dorsal iliac spine is evident. A sharp incision is made in the dorsal periosteal attachment of the middle gluteal muscle and this muscle is elevated fully from the lateral aspect of the iliac wing. The sacrospinalis muscle is similarly elevated from the medial side of the ilium; however, this muscle and the dorsal sacroiliac ligament have often been disrupted by the trauma. Manipulation of the iliac wing with a bone forceps in a ventral direction and removal of fibrinous debris allows a direct view of the oblique surfaces of the sacral wing (Figure 60-3A). The curved cartilage-covered surface seen on the ventral aspect of the sacral wing is the auricular surface.[4] The surgeon can also identify the dorsal and cranial aspects of the sacral wing by palpation through a layer of fascia. The locations of the spinal canal, the sacral nerve roots, and the sacral body can be deduced in relation to these two structures. The ideal location for the lag screw deeply seated into the sacral body is ventral to the spinal canal, caudal to the lumbosacral intervertebral disc, and cranial to the sacral nerve roots.

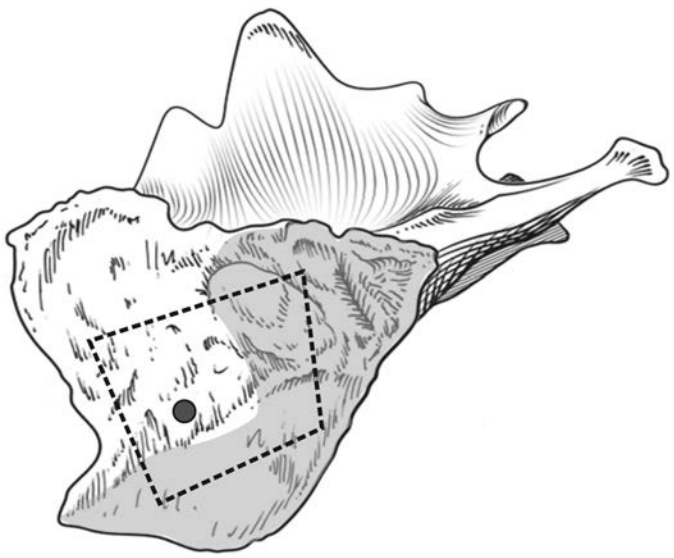


Figure 60-2. Sacral wing anatomy relevant to application of fixation includes area of sacral body (box) and auricular surface (grey area). The black dot indicates site of drill placement for the first, long sacral body screw.

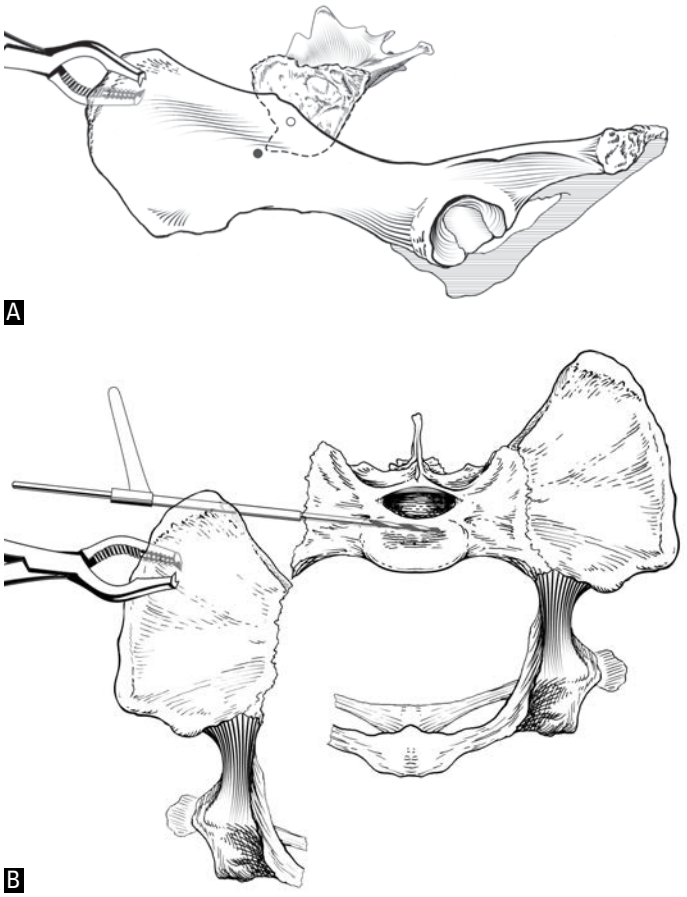


Figure 60-3. **A.** A bone forceps may be used to pull the ilial wing in a ventral direction to identify sacral wing anatomy for precise drill placement. Dots indicate sites of drill holes for the ilium and sacral wing. **B.** A cranial view of the pelvis and sacrum illustrating drill hole placement for the first lag screw, ventral to the spinal canal and beyond midline.

Lag Screw Fixation for Sacroiliac Luxation

One lag screw will be placed through a glide hole in the ilial wing and seated deeply, ventral to the spinal canal into the sacral body. The sacral body generally has space to allow for placement of only one screw, except perhaps in giant breed dogs. A shorter screw is placed through the ilial wing into the dorsocranial aspect of the sacral wing, stopping short of the spinal canal. The screw size selected will depend upon the size of the animal. A screw size of 2.0 to 2.7 mm is selected for cats and small dogs, 3.5 to 4.0 mm cortex or cancellous bone screws are employed in dogs up to approximately 20 kg, while 4.5 mm cortex or 6.5 mm cancellous bone screws can be used in larger dogs. The surgeon must be acutely aware of sacral anatomy to avoid placement of the sacral body screw into the intervertebral space or the spinal canal. Another common mistake is for the screw to exit the sacral body prematurely on its ventral surface resulting in a lag screw with insufficient strength of fixation.

To accomplish accurate screw placement, the surgeon must first identify the sacral wing and the auricular surface. The cranial edge of the sacral wing is established by projecting a line between the craniodorsal aspect of the sacral wing and the ventral aspect of the auricular surface.[4] The screw hole for the sacral body screw is drilled just caudal to this line, approximately 40% from the ventral limit of the sacral wing, taking care to keep the drill hole perpendicular to the lateral surface of the dog. The site for this hole is often centered in the lesser curvature of the auricular surface (See Figure 60-2). If positioned properly, this hole is drilled beneath the spinal canal to a depth of at least 60% of the width of the sacrum (Fig. Figure 60-3B). To achieve this depth, the hole must be drilled in a perfect lateral to medial direction, with the dog perfectly positioned in lateral recumbency. The sacral wing surface is mildly sloped, so that the "safe corridor" drill hole angle, with respect to the sacral wing surface, has been characterized to be 97 + 4°.[5] If the drill exits the sacrum ventrally, the depth must be measured and if insufficient, the angle of the drill must be corrected. When proper depth is achieved, the hole is measured and partially tapped. The glide hole is next drilled through the ilial wing. The site for this glide hole is identified by digital palpation of the roughened surface of the sacroiliac joint on the medial side of the ilial wing, caudal to a bony prominence at this site. The sacral body screw is then placed through the glide hole, and with reduction of the luxation using bone forceps on the ilial wing, the screw is directed by sight into the hole in the sacral body. The screw is tightened to compress the joint and the reduction achieved may be checked by palpation dorsally.

A second screw is placed immediately dorsal and cranial to the first screw, which will locate the screw into the dorsocranial aspect of the sacral wing. This second screw must be shorter to avoid penetration into the spinal canal (Figure 60-4). Closure includes simple interrupted sutures into the layers of the middle gluteal and sacrospinalis fascia, deep lumbar fascia and fat, subcutis, and skin.

Bilateral sacroiliac fracture-luxation is less common than unilateral injury, constituting approximately 23% of sacroiliac injuries.[6] Surgical repair may be completed bilaterally by using the technique described. Although there will be limited space within the sacral body to receive one long screw from either side, screw placement is generally successful. Alternative surgical methods have been described for bilateral sacroiliac repair. One method involves placing the dog in ventral recumbency and approaching both sacroiliac joints simultaneously. A large aiming device is then used to drill a screw hole completely across the sacrum, through the sacral body and both ilial wings.[7] One long screw is placed, compressing the sacroiliac joint on one side and providing a positional screw effect on the other. Another procedure uses a transilial pin, independent of the sacrum to stabilize the sacroiliac joints.[8] This procedure provides less stable fixation, but may be used if lag screw fixation is for any reason unsuccessful.

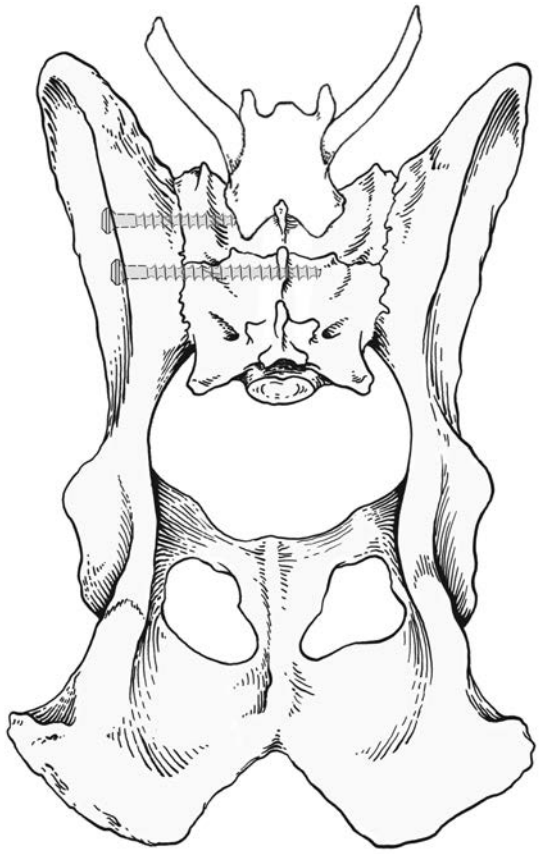


Figure 60-4. Dorsal view of the pelvis and sacrum that illustrates placement of sacral screws.

Minimally Invasive Technique

A technique for closed reduction and percutaneous insertion of lag screw fixation for sacroiliac luxation has been described.[9] Reduction of the hemipelvis is achieved by percutaneous intramedullary pin or bone forceps application to the ischium. Intraoperative fluoroscopic imaging of sacral anatomy is completed using c-arm and radiolucent table top technique. Reduction is achieved and a temporary pin is placed to maintain reduction of the joint. Lag screw fixation, with placement within the sacral body, is then applied using c-arm guidance through several stab incisions.[9]

Prognosis and Results

The clinical results in dogs undergoing sacroiliac repair are generally excellent. Weight bearing begins within several days, often depending upon the severity of associated fractures and other injuries. Slow improvement in lameness and musculoskeletal function can be expected over several months. Exercise restriction is maintained until healing of all fractures is evident clinically and radiographically. A retrospective study reported a rate of loosened sacroiliac fixation of 38%, with frequent shallow screw placement into the sacral body.[6] This same study reported that those fixations with deep screw placement into the sacral body did not loosen. An in vitro biomechanical study of sacroiliac screw fixation reported that two screws placed for sacroiliac fixation were always stronger than one screw and that fixation strength was optimized by use of the largest screws possible.[10]

It is evident that precise and aggressive screw placement in sacroiliac repair improves with clinical experience and provides the best clinical result.

References

1. Miller ME: Ligaments and joints of the pelvic limb. In Evans HE, ed.: Miller's Anatomy of the Dog, 3rd ed. Philadelphia: W.B. Saunders, 1993, p. 244.

2. Piermattei, DL, Johnson KA: Approach to the wing of the ilium and dorsal aspect of the sacrum. An Atlas of Surgical Approaches to the Bones of the Dog and Cat, 4th ed. Philadelphia: W.B. Saunders, 2004.

3. Piermattei, DL, Johnson KA: Approach to the ventral aspect of the sacrum. An Atlas of Surgical Approaches to the Bones of the Dog and Cat, 4th ed. Philadelphia: W.B. Saunders, 2004.

4. DeCamp CE, Braden TD: The surgical anatomy of the canine sacrum for lag screw fixation of the sacroiliac joint. Vet Surg; 14:131, 1985.

5. Shales CJ, Langley-Hobbs SJ: Canine sacroiliac luxation: anatomic study of dorsoventral articular surface angulation and safe corridor for placement of screws used for lag fixation. Vet Surg; 34(4):324-331, 2005.

6. DeCamp CE, Braden TD: Sacroiliac fracture-separation in the dog: A study of 92 cases. Vet Surg; 14:127, 1985.

7. Kaderly RE: Stabilization of bilateral sacroiliac fracture-luxations in small animals with a single transsacral screw. Vet Surg; 20(2):91-96, 1991.

8. Olmstead ML, Matis U: Fractures of the pelvis. In Brinker WO, Olmstead ML, Sumner-Smith G, Prieur WE, eds.: Manual of Internal Fixation in Small Animals, 2nd ed. Berlin: Springer-Verlag, 1998, pp. 148-154.

9. Tomlinson JL, et al: Closed reduction and lag screw fixation of sacroiliac luxations and fractures. Vet Surg; 28(3):188-193, 1999.

10. Radasch RM, Merkley DF, et al: Static strength evaluation of sacroiliac fracture-separation repairs. Vet Surg; 19(2):155-161, 1990.

Trans-ilial/Trans-sacral Pinning of Sacral Fractures

Randall B. Fitch

Introduction

Trans-ilial pin fixation is a useful technique for stabilizing fractures and luxations involving the sacrum. Trans-ilial pins can be used as primary fixation or in combination with other implants (sacro-iliac pin or lag screw fixation) to provide reliable stability with minimal additional morbidity. Implantation is technically simple and implant placement can be verified visually and palpably in surgery. The trans-ilial pin engages the thick dorsal iliac spine providing multiple points of fixation intended to maintain rigid pelvic alignment. Standard 5/64 to 1/8 inch Steinmann pins are sufficiently strong for most patients and suitably malleable for ease of application. The implants are solidly attached to the ilia through their own ilial penetration with additional stability provided by polymethylmethacrylate composite fixation to screws placed within the ilia. This fixation is intended to disperse force through multiple attachment sites in the thick dorsal iliac spine of the ilium. The composite repair provides a forgiving and adaptable construct which is less technique sensitive so that ideal apposition or implant position are not necessarily required for construct rigidity and clinical success. The technique is highly adaptable for odd injuries including severe sacral fractures, bilateral injuries and very small patients.

The sacrum has very unique anatomy due to its dual functional roles as a weight-bearing support and as a neurologic conduit. The sacroiliac joint is both a synovial joint and a fibrocartilaginous synchondrosis. Its distinctive anatomy results in a wide variety of injuries many of which do not necessitate surgical intervention. The majority of sacroiliac trauma requiring surgical stabilization occurs in patients with bilateral injuries. Frequently the contralateral injury is not sacral damage, but other orthopedic trauma such as a contralateral pelvic fracture. Therefore common indications for sacroiliac stabilization include providing weight-bearing function, reducing pain and protecting other orthopedic fixations. However, fixation must be provided while respecting the sacrum's neurologic role. The unique structural architecture of the sacrum combines cancellous bone intertwined with nerve roots providing an extraordinary repair challenge. Due to the variety of sacral injuries that occur, the following chapter is subdivided into sections by injury type to provide coherent specific suggestions for different injuries.

Surgical Preparation

Surgical preparation for the majority of sacral injuries consists of placing the patient in ventral recumbency with the legs placed under the patient in a near normal sitting position with the stifles flexed under the body, but the tarsus extended for better stability. Towels, sand bags or positioning bags are placed to ensure symmetry and security of the patient. The patient is prepped from 10 cm cranial to the ilial wings caudally to the tail (which is commonly placed in a temporary wrap). The surgical preparation extends laterally and ventrally to below the greater trochanters of the femur. For patients requiring multiple orthopedic repairs, the sacral trauma is typically addressed first since the sacral repair is more position sensitive. The patient can then be repositioned as required for the additional repairs. Pelvic symmetry and implant position can be more easily assessed with the patient symmetrically positioned in ventral recumbency.

A key to facilitating exposure and pin placement is performing curvilinear incisions on each side of the ilia to facilitate exposure and pin placement. The incisions should start at the cranial ventral iliac spine extending vertically in a dorsal direction and curving caudally to follow the dorsal margin of the ilial shaft to a few centimeters cranial the acetabulum (Figure 60-5). This incisional technique provides good visibility of the sacral articular surface with minimal skin interference during implant placement. The dorsal medial skin edges of both incisions can be sutured to each other thus everting the skin to increase exposure. A more limited surgical approach can be used for single ilial pin placement (commonly performed on the contralateral side). Strong gluteal fascia overlies the iliac spine at the origin of the middle gluteal muscle. Sharply incising over the lateral aspect of the iliac spine and reflecting the middle gluteal muscle caudally provides good visibility and retains the integrity of the tissue for surgical closure. When trans-sacral implants are utilized, the incision is expanded and muscle elevation will include the origin of the

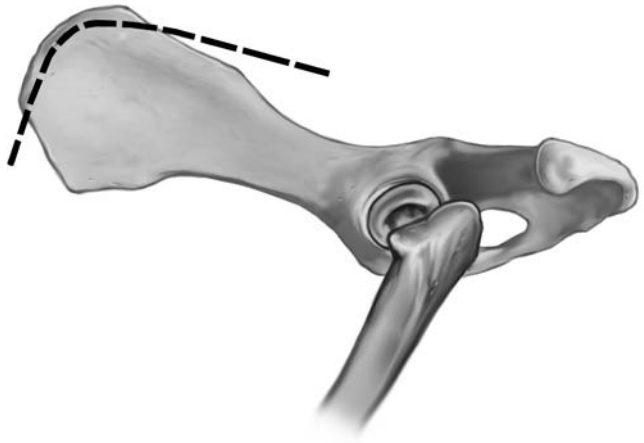


Figure 60-5. (surgical approach) A curvilinear incision is made over the ilium starting at the cranial ventral iliac spine and advancing in a dorsal direction and curving caudally to follow the dorsal margin of the ilial shaft. This incision provides good visibility of the sacral articular surface with minimal skin interference during implant placement. A more limited approach is used for simple ilial pin placement.

deep gluteal muscle. Surgical closure includes reestablishing the gluteal fascia attachment which provides good mechanical strength, minimizes suture interference with functional muscle, and provides coverage of implants. The epaxial fascia and dorsal sacroiliac ligaments when disrupted are closed in a similar manner. The subcutaneous tissue and skin are closed in a traditional matter.

Cement Tips

The following surgical techniques utilize composite fixation in which a small quantity of polymethylmethacrylate (PMMA) bone cement is used to bond the metal implants forming a rigid brace that is firmly attached to the ilia. Care must be taken to ensure aseptic technique when using bone cement, since skin contamination could result in infection and colonization of the PMMA which is difficult to treat; for this reason prophylactic peri-operative antibiotics are commonly administered. A stockinette or towel can be sutured into the incisional edge to improve visibility and minimize skin exposure. Frequent lavage with sterile saline is encouraged. A 20 g packet of PMMA is sufficient for both sides. Setting of the PMMA following addition of the polymer powder to the liquid monomer takes approximately 8 to 15 minutes. The PMMA is typically mixed for 1 to 2 minutes prior to application and applied in a viscous liquid stage. Application of the cement with a syringe provides better control with less spillage. Screws are inserted into the lateral ilium with 3 to 4 mm of the screw head exposed above the bone surface to allow bonding to the PMMA. A flat instrument (such as a periosteal elevator) is used to form and mold the PMMA around the implants, but only a small quantity is required. A commercially available trans-ilial rod with nuts is also available which avoids the use of PMMA and the necessity for a contralateral surgical approach (IMEX Veterinary, Inc.).

Axial Sacral Fractures

The sacrum consists of an osseous spinal canal and multiple foramina which protect the cauda equina and associated ventral and dorsal spinal nerves (Figure 60-6). When the structural integrity of the sacrum is compromised, placing an implant such as a lag screw across the fracture risks inadvertent nerve root damage. Fixation across a sacral fracture may induce nerve trauma directly, by displacement or compression. Forty-three percent of patients undergoing sacral fracture fixation with traditional techniques had neurologic deficits following surgery that were not noted prior to surgery (Kuntz 1995). Trans-ilial pin fixation relies on stabilization anchored at multiple points between contralateral ilia without necessitating placing implants through or compression across the sacrum.

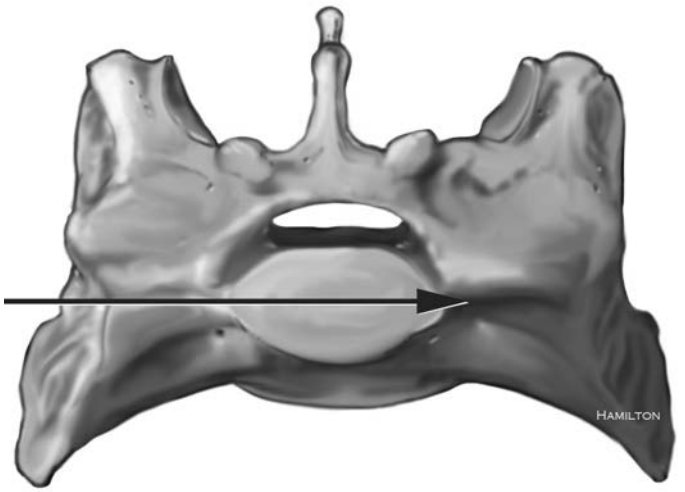


Figure 60-6. The sacrum contains nerve roots that contribute to the pelvic, pudendal and perineal nerves as well as components of the sciatic nerve. Disruption of these osseous canals can produce neurologic dysfunction either through the initial injury or additional surgical trauma. The particular architecture of the sacrum provides only small corridors for substantial bone engagement used for surgical fixation.

Surgical Technique

Following surgical approach and alignment of the pelvis, two pins are placed transversely through both ilia dorsal to the sacrum (Figure 60-7). One pin is placed directly behind the lumbosacral diarthrodial joint resting on the dorsal surface of the sacrum and engaging both ilia at the caudal iliac spine. The second pin is placed transversely, cranially and parallel to the first pin engaging both ilia in the cranial dorsal iliac spine (approximately 2.5 cm cranial to the first pin in a 35 Kg dog). The fixation and pin penetration can be visualized to ensure adequate ilial bone pentration through the thick dorsal caudal iliac spine. The pin is typically driven with a power drill. A blunt instrument can be used to direct the penetration of the contralateral ilium which commonly requires ventral deflection of the pin for maximal bone engagement. Fracture alignment can be additionally adjusted during the placement of pins. Compression at the cranial pin location will displace the caudal pelvic alignment laterally correcting medial displacement which is common in these injuries. The pins are bent at a 90° angle against the lateral surface of the ilium and cut to a length so when rotated they

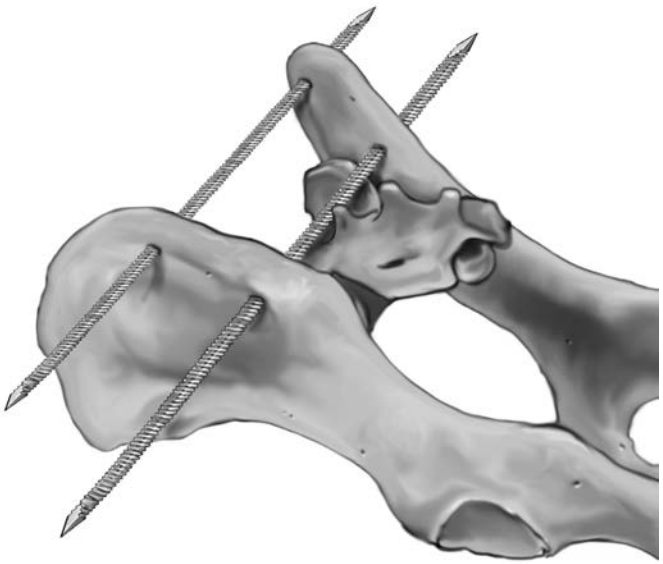


Figure 60-7. Trans-ilial brace: Two trans-ilial pins placed transversely through both ilia dorsal to the sacrum. One pin is placed directly behind the lumbosacral diarthrodial joint contacting the dorsal surface of the sacrum and penetrating both ilia at the caudal iliac spine. The second pin (arrow) transversely and parallel to the first engaging both ilia, but cranial to the first in the cranial dorsal iliac spine.

will overlap (approximately 2 cm). Two screws are applied to the lateral surface of the ilia and polymethylmethacrylate is applied and molded to the pin and screw construct on each side. The ilium is subjected to torsional and fulcrum forces transferred through the acetabulum during weight-bearing. The two trans-ilial pins are intended to provide a rigid brace with multiple points of fixation which counteract weight-bearing forces. Minimal pelvic displacement and good early weight-bearing were observed in dogs with sacral injuries, including comminuted sacral fractures, using this fixation. Anatomic reduction is not required for rigid fixation, thus intentional malalignment can be maintained when desired (i.e. prevention of further nerve root manipulation and possible entrapment).

Unilateral Abaxial Sacral Fractures and Sacroiliac Luxations

Abaxial sacral injuries occur lateral to the sacral foramina and include fractures of the wing of the sacrum and separation of the sacroiliac joint. Placement of implants through the sacral body or dorsal to the spinal canal through the ilia will provide mechanical support that is unlikely to cause additional neurologic injury. Traditional lag screw fixation through the ilium and into the sacral body with greater than 60% depth of penetration across the sacrum provides reasonable stability with 88% success achieved with ideal implant placement (DeCamp 1985) using open reduction or 100% success with fluoroscopic guidance in closed fixations (Tomlinson 1999). However, sacroiliac luxations often occur with fractures that obscure traditional landmarks making identification of the sacral body more challenging without the aid of fluoroscopy. In one study only 33% of lag screws were placed in the sacral body. Trans-ilial pin fixation can be used to reinforce stability of traditional lag screw repairs especially in polytrauma cases in which early increased stress across the repair is anticipated or in which lag screw fixation may be problematic. Single trans-ilial pin fixation has also been used as a less invasive alternative in juvenile patients with painful, less severe sacroiliac luxations.

Surgical Technique

In this technique, sacroiliac lag screw fixation is placed by traditional surgical technique into the sacral body and reinforced with a trans-ilial pin. The sacroiliac joint is exposed through a dorsal approach. The lateral surface of the sacrum is exposed by ventrolateral retraction of the ilial wing. Careful placement of a blunt Hohmann retractor under the ventral surface of the sacrum provides excellent retraction of the ilial wing and provides exposure of the lateral sacral surface. Care should be used to ensure the tip of the Hohmann remains lateral and does not penetrate medially. The landmarks of the lateral surface of the sacrum should be visible. These include the crescent shaped articular surface, a fibrocartilaginous dorsal articular surface, and a ventral edge of the sacrum (Figure 60-8). A line is visualized from the craniodorsal point of the sacral wing to the ventral point of the wing. The point of drill bit entry is just caudal to the line at 60% of the distance from dorsal to ventral (slightly caudoventral to the halfway point). Difficult placement of the transsacram screw hole can occur due to many reasons including loss of visible landmarks (most commonly due to fracturing of the craniodorsal landmark) and incorrect orientation of the transsacral screw hole (most commonly due to tilting of the sacral that arises during retraction or loss of proper patient position). The sacral wing notch and articular surface can be used as additional landmarks to confirm an ideal drill entry point. The

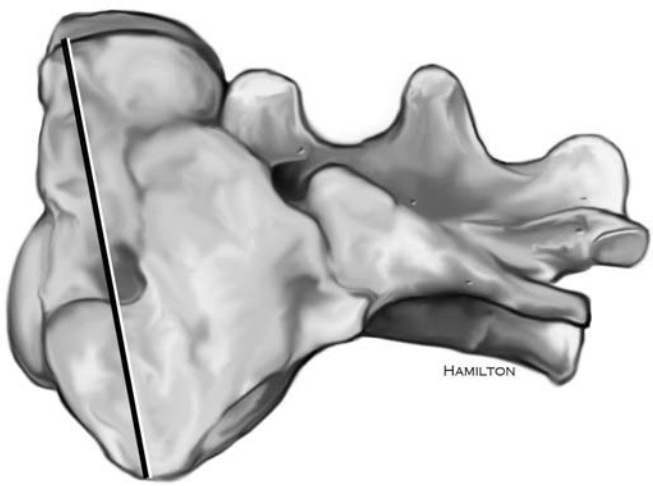


Figure 60-8. The lateral surface of the sacrum: The landmarks of the lateral surface includes the crescent shaped articular surface, a fibrocartilaginous dorsal articular surface, and the ventral edge of the sacrum. The ideal entry point for engagement of the sacral body can be identified by drawing a line from the from the craniodorsal point of the sacral wing to the ventral point of the wing. The point of drill bit entry is just caudal to this line at 60% of the distance from dorsal to ventral. The sacral wing notch and articular surface can be used as additional landmarks to confirm ideal drill entry point. The orientation of the drill must compensate for the offset of the sacral surface to achieve maximal bone engagement.

orientation of the sacral drill hole can be aided within surgery by observing the lateral surface of the sacrum. A small Steinman pin (5/64 in.) can be used in place of a drill bit. The additional pin length, as compared to a drill bit, serves for better assessment of pin orientation with less interference with regional structures and additionally, trans-ilial pin penetration helps assure proper pin placement. Remember that the pin direction is not perpendicular to the surface of the lateral sacral surface since the lateral surface of the sacrum is tilted caudodorsal approximately 15 degrees. Aligning the pin perpendicular to the lateral surface of the sacrum typically causes the pin to breach the ventral surface of the sacrum or to enter the lumbosacral disk space. Pin placement should be perpendicular to the axis of the dog, but retraction can alter the orientation of the sacrum. Thus, some relaxation of the retraction can correct disorientation especially if hard retraction is being utilized.

Following placement of the screw pilot hole into the sacrum, a guide hole is placed through the ilial wing at the level of the sacroilial articulation on the medial aspect of the displaced ilium. The articular surface on the medial side of the ilium is palpable and can be used to assist guide-hole placement. Remember the ilium is also oriented obliquely so the guide hole should be tilted approximately 15 degrees from the saggital axis of the ilial wing and enters more ventrally than expected (approximately 1/3 the distance from the ventral border). The guide-hole diameter needs to be greater than the outside thread diameter of the screw to provide lag compression. A washer can be used in combination with the screw to ensure good compression across the sacroiliac joint especially in younger dogs with softer bone. Depth of screw purchase is estimated from pre-operative radiographs and a screw length is chosen that crosses greater than 60% of sacral width including the thickness of the ilium. The screw is placed through the guide hole in the ilium and lined up with the pilot hole in the sacrum. The sacroiliac joint is reduced as the screw is driven into the sacral body. Reduction most commonly requires caudal retraction and occasional rotation of the ilium. Symmetry and reduction can be ensured by palpation of the contralateral ilial wing prior to final tightening of the screw which will compress the sacroiliac joint.

Difficult reductions can also be aided by temporarily replacing the screw with a pin. The pin (with chuck) is placed through the ilial guide hole into the sacral pilot hole and used as a lever to reduce and align the sacroiliac joint. The pin provides a mechanical lever (no screw and driver interface) and the smooth pin surface allows it to slide without resistance. The sacroiliac joint is temporarily stabilized with an additional sacroiliac pin which is later removed after the original pin is again replaced with a screw or converted to a trans-sacral pin brace (see next section).

When additional stability is desired, a trans-ilial pin can be added intra-operatively. This requires a limited contralateral dorsal surgical approach to expose the dorsolateral aspect of the ilial wing. A Steinmann pin is driven transversely through both ilia, over the dorsal surface of the sacrum just behind the lumbosacral articulation. The pin location can be verified visually and by digital palpation to ensure that the ilia are well engaged and the pin contacts the dorsal surface of the sacrum. The ends of the

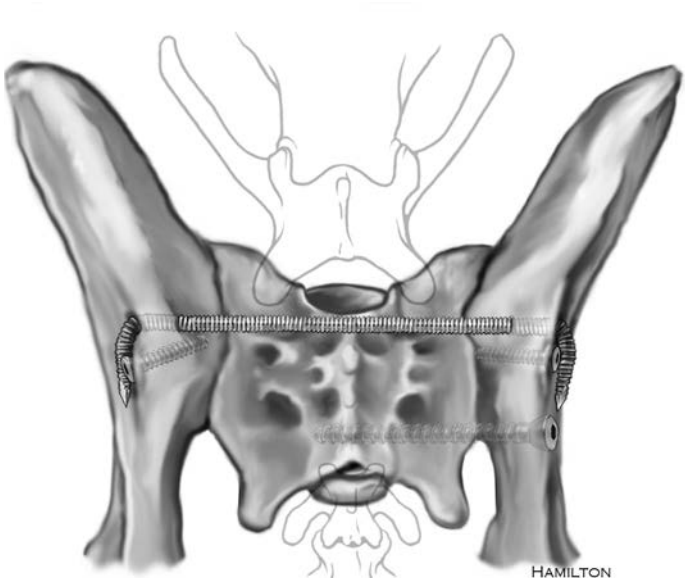


Figure 60-9. Trans-ilial pin fixation used in combination with traditional sacroiliac lag screw fixation. A sacroiliac screw is first placed through the ilium and into the sacral body using lag screw technique. When additional stability is desired a trans-ilial pin is driven transversely through both ilia, over the dorsal surface of the sacrum just behind the lumbosacral articulation. The ends of the pin are bent over and an additional screw is placed through the lateral surface of the ilia and polymethylmethacrylate (not shown) is applied incorporating the pins and neighboring screws. A limited dorsal approach to the contralateral ilial wing is required.

Steinmann pins are bent over at the level of the ilial surface. One or two additional screws are placed through the lateral surface of the ilia adjacent to the pin and polymethylmethacrylate is applied incorporating the pins and neighboring screws (Figure 60-9).

Bilateral Sacral Iliac Luxations and Fractures

Repair of bilateral abaxial sacral injuries can be challenging due to anatomic limits in ideal bone purchase. Placing two lag screws into the sacral body with greater than 60% purchase can be problematic due to interference of the two converging screws in a very small target. Single screw techniques theoretically have some advantages, but become problematic due to technical difficulty and availability of proper implants in many practices (proper screw length and nut availability). Trans-sacral pin placement is relatively simple. It avoids the use of a bone tap, decreasing the opportunity for damage to the cauda equina. The pin orientation within the sacral body can be verified intra-operatively by comparing the exit points of the pin in the lateral surfaces of the sacrum. The pin is easily replaced if ideal orientation is not achieved. Reduction of the sacroiliac joint does not require alignment of drill holes which can be fickle with screw placement. Trans-sacral pin placement is done following reduction of the sacroiliac joint by simply advancing the pin through the ilium. Complete reduction can be achieved during bending of the pin using a chuck, but a trans-ilial pin is placed to provide additional stability. This fixation engages multiple cortices providing good quality bone purchase and stability, thus decreasing the chance of the implant fracturing out of the sacrum which can occur with screws. The trans-sacral pin is relatively uncomplicated to place and a viable alternative

to placing bilateral lag screws in dogs with bilateral injuries, therefore simplifying the surgical technique and shortening operative time.

Surgical Technique

The lateral surfaces of the sacrum are exposed and visualized. The center of the sacral body is identified by visualizing a line from the craniodorsal point of the sacral wing to the ventral point of the wing (See Figure 60-8). The point of pin entry is just caudal to this line at 60% of the distance from dorsal to ventral (slightly caudoventral to the halfway point). The sacral wing notch or the crescent shaped articular cartilage can be used as additional landmarks which is especially helpful when landmarks are obscured due to trauma. The pin is advanced transversely across the sacrum and should exit at the same location on the opposite lateral surface of the sacrum (Figure 60-10). A "C" shaped drill guide is helpful in providing accurate drill orientation. Once proper trans-sacral pin placement is established, the pin is retracted on one side of the sacroiliac joint to allow unilateral sacroiliac reduction. Sacroiliac reduction is achieved and the trans-sacral pin is advanced through the ilium. The drill is replaced on the opposite end of the pin and the pin is retracted in the opposite direction to allow reduction of the contralateral sacroiliac joint. The pin is then advanced across this ilium just as before, but in the opposite direction.

Following trans-sacral pin placement, a trans-ilial pin is placed with the Steinmann pin driven transversely through both ilia, contacting the dorsal surface of the sacrum just caudal to the lumbosacral articulation (as previously described). The pin location can be verified visually and by digital palpation to ensure that the ilia are well engaged and the pin contacts the dorsal surface of the sacrum. The ends of the Steinmann pins are bent over at approximately 90 degrees and cut so that the pins can be rotated to overlap. One to two additional screws are placed into the lateral surface of the ilial wing adjacent to the overlapping pins. PMMA is applied to incorporate the pins and screws into a composite fixation.

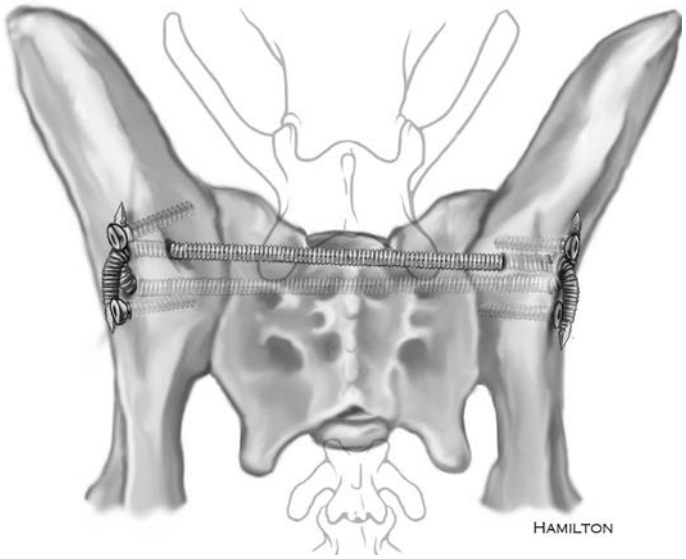


Figure 60-10. Combined trans-ilial and trans-sacral pin fixation can be used for bilateral sacral injuries. One pin is placed transversely through the sacrum and associated sacroiliac joint and ilia. A second pin is placed dorsal to the first pin transversely contacting the dorsal surface of the sacrum penetrating the thick ilial wing slightly caudal of the lumbosacral joint. The two pins are bent over ninety degrees, cut and rotated until they overlap. Screws are placed in the lateral surface of the ilium and polymethylmethacrylate (not shown) is applied to incorporate the implants into a component fixation.

Post-Operative Care

The trans-ilial pin provides a rigid fixation with low morbidity, so early weight-bearing is anticipated. Enforced restricted activity is recommended for six weeks. However, aggressive physical therapy has been performed for concurrent injuries in many patients. Pin migration, implant discomfort or infection has not been commonly associated with this technique and implant retrieval is seldom required.

Suggested Readings

Averill SM, Johnson AL, Schaeffer DJ. Risk factors associated with development of pelvic canal stenosis secondary to sacroiliac separation: 84 cases (1985-1995). *J Am Vet Med Assoc* 211:75, 1997.

DeCamp CE, Braden TD. Sacroiliac fracture-separation in the dog. A study of 92 cases. *Vet Surg* 14:127, 1985.

DeCamp CE, Braden TD. The surgical anatomy of the canine sacrum for lag screw fixation of the sacroiliac joint. *Vet Surg* 14:131, 1985.

Hulse DA, Shires P, Waldron D, Hedlund C. Sacroiliac luxations. *Comp Contin Ed Pract Vet* 7:493, 1985.

Jacobson A, Schrader SC. Peripheral nerve injury associated with fracture or fracture-dislocation of the pelvis in dogs and cats: 34 cases (1978-1982). *J Am Vet Med Assoc* 190:569, 1987.

Kuntz CA, Waldron D, Martin RA, Shires PK, Moon M, Shell L. Sacral fractures in dogs: a review of 32 cases. *J Am Anim Hosp Assoc* 31:142, 1995.

Pare B, Gendreau CL, Robbins MA. Open reduction of sacral fractures using transarticular implants at the articular facets of L7-S1: 8 consecutive canine patients (1995-1999). *Vet Surg* 30:476, 2001.

Tomlinson JL, Cook JL, Payne JT, Anderson CC, Johnson JC. Closed reduction and lag screw fixation of sacroiliac luxations and fractures. *Vet Surg* 28:188, 1999.

Ullman SL, Boudrieau RJ. Internal skeletal fixation using a Kirschner apparatus for stabilization of fracture/luxations of the lumbosacral joint in six dogs. A modification of the transilial pin technique. *Vet Surg* 22:11, 1993.

Repair of Ilial Fractures

Charisse D. Davidson, Timothy M. Lenehan, and Guy B. Tarvin

Introduction

It has been reported that 20 to 30% of all fractures in small animals are pelvic fractures and of these 18 to 46% are ilial in the canine.[1,2] In dogs, pelvic fractures are commonly the result of vehicular trauma, while in cats, falls from a great height are the most common cause. Due to the nature of these injuries, it is essential that other organ systems be assessed and treated appropriately before repair of the orthopedic injuries is initiated. Pelvic fractures have been associated with abdominal trauma, (urinary tract

and abdominal organs), thoracic injury, and peripheral nervous system insult. In particular, cranial or craniomedial displacement of the iliac bone has been associated with damage to the L6 and L7 nerve roots and injury to the lumbosacral trunk.[3]

The lumbosacral trunk is composed of the ventral branches of the last two lumbar and first two sacral nerves and it runs caudally along the medial surface of the ilium. The ischiatic nerve begins when the second sacral nerve joins the lumbosacral trunk. Although the ischiatic nerve is located medial to the ilium it is less closely associated with bone and therefore less susceptible to direct injury (Figure 60-11). Ischiatic nerve injury is more often associated with acetabular fractures and secondary fibrosis associated with the healing of ischial fractures.[3] Cutaneous, sensory, and voluntary motor deficits associated with the L6, L7, S1 and S2 nerve roots are the most common peripheral nerve deficits associated with pelvic fractures. However depression of the sciatic reflex (cranial tibial reflex) and decreased sensation of the lateral digit of the affected limb may also be present.

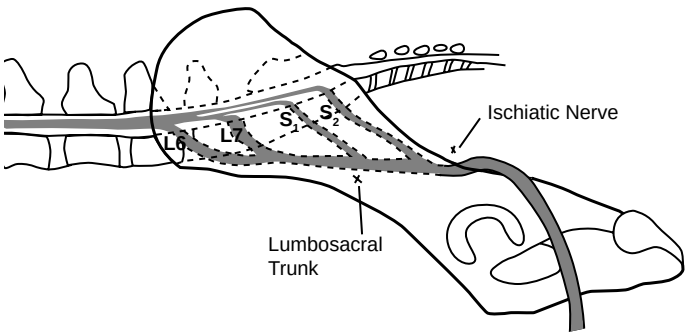


Figure 60-11. The lumbosacral trunk is composed of the ventral braches of the last two lumbar and first two sacral nerves and it runs along the medial surface of the ilium.

Classification of Ilial Fractures

Ilial fractures have been classified as either ilial body fractures with an interruption of the weight bearing arch or ilial wing fractures which are sustained cranial to the sacroiliac joint whereby the weight bearing arch is left intact.[4] Ilial wing fractures have been further classified as either cranial avulsion fractures (where the most cranial part of the ilial wing is separated from the ilial body at the insertion site of the sartorius and tensor fascia latae muscles) or central ilial wing fractures (where the separation occurs in the region on the middle gluteal muscle insertion). Ilial fractures can be further described as simple or multifragmentary, unilateral or bilateral. Very often they are associated with other pelvic fractures.

For most ilial fractures, a lateral approach allows optimal visualization of all portions of the ilium (Figure 60-12).[5] The patient is placed in lateral recumbency with the affected side up, and the limb is prepared for aseptic surgery. A skin incision is made starting cranially at the center of the iliac crest and continued caudally in a straight line to the greater trochanter. The subcutaneous fat and fascia are incised along the same line. The tensor fascia lata is reflected cranially to expose the middle gluteal muscle. Dissection is continued in a cranial direction between the tensor fascia lata and middle gluteal muscle to the wing of the ilium. Elevation and retraction of the middle and deep gluteal muscles exposes the wing and body of the ilium.

If exposure of the ventral ilium or sacroiliac joint is needed this can be accomplished by a ventral extension of the above approach.[6] The iliacus muscle is incised along its origin at the ventromedial border of the ilium. The iliacus muscle is elevated subperiosteally allowing exposure of the ventral ilium and/or digital palpation of the sacroiliac joint and lumbosacral trunk. The lateral approach to the ilium can also be extended caudally and combined with either a craniolateral, dorsal approach, or a caudal approach to the coxofemoral joint, allowing access to the acetabulum and ischium when indicated.

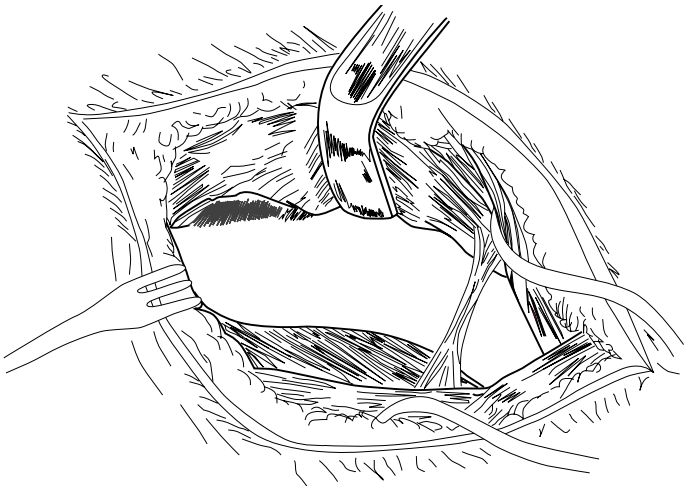


Figure 60-12. Lateral approach and exposure of the ilium.

Repair Options

Open reduction and internal fixation of ilial fractures is indicated when the weight bearing portion of the ilium is involved (ilial body fractures), when there is gross displacement of the fracture fragments, when the diameter of the pelvic canal is compromised, when the fracture impinges on the lumbosacral trunk, if there is gross pelvic instability(as is often the case with bilateral pelvic fractures) or when there are concurrent fractures of the ipsilateral acetabulum, ishium, and/or pubis. Precise reduction and rigid fixation will allow for early ambulation and healing. This in turn reduces complications associated with conservative management and prolonged recumbancy.

Plate fixation is the most common method of repair. Lag screw fixation has also been advocated and may also be useful to supplement plate fixation when needed. Pin/ wire fixation +/- polymethymethacrylate, external skeletal fixation, and mini-plate fixation are also possible but have been associated with increased morbidity and complication rates.[2,7]

Bone Plating

Stabilization of ilial fractures using a laterally placed bone plate is the most common repair technique used and the simplest to perform. The ilium is a wide, flat bone and lends itself readily to plating. The ilial fragments should be of sufficient length to allow at least two bone screws proximally and distally. Reduction can

be accomplished by grasping the fragment ends with Verbrugge or speedlock forceps and bringing the ends into proper alignment; however, further manipulation is often needed. One technique that can be used when the hip joint is intact but the ischium is broken, is to grasp the greater trochanter with Lewin forceps and then manipulate the distal ilial fragment into reduction (Figure 60-13). Alternatively, if the hemipelvis is intact, Kern bone-holding forceps or an intramedullary pin can be placed in the tuber ischium to allow manipulation of the distal segment. Once the fracture has been reduced, bone holding forceps are applied, or an assistant maintains reduction while the plate is contoured and applied.

In some cases, the aforementioned reduction techniques are insufficient because of muscle contracture. In these patients the plate may be contoured, using the radiograph of the intact opposite side as a guide when possible, and is applied only to the distal fragment. The fragment ends are brought as close to reduction as possible. A Verbrugge clamp then is used to complete reduction, and the plate is secured to the proximal segment (Figure 60-14 A, B and C).[8]

During drilling, measuring with a depth gauge, and tapping of the screw holes, care must be taken not to injure medial structures such as the rectum and lumbosacral trunk. Optimally, at least one screw in the proximal segment should engage the wing or body of the sacrum. Although this maneuver results in greater holding power, care should be taken, just as in the repair of sacroiliac dislocation, to avoid penetrating the spinal canal in that area. Traversing the sacroiliac joint with a screw may lead to degenerative sacroiliitis, however to date there are no significant reports of this phenomenon in the dog.

If needed, rigidity of the repair can be increased by the addition of a mini or cuttable plate or intrafragmentary screws to the ventral (tension-side) of the ilium (Figure 60-15). Ventral fixation can be applied prior to the lateral plating to maintain reduction during plating.[2,7] Steinmann pins placed through the contoured plate screw-holes can also be used to maintain reduction. Pin size should not be greater that the diameter of the drill bit for the screws to be used. As plating proceeds the pins are removed and replaced with screws.

Fractures of the ilium with concurrent sacroiliac luxations are best treated with plate fixation. The ventral aspect of the ilium is exposed as described previously. Blunt dissection, preferably with the finger, is directed along the medial face of the ilium until the articular surface of the sacral body and ilium are palpated (Figure 60-16 A and B). Once the sacroiliac luxation has been reduced, a small Kirschner wire can be inserted through the ilium and into the sacral body to maintain reduction. The plate is applied as previously described for ilial fractures. If possible, one of the plate screws is placed thru the sacroiliac joint in a lag fashion to afford compression of the ilium to the sacrum. If the fracture precludes this, the sacroiliac luxation is reduced with a lag screw and the iliac fracture is reduced and plated separately.

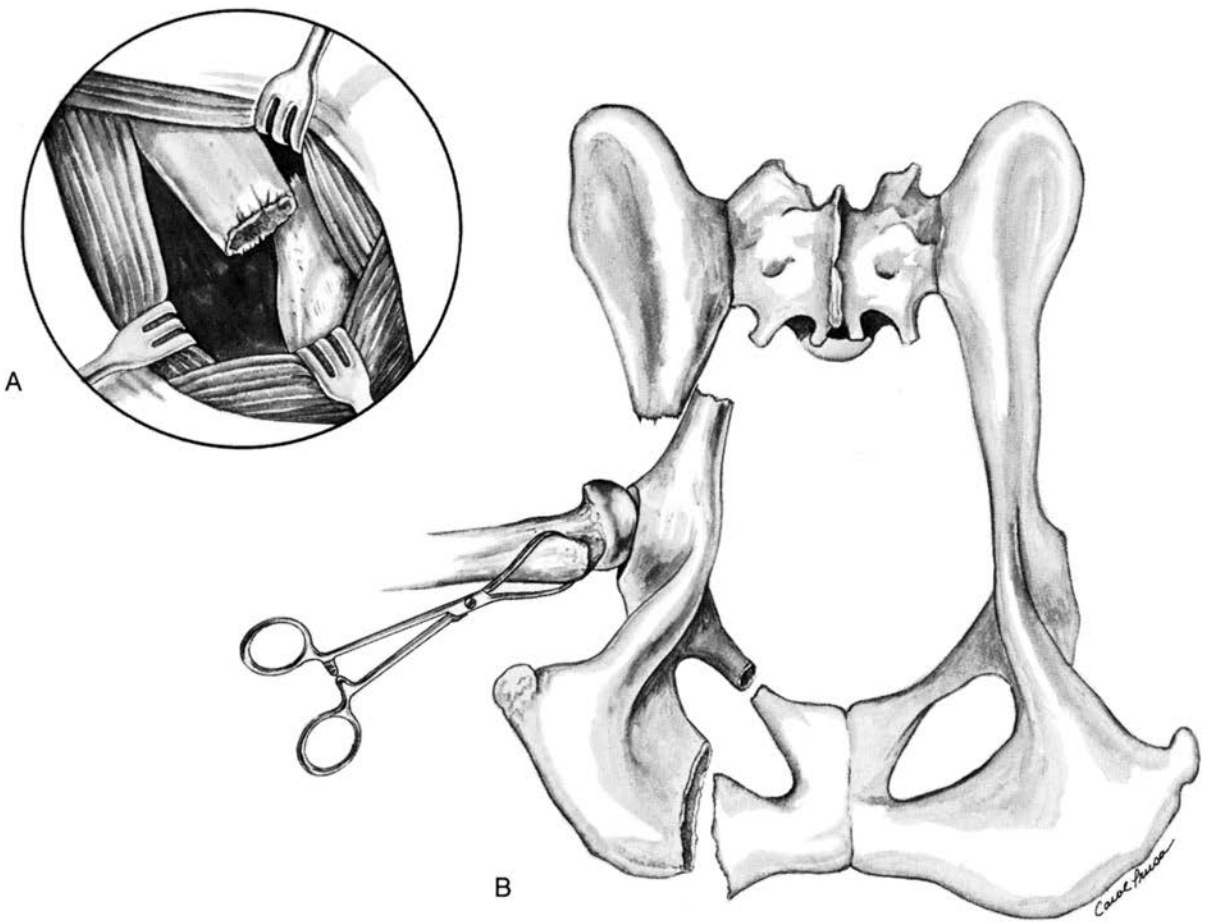


Figure 60-13. Reduction with aid of a Lewin clamp attached to the greater trochanter.

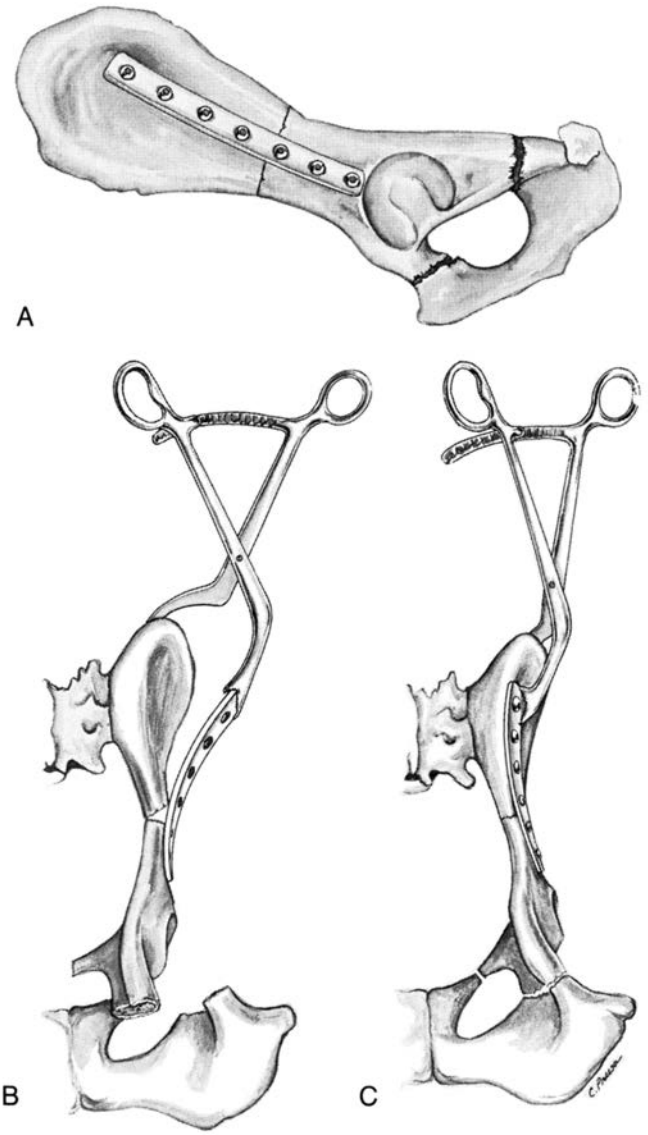


Figure 60-14. Repair of ilial fracture with bone plate. **A.** Reduced fracture with bone plate in place. **B** and **C**. Reduction by precontouring a plate, attaching it to one fragment, and then levering the other fragment in place with a Verbrugge clamp.

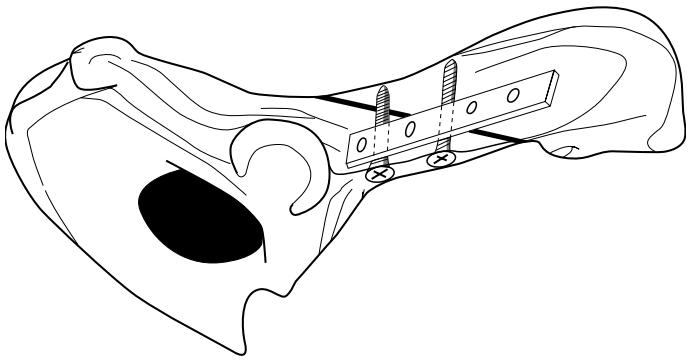


Figure 60-15. Rigidity of the repair can be increased by addition of interfragmentary screws to the ventral aspect of the ilium.

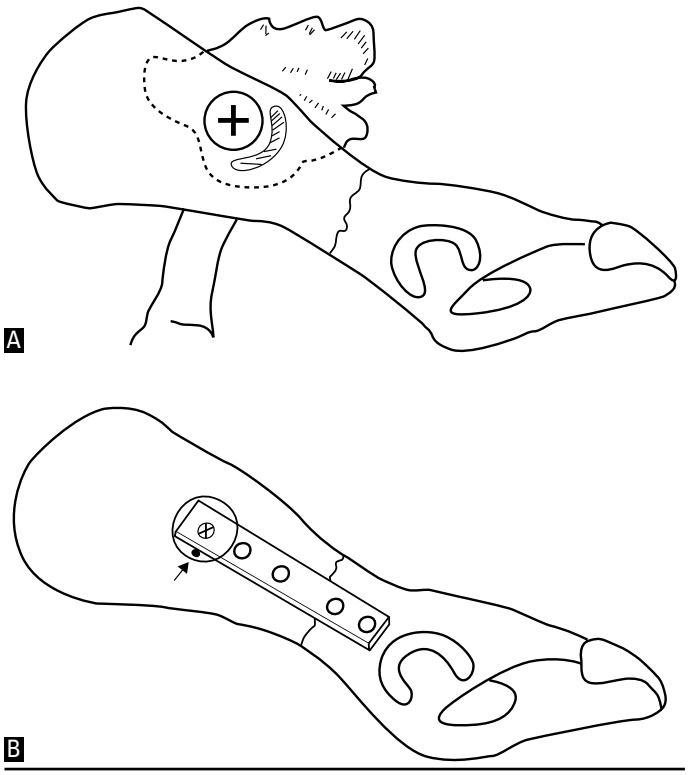


Figure 60-16. Repair of concurrent ilial fracture and sacroiliac luxation. **A.** The index finger is used to palpate the sacrum from the ventrolateral approach. This helps to reduce the sacroiliac luxation and in screw placement. **B.** After a small pin *(arrow)* is placed, the plate is applied to the ilium. The most rostral screw is placed through the ilium and into the sacrum.

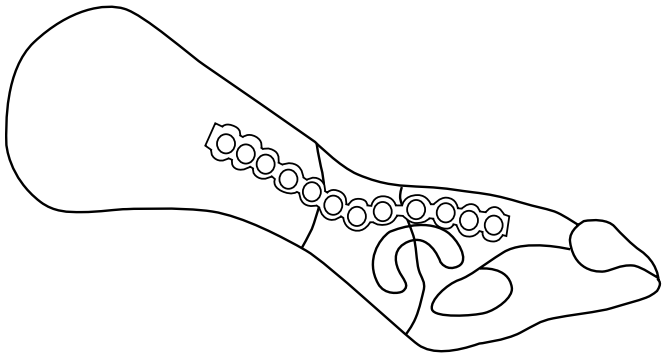


Figure 60-17. Fixation of segmental ilial fractures with an acetabular component can be achieved with a reconstruction plate contoured to match the dorsal aspect of the acetabulum.

Additional exposure via trochanteric osteotomy may be needed when repairing ilial fractures near the acetabulum or segmental ilial fractures with an acetabular component. Fixation of these fractures is achieved with a bone plate or a reconstruction plate contoured to match the dorsal aspect of the acetabulum (Figure 60-17).

Alternatives to Plating

When plating equipment is unavailable, some fractures of the ilium are amenable to lag screw fixation or pinning. Long oblique fractures of the ilial body can be effectively stabilized with two lag screws. The ventral aspect of the ilium is exposed

as described previously and the iliacus muscle is retracted medially. Screws are inserted in a ventral to dorsal direction across the fracture line resulting in compression. When applied properly to the appropriate fracture, lag screw fixation may be mechanically equivalent to plate fixation.[7]

Although mechanically inferior, pinning can be successful in fractures involving the proximal or midbody area of the ilium in small dogs and cats. Fractures distal to the midbody of the ilium do not often permit sufficient length of the insertion of the pins to provide adequate stability.

Insertion of each pin is started in the proximal fragment near the cranial dorsomedial aspect of the wing of the ilium. The pin is driven down the shaft of the ilium and into the distal segment (Figure 60-18. A and B). A pin of identical length is used to check the distance traversed. The hip joint should also be palpated to determine whether the implant has entered the joint. If so, the pin is retracted until no palpable evidence of joint invasion is noted. At least two pins should be driven in a similar manner to improve rotational stability. Ilial pinning is technically difficult because the medullary cavity of the ilium is narrow, and the cortex is often penetrated during pin insertion.

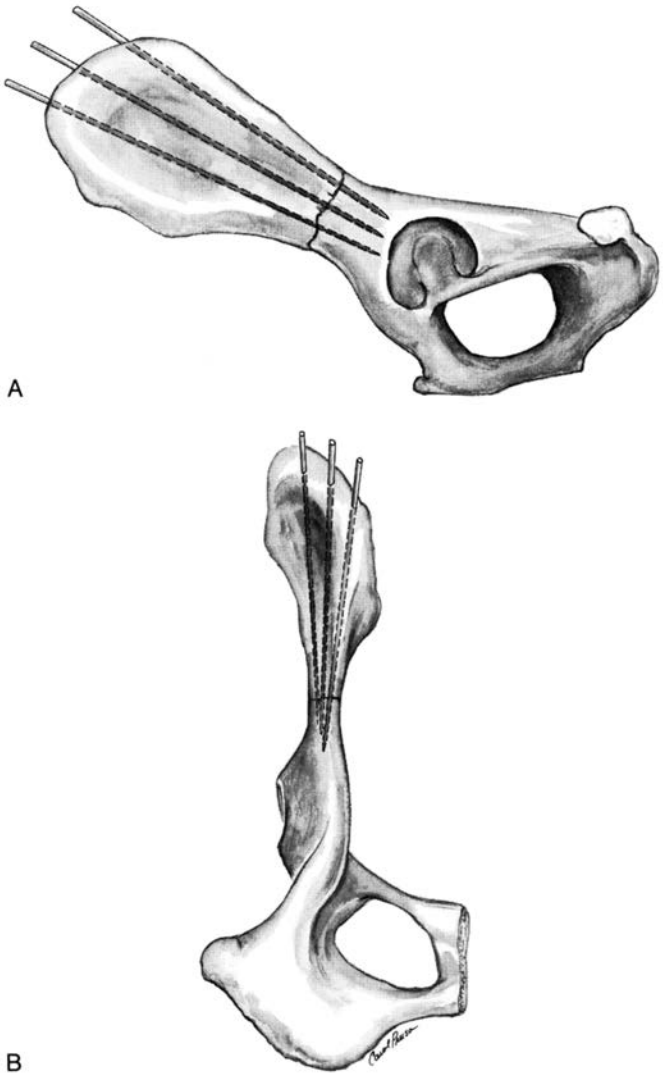


Figure 60-18. A and **B.** Placement of pins for repair of ilial fractures.

Hemicerclage wiring also can be used in smaller dogs and cats to aid in stability in fractures of the ilial midbody.

Postoperative Care

Postoperative radiographs (ventrodorsal, lateral, and oblique hemipelvic) are indicated to evaluate the implants and reduction. Appropriate steps should be taken if errors in reduction have occurred. If adequate fixation is accomplished, no special aftercare is required. Appropriate bedding and nursing care, along with confinement for 4 to 8 weeks, are advised. Physical and radiographic assessment at 4 and 8 weeks post-operatively are recommended to evaluate implant stability and fracture healing. Surgical procedures can be staged approximately 1 to 2 days apart if the animal's condition disallows simultaneous fixation of both sides.

References

1. Verstraete FJM, Lambrechts NE: Diagnosis of soft tissue injuries associated with pelvic fractures, *Compend Contin Educ Pract Vet* 14: 921, 1992.

2. Breshears LA, Fitch RB, Wallace LJ, et al: The radiographic evaluation of repaired canine ilial fractures. *Vet Comp Orthop Traumatol* 17: 64, 2004.

3. Jacobson A, Schrader, SC: Peripheral nerve injury associated with fracture or fracture-dislocation of the pelvis in dogs and cats: 34 cases (1978-1982) *J Am Vet Med Assoc* 190: 569, 1987.

4. Messmer M, Montavon PM: Pelvic fractures in the dog and cat: a classification system and review of 556 cases *Vet Comp Orthop Traumatol* 17: 167, 2004.

5. Hohn RB, Janes JM: Lateral approach to the canine ilium, J Am Anim Hosp Assoc 2: 111, 1966.

6. Montavoin PM, Bouchieau RJ, Hohn RB: Ventrolateral approach for the repair of sacroiliac fracture-dislocation in the dog and cat. *J Am Vet Med Assoc* 186: 1198. 1985.

7. Vangundy TE, Hulse DA, Nelson JK, et al: Mechanical evaluation of two canine iliac fracture fixation systems. *Vet Surg* 17: 321, 1988.

8. Brown SG, Biggart JF: Plate fixation of ilial shaft fractures in the dog. *J Am Vet Med Assoc* 167: 472, 1975.

Surgical Repair of Acetabular Fractures

Marvin L. Olmstead

Introduction

One of the principles of joint fracture repair is that the weight bearing articular surface must be reconstructed so that it is as anatomically correct as possible. This reduces the injured joint's risk of developing osteoarthritis. The acetabulum is one half of the coxo-femoral joint and its cranial 2/3's are generally considered its primary weight bearing area. Optimal surgical repair should restore normal joint mechanics and gliding motion.

Surgical treatment of acetabular fractures involves four steps: exposure of the fracture site, reduction of the fracture, fracture stabilization and closure. Several different approaches and

surgical techniques have proven effective to successfully complete these steps.

Surgical Technique

Acetabular fractures are approached either by a trochanteric osteotomy or the caudal approach. In most cases the author prefers the caudal approach. The caudal approach provides exposure of the acetabulum equal to a trochanteric osteotomy, does not require creation of a femoral fracture and is more quickly closed than a trochanteric osteotomy.

With both approaches, the superficial gluteal muscle is first isolated, incised at its insertion and reflected dorsally. If the surgeon is performing an osteotomy of the greater trochanter, it is started at the level of the third trochanter and extended dorsally to the junction of the greater trochanter and the femoral neck. The middle and deep gluteal muscles are reflected dorsally with the greater trochanter. The caudal portion of the deep gluteal and the gemellus muscles are elevated with a periosteal elevator from their origin over the dorsal rim of the acetabulum. This exposes the fracture site. The sciatic nerve is identified and protected. Following repair of the fracture, the greater trochanter is reattached to the proximal femur with the tension band technique (Figure 60-19). The remaining layers are closed routinely.

In the caudal approach, after the superficial gluteal muscle is incised and retracted dorsally, the external and internal obturator muscles and gemelli muscle, are incised at their insertion in the trochanteric fossa, tagged and retracted caudo-dorsally. Elevation of these muscles exposes the caudal acetabulum. The muscles can be used to protect the sciatic nerve. The caudal portion of the deep gluteal and gemellus muscles are elevated exposing the dorsal aspect of the acetabular rim. The caudal ilium is exposed by inserting a Hohmann retractor under the middle and the deep gluteal muscles and hooking its tip just cranial to the acetabulum on the ventral border of the ilium. Pushing the retractor's handle ventrally displaces the middle and deep gluteal muscles distally. Maintaining the hip in an extended and internally rotated position provides maximal exposure to the acetabular rim (Figure 60-20). After the fracture is stabilized with a fixation device, the external and internal obturator and gemelli muscles are sutured to fascial tissue over the lateral surface of the trochanter near their original insertion point. The remaining tissues are closed routinely.

The acetabulum must be anatomically reduced if a successful outcome is to be achieved. The caudal bone segment is often displaced cranially and medially. The fragment can be moved to a caudal position by one of two methods. An intramedullary pin is driven ventral to dorsal through the ischium just cranial to the ischial rim while the hip joint is flexed. The pin should penetrate the skin dorsal and ventral to the ischium. Pin chucks are attached to the exposed ends the pin and used as handles to pull the fracture segment caudally (Figure 60-21). Limited rotation of the segment is provided with this method. Another method for providing caudal traction uses a large Kern bone holding clamp. An incision wide

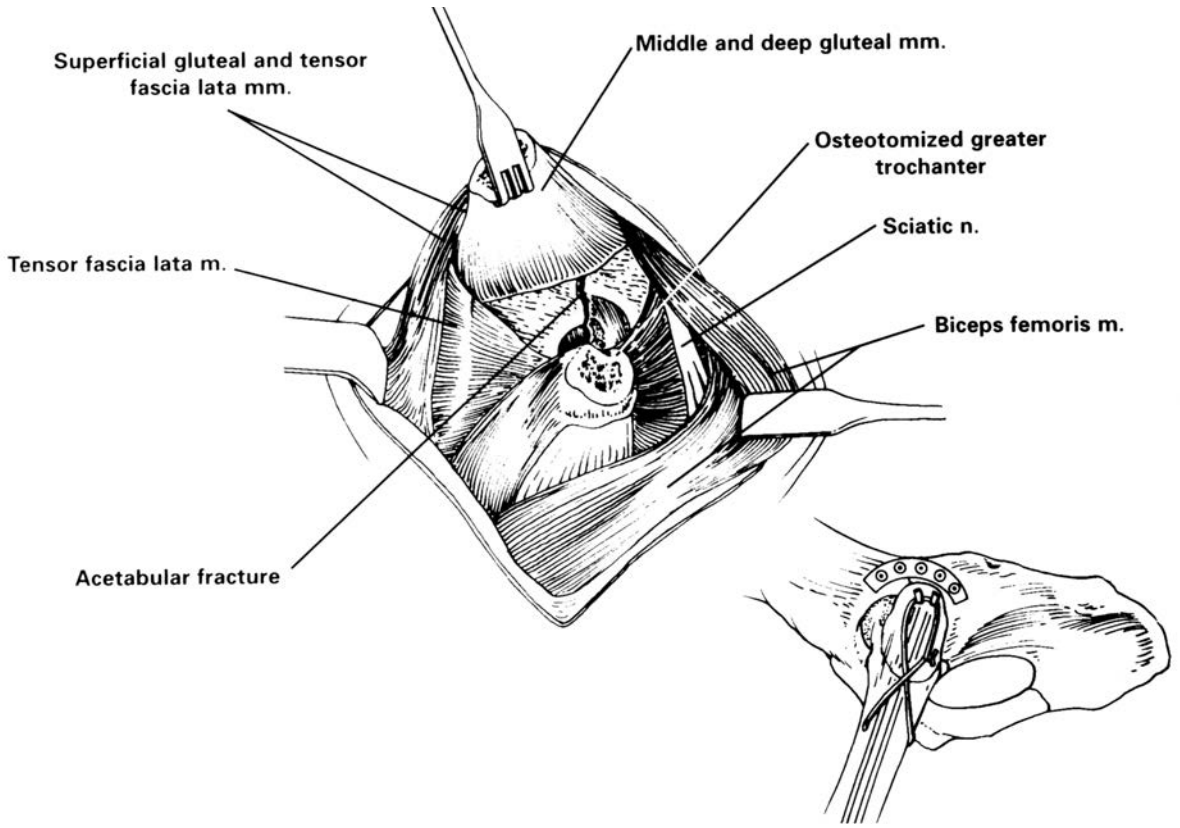


Figure 60-19. The trochanteric osteotomy approach is used to expose fractures of the acetabulum. The sciatic nerve is isolated before the osteotomy is preformed. Two pins and a tension band wire reattach the trochanter following fracture repair. (Olmstead, ML. Small Animal Orthopedics, pg 223, 1995).

enough to allow insertion of the end of the clamp is made parallel with the ischial rim. Because the fixation teeth of the Kern clamp provide 4 points of fixation, this instrument can be used for both caudal retraction and rotation of the segment (Figure 60-22). If the fracture segments are collapsed medially, the Lahey retractor is helpful in repositioning the fragments laterally. A Lahey retractor, which is blunt, strong, and bent 90° at its end, is passed along the medial wall of the free segment. The retractor's tip is maintained on the bone's surface as it is passed along the medial wall to avoid compromising the sciatic nerve. Pulling laterally moves the fracture segments laterally (Figure 60-23).

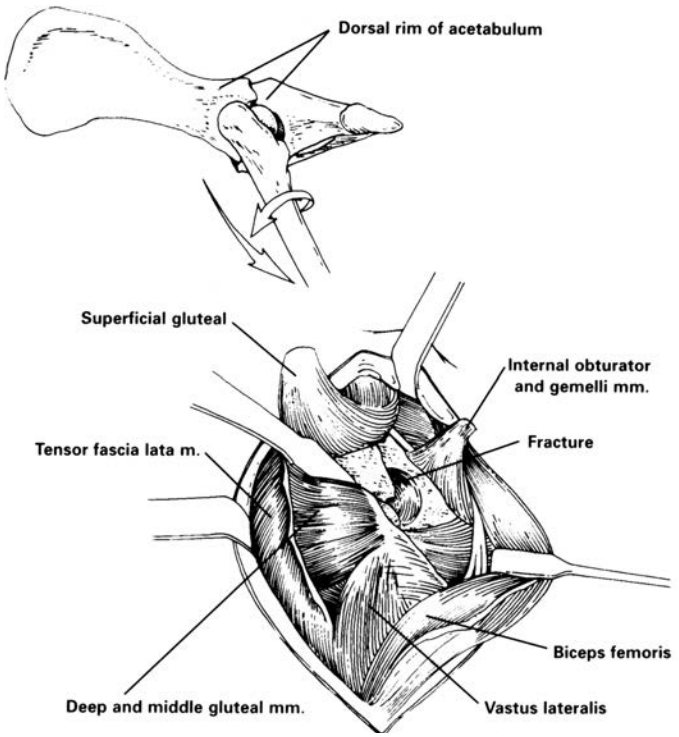


Figure 60-20. The external rotators of the hip are incised at their insertion in the trochanteric fossa during a caudal approach. These muscles are retracted caudally protecting the sciatic nerve. Extension and internal rotation of the femur enhances fracture exposure. These muscles are retracted ventrally by a Hohmann retractor placed under the middle and deep gluteal muscles and hooked on the ventral edge of the ilium. (Olmstead, ML. Small Animal Orthopedics, pg 222, 1995).

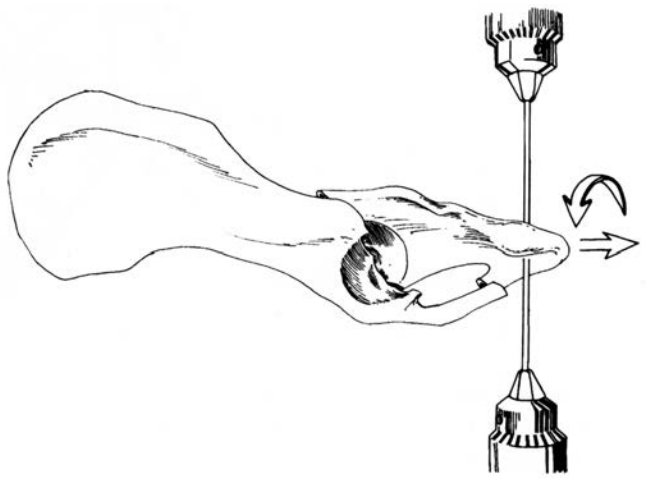


Figure 60-21. An intramedullary pin driven through the ischium can be used for caudal traction and minimal rotation of the free pelvic segment. (Olmstead, ML. Small Animal Orthopedics, pg 225, 1995).

Acetabular fracture reduction is maintained by manually holding the fragments in place until the permanent stabilization procedure is completed. Reduction of an acetabular surface can be evaluated visually through an incision in the joint capsule or an existing capsular tear by applying ventral traction on the greater trochanter. This will pull the femoral head out of the acetabulum enough so the articular surface of the acetabulum can be observed.

Non-plating surgical techniques for repair of acetabular fractures have not proven to be as effective as bone plates. They also have not consistently provided the clinical results obtained with bone plates. Two different sizes of C-shaped acetabular plates, mini fragment plates and standard Dynamic Compression Plates® [Synthes (USA), Paoli, Pennsylvania] have been used successfully to stabilize acetabular fractures. Some surgeons use reconstruction plates for acetabular fractures because they can be bent easily in several different planes.

Bone plates must be anatomically contoured to the dorsal rim of the acetabulum. The bone fragments will shift in position as the screws are tightened if the plate is not properly contoured. The C-shaped acetabular plates are easily contoured to the acetabulum's dorsal surface. Mini plates are also easy to bend because they are thin. However, this makes them relatively weak and limits the size of animal in which they can be used. The acetabulum's dorsal surface is used for plate placement

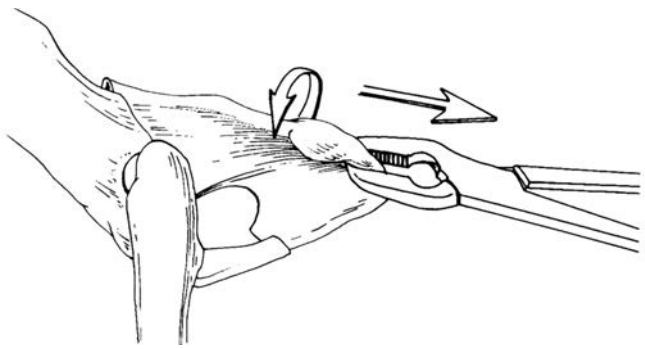


Figure 60-22. A Kern bone holding clamp applied to ischium through an incision over the tuber ischia is used to rotate and caudally retract the free segment. (Olmstead, ML. Small Animal Orthopedics, pg 226, 1995).

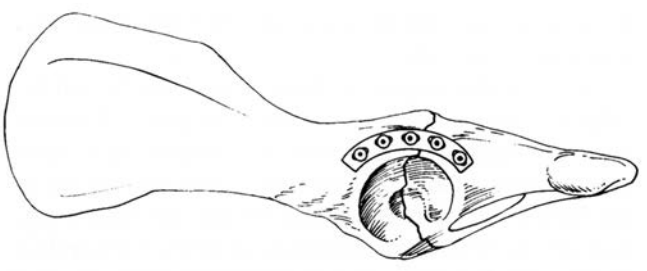


Figure 60-23. Bone plates are placed over the dorsal rim of the acetabulum because it is acetabulum's most accessible area, largest visible bone surface and tension surface. (Olmstead, ML. Small Animal Orthopedics, pg 227, 1995).

because adequate bone is present there and this is the tension surface of the bone. In all acetabular fractures at least two screws should be located on either side of the fracture line, and they should be angled so that they do not penetrate the articular cartilage surface (Figure 60-24).

One of the most difficult fractures to stabilize is one that has a component of the medial wall of the acetabulum fractured out. If a large section of this wall is involved, the femoral head will displace medially into the pelvic canal. If the fracture segment containing the medial wall extends far enough cranially, a lag screw and/or intramedullary pin fixation of the ilial segment are used to stabilize the fragment. If the fragment can not be stabilized, a slight over-bending of the plate closing the diameter of the articular surface, makes it more difficult for the femoral head to displace medially. If the femoral head cannot be prevented from displacing medially, a salvage procedure, excision arthroplasty, should be considered. For severe acetabular fractures where reconstruction is not possible excision arthroplasty may also be performed. This procedure is done only as a last resort as it sacrifices joint function but is intended to save limb function.

The weight bearing surface of the acetabulum, its cranial 2/3's, must be reconstructed if its integrity is to be maintained. Repair of fractures in the caudal 1/3 of the acetabulum is controversial. Although unrepaired fractures in this area will result in coxofemoral osteoarthritis, it has not been definitively proven that repairing fractures in this area will improve the patients' recovery. Although osteoarthritis may be present, limb function may be unaffected. Due to their small size, fractures of the caudal 1/3 of the acetabulum can be difficult to adequately stabilize. With a caudal fracture the sciatic nerve is at greater risk of injury during surgery then when the fracture is located more cranially.

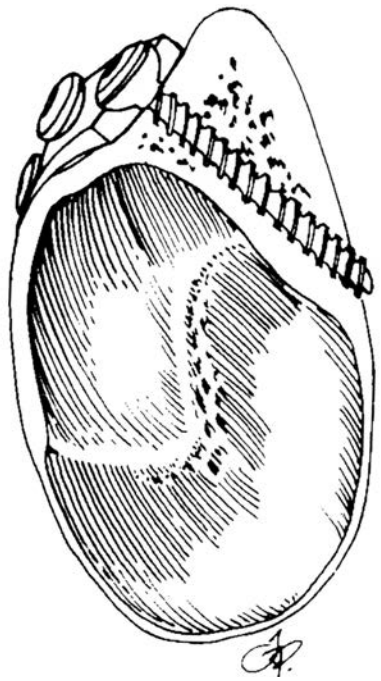


Figure 60-24. This cut-away view of the acetabulum shows a bone screw directed through the plate in a direction that does not violate the articular surface. (Olmstead, ML. Small Animal Orthopedics, pg 227, 1995).

When both a fracture of the ilium and the acetabulum are present, the author prefers to repair the ilial shaft first. Repair of the ilium is often done with a stronger fixation system than is used on the acetabulum because usually more screws and a longer and stronger plate can be applied to the ilium. The reconstruction of the ilium does not have to be as anatomically exact as reconstruction of the acetabulum. When the acetabulum is repaired last it will be fixed to a solidly stabilized ilial segment. Also, its fixation will not be subjected to additional loads that would be generated during manipulation of the ilial fragments if the ilium were fixed last.

Suggested Readings

Boudrieau, RJ, Kleine, LJ: Nonsurgically managed caudal acetabular fractures in dogs: 15 cases (1979-1984). *J Am Vet Med Assoc* 193:701, 1988.

Hulse, DL: Acetabular Fractures. In Fossum T, ed.: *Small Animal Surgery,* 2nd ed. St. Louis: Mosby, 2002, p 971.

Olmstead ML. Surgical repair of acetabular fractures. *In* Bojrab, MJ,ed: *Current Techniques in Small Animal Surgery,* 4th ed. Baltimore: Williams & Wilkins, 1990, p 1036.

Olmstead, ML: Fractures of the Bones of the Hind Limb. *In* Olmstead, ML, ed: *Small Animal Orthopedics.* St. Louis: Mosby, 1995, p 219.

Piermattei DL., Johnson, KA: *An Atlas of Surgical Approaches of the Bones of the Dog and Cat.* (4th ed). Philadelphia: W.B. Saunders, 2004, p. 290.

Slocum B, Hohn RB: A surgical approach to the caudal aspect of the acetabulum and body of the ischium in the dog. *J Am Vet Med Assoc* 65:167, 1975.

Tomlinson, JL: Fractures of the Pelvis. *In* Slatter, D, ed. *Textbook of Small Animal Surgery,* 3rd ed. Philadelphia: W. B. Saunders, 2003, p 1989.

Treatment of Coxofemoral Luxations

James L. Tomlinson

Introduction

Coxofemoral luxation is a common injury suffered by both dogs and cats after various forms of trauma to the pelvis. The hip joint is the most commonly luxated joint in dogs and cats. In most coxofemoral luxations the femoral head is displaced cranial and dorsal to the acetabulum. In about 10% of hip luxations, the femoral head is displaced either ventrally or caudodorsally.

The severity of tissue damage associated with hip luxations varies. In all luxations, the round ligament and part of the joint capsule are torn. In more severe cases, part of the gluteal musculature also may be torn. Small avulsion fractures of the femoral head where the round ligament attaches are common. Erosion of the cartilage of the femoral head sometimes results from the femoral head's rubbing on the ilium, especially in more chronic cases. On rare occasions, portions of the dorsal rim of the acetabulum are fractured off.

Diagnosis of a coxofemoral luxation usually is simple. Most animals have a history of trauma such as having been hit by a

car. The animal does not bear weight on the leg and stands with the adducted and externally rotated with a craniodorsal luxation. On physical examination, a greater than normal distance can be palpated between the greater trochanter of the femur and the tuber ischiadicum. The "thumb test" also is useful in diagnosing a craniodorsal luxation. To perform this test, the animal is placed in lateral recumbency with the affected leg up. The examiner stands behind the animal and places the thumb of the hand closest to the spine in the depression between the greater trochanter of the femur and the tuber ischiadicum while the other hand is grasping the stifle joint. The leg is then externally rotated. In a normal animal, the greater trochanter of the femur should pinch or displace the thumb from the depression between the greater trochanter of the femur and the tuber ischiadicum during rotation, whereas in an animal with a dislocated hip, the thumb is not pinched or displaced. A third way to evaluate a patient for a luxated hip is to extend the animal's legs out caudally while the animal is in either dorsal or lateral recumbency. With a craniodorsal luxation, the affected limb appears shorter than the normal leg; with a ventral luxation, the leg appears longer. Radiographs are needed to confirm the diagnosis, because animals with fractures of the femoral head or neck present with clinical signs similar to those of animals with luxations. The radiographs should be evaluated for direction of luxation, avulsion fractures of the femoral head, other pelvic fractures, and hip dysplasia.

Surgical Options

Closed reduction with application of a non weight bearing sling is the method of choice for most acute luxations. An Ehmer sling is applied after closed reduction as described in Chapter 63. Failure rates for coxofemoral luxations treated by closed reduction have been reported to be as high as 50 to 70%.[1,2]

Open reduction is indicated for acute luxations that will not remain reduced closed, irreducible acute luxations, chronic luxations, luxations associated with avulsion fractures of the femoral head, and luxations associated with other fractures (ipsilateral pelvis, femur, or tibia). Animals with moderate-to-severe degenerative changes of the hip are not candidates for open or closed reduction. Other methods of treatment should be used with such animals.

Numerous methods for open reduction of coxofemoral luxations have been devised including DeVita pinning, Yarbough pinning, use of Knowles toggle pin, joint capsule imbrication with trochanteric transposition, acetabular rim extension, transacetabular pinning, and retention suturing with joint capsule imbrication. The goal of open reduction of a coxofemoral luxation is to reestablish normal function and conformation of the hip. Once healing is complete, the anatomic shape of the hip joint and fibrosis of the joint capsule hold the hip in place.

Surgical Techniques

The techniques for performing joint capsule imbrication with transposition of the greater trochanter, toggle pinning, transacetabular pinning and retention suturing are described in this section.

Open reduction of coxofemoral luxations can be performed by one of two surgical approaches to the joint. Transacetabular pinning, toggle pinning and single retention suturing are best performed through a craniolateral approach,[3] except in patients with chronic luxations. Double retention suturing, and joint capsule imbrication with transposition of the greater trochanter are performed through a dorsal approach by osteotomy of the greater trochanter of the femur.[3] With acute craniodorsal luxations, the femoral head is easily identified during the approach. If the luxation is chronic, the femoral head is surrounded by a fibrous pseudo-joint capsule. With acute craniodorsal luxations, the acetabulum is caudoventral to the femoral head and may be difficult to find, especially in chronic luxations. The acetabulum may have joint capsule, blood, or fibrin clots, remnants of the round ligament, avulsed pieces of the femoral head, and fibrous tissue (chronic luxations) within the joint. The joint must be cleaned out before the femoral head can be reduced into the acetabulum. The joint capsule should be preserved for later suturing. The femoral head can be retracted caudal to the acetabulum with a Hohmann retractor by hooking the tip of the retractor on the caudal edge of the acetabulum and prying caudally against the proximal metaphysis of the femur. Care must be taken not to entrap the sciatic nerve under the retractor.

Joint Capsule Imbrication with Transposition of the Greater Trochanter

Joint capsule imbrication with transposition of the greater trochanter of the femur is a useful method for treating patients with acute luxations, chronic luxations, and luxations with concurrent lesions such as acetabular fractures that require an approach to the hip by osteotomy of the greater trochanter of the femur.

The animal is placed in lateral recumbency with the affected hip up and is prepared for aseptic surgery. The luxated joint is exposed through a dorsal approach by osteotomy of the greater trochanter of the femur.[3]

Great care must be taken during this approach to preserve the joint capsule for later suturing.

After the femoral head has been identified and the acetabulum cleared of debris, the luxation is reduced. If adequate joint capsule is present on both sides of the joint, a simple interrupted or horizontal mattress pattern of 3-0 or 2-0 polypropylene or PDS is used to appose the joint capsule (Figure 60-25A). Placement of sterile towels on the medial side of the leg is beneficial to hold the leg in abduction during the imbrication to relieve the pressure on the joint capsule. If insufficient joint capsule is present on the acetabular side of the joint, the joint capsule can still be attached by using screws or tissue anchors (IMEX™ Veterinary, Inc. 1001 McKesson Drive, Longview, Texas 75604) to secure the suture on the acetabular side (Figure 60-25B). Once the joint capsule repair is completed, the greater trochanter is replaced in a position caudal and distal to its normal position (See Figure 60-25B). By positioning the greater trochanter caudal and distal to its normal location, the gluteal muscles try to abduct and internally rotate the femur thus making it more difficult for the femoral head to luxate. The greater trochanter is attached using a tension band device.

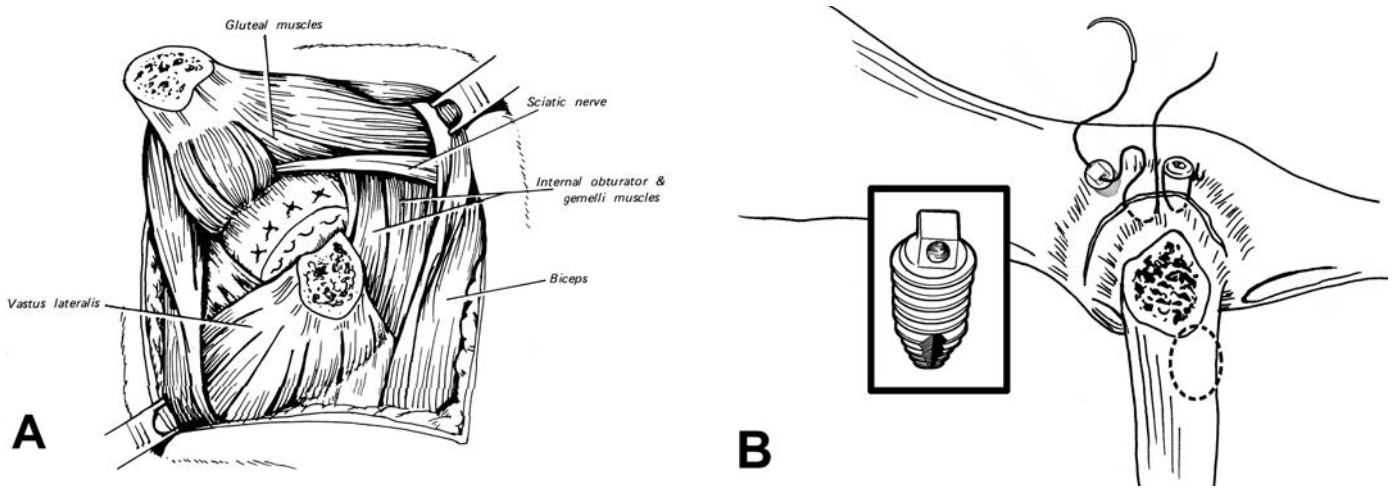


Figure 60-25. Imbrication of coxofemoral joint capsule. **A.** When sufficient joint capsule is present, nonabsorbable sutures are placed in a horizontal mattress pattern. (From Brinker WO, Piermattei DL, Flo GL, eds. Handbook of small animal orthopedics and fracture treatment. Philadelphia: WB Saunders, 1983;272.) **B.** When insufficient joint capsule is present on the acetabular side for suturing, bone screws or tissue anchors can be used to secure the suture on the acetabular side of the joint. The insert shows a tissue anchor. The suture is passed through the joint capsule on the femoral head side of the joint and tied. The dotted line on the femur illustrates where the greater trochanter of the femur is reattached with a tension band device distal and caudal to its normal location.

Toggle Pinning

Toggle pinning is an old technique for open reduction of coxofemoral luxations that is still useful today. One of the benefits of using this technique to repair coxofemoral luxations is that the dog can be allowed to walk on the leg after surgery.[4] Having a leg that can bear weight is very important for dogs with multiple leg injuries. Recent advancements in the equipment that is available for performing toggle pinning has simplified the technique and made it something that is realistic to do in small animal practices. Toggle pins, surgical buttons, an aiming device, and a suture passer that simplifies the procedure are commercially available (IMEX™ Veterinary, Inc.1001 McKesson Drive, Longview, Texas 75604). A cranial lateral approach to the hip is performed.[3] Some surgeons prefer to approach the hip through an approach that osteotomizes the greater trochanter of the femur to provide greater exposure of the joint. In most cases, the cranial lateral approach to the hip provides adequate exposure to perform the surgery with less morbidity for the dog. Once the femoral head and acetabulum are exposed, blood clots and remnants of the round ligament are removed from the acetabulum. Any joint capsule that remains needs to be preserved for suturing. A hole is drilled through the acetabular fossa from lateral to medial with a drill bit or pin slightly larger than the diameter of the toggle pin (Figure 60-26). The toggle pin with suture is passed through the hole so that the toggle pin anchors on the medial wall of the acetabulum (Figure 60-27). Using the aiming device, a hole is drilled through the femur from an area just below the greater trochanter of the femur up the femoral neck and exits at the fovea capitus (the area where the round ligament normally attaches to the femoral head) (Figure 60-28). An alternative to using the aiming devise is to externally rotate the femur until the fovea capitus of the femoral head is visualized. The hole is then drilled from the fovea capitus down the femoral head and neck so that it exits slightly below the greater trochanter. Two types of suture material are used for this procedure. The first is fiber wire (IMEX™ Veterinary, Inc. 1001 McKesson Drive, Longview, Texas 75604) which has a small diameter but is very strong. The second

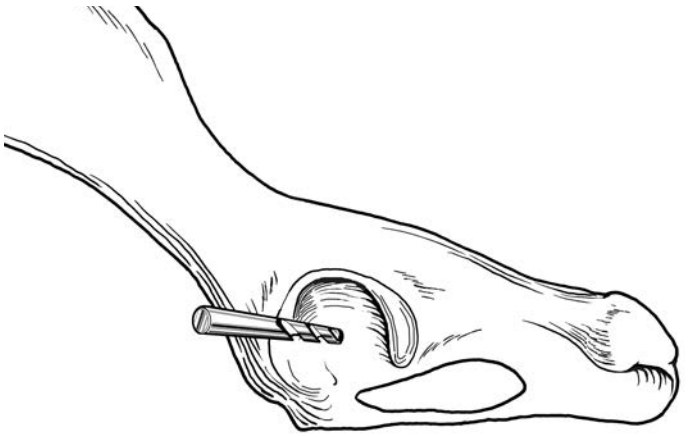


Figure 60-26. A hole is drilled through the acetabular fossa from lateral to medial so that the toggle pin and suture can be anchored on the medial side of the acetabulum.

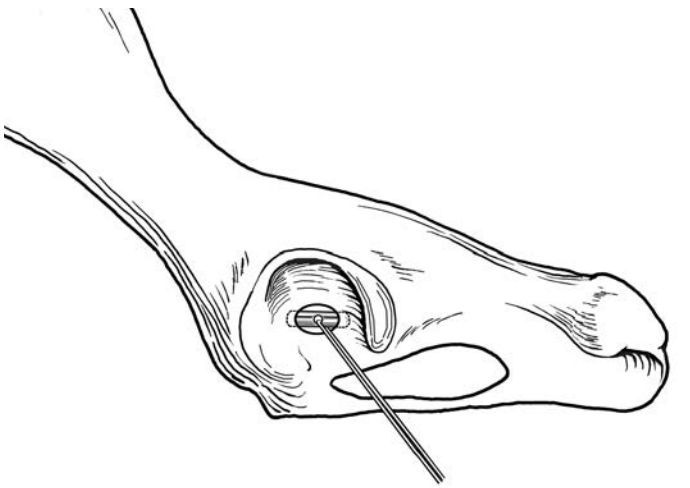


Figure 60-27. The toggle pin with suture attached is passed through the hole in the acetabulum and anchored on the medial side of the acetabulum.

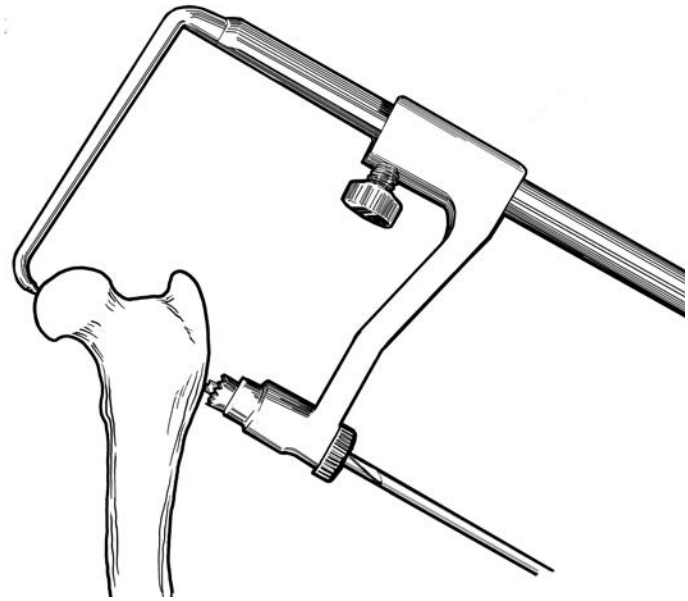


Figure 60-28. Using an aiming devise, a hole is drilled from an area just distal to the greater trochanter, up the femoral neck and out the fovea capitus.

type of suture is the same heavy leader line suture material many veterinarian use for cruciate repair. The suture is passed through the tunnel from the femoral head to the lateral side of the femur (Figure 60-29). A suture passer facilitates passing the suture if fiber wire type of suture is being used. Heavy nylon suture will slide through the hole without need for the suture passer. The easiest method of anchoring the suture on the lateral side of the femur is with a surgical button. The suture is passed through the two holes in the surgical button. The femoral head is reduced into the acetabulum and the suture tied over the button (Figure 60-30). If possible, the joint capsule is sutured into apposition. Closure of the surgical site is routine. The animal is allowed to bear weight on the leg in a controlled manner after surgery.

Transacetabular Pinning

Transacetabular pinning is a practical and successful procedure for repair of coxofemoral luxations. The best results are obtained when this procedure is used for acute luxations in nondysplastic patients, although I have used this procedure successfully for chronic luxations. The only equipment needed is standard operating instruments, Jacob's pin chuck, and intramedullary pins.

The animal is placed in lateral recumbency on the operating table with the affected leg suspended from an intravenous pole. The leg is scrubbed and draped for aseptic surgery. For acute luxations, the hip is exposed through a craniolateral approach.[3] For chronic luxations, a dorsal approach to the hip by osteotomy of the greater trochanter of the femur[3] may be needed. Once the femoral head is exposed and the acetabulum is cleaned of debris, the luxation is reduced temporarily. The hip is reluxated, and the femur is rotated externally until the fovea capitis of the femoral head is visible (Figure 60-31A).

An intramedullary pin, with a diameter that is two-thirds to three-fourths that of the fovea capitis, is selected. The pin is advanced

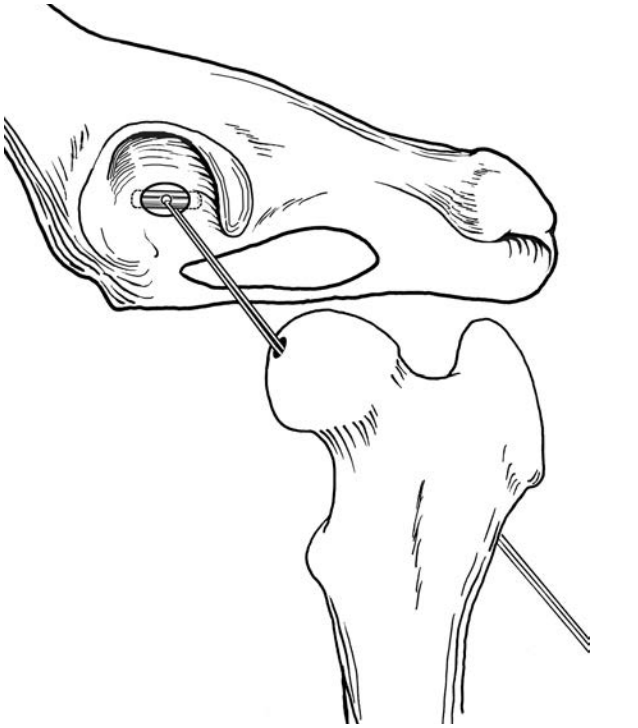


Figure 60-29. The end of the suture is now passed through the femoral tunnel starting at the femoral head and exiting at the lateral side of the femur.

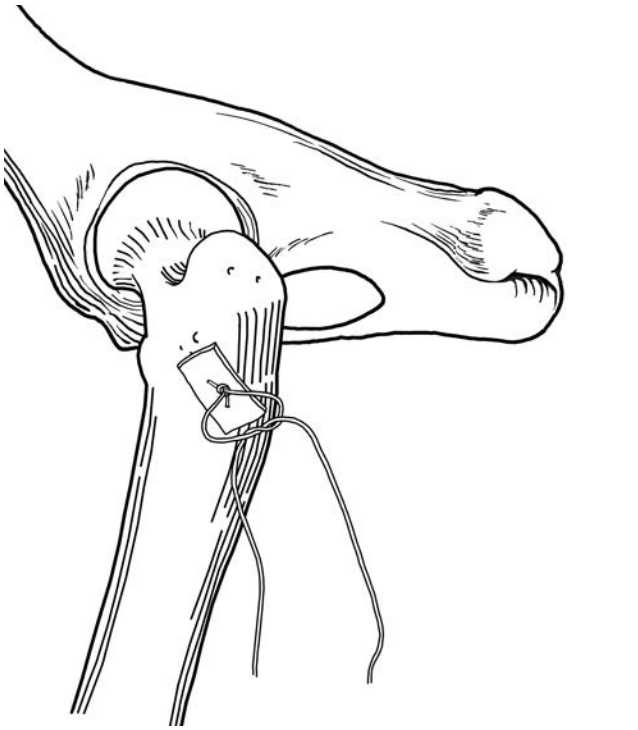


Figure 60-30. The femoral head is reduced and the suture passed through holes in a surgical button. The surgical button is placed under the vastus muscles. The suture is tightened so that the femoral head can not luxate.

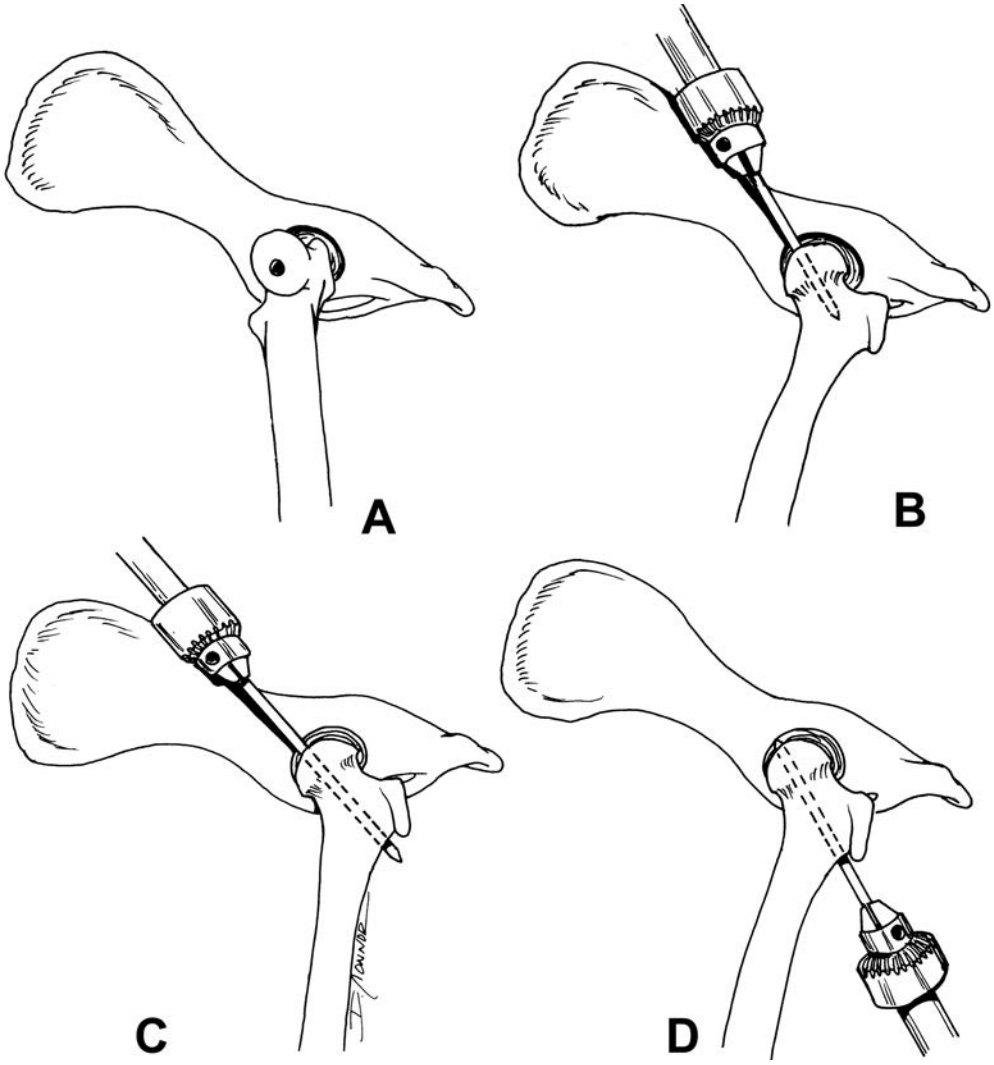


Figure 60-31. Placement of transacetabular pin. After exposure of the femoral head, the leg is rotated to bring the fovea capitis into view. **A.** An intramedullary pin is placed on the fovia capitis. **B.** The pin is advanced through the head and neck of the femur. **C.** The pin exits at the level of the third trochanter. **D.** The pin is adjusted until the end is flush with the fovea capitus.

from the fovea capitis, down the femoral neck, and out the cortex of the third trochanter of the femur (Figure 60-31B and C). The pin is adjusted until the tip is flush with fovea capitis (Figure 60-31D). After the luxation is reduced, the femur is placed parallel to the table top and at a 90° angle to the spine. The pin is driven across the acetabulum while firm downward pressure is applied to the greater trochanter of the femur. If inadequate pressure is applied to the greater trochanter, the femoral head will back part way out of the acetabulum. The pin is driven approximately 1cm into the pelvic canal for the average-size dog. An assistant can palpate the pin rectally to determine whether it has been driven the correct distance. Care must be taken not to puncture the colon. Once the pin has been driven the correct distance, the end of the pin is bent over and cut off (Figure 60-32A, B, and C). Bending the pin over prevents it from migrating further into the pelvic canal.

Postoperatively, the hip is radiographed to check for proper pin placement and reduction of the luxation. The leg is placed in a non-weight bearing sling (Ehmer or Robinson), and the animal is discharged with instructions for limited exercise until the pin is removed. The pin should be removed in 14 to 21 days; the animal's activity is restricted for 3 weeks after pin removal.

Complications associated with transacetabular pinning include pin migration and breakage and reluxation of the hip. Pin migration and breakage generally result from failure of the owner to keep a sling on the animal. The owner should be instructed to return the animal immediately if the sling comes off.

Retention Suturing

Retention suturing can be a valuable technique by itself when the joint capsule is missing or traumatized to such an extent that it will not effectively hold sutures. Retention suturing can be combined with other methods of repair also. Two methods for retention suturing have been described. The single-suture method[5] is started by drilling a hole dorsal to ventral at the attachment of the rectus femoris to the ventral aspect of the ilium (Figure 60-33A). An alternative method of anchoring the suture in the ilium is with a tissue anchor. A second hole is drilled cranial to caudal through the greater trochanter of the femur (after the trochanter is reattached) at about the level of attachment of the deep gluteal tendon (Figure 60-33B). Heavy nonabsorbable suture material (No. 5 Ethibond or nylon leader line [Ethicon, Inc., Somerville, NJ]) is threaded through the holes, and the suture is

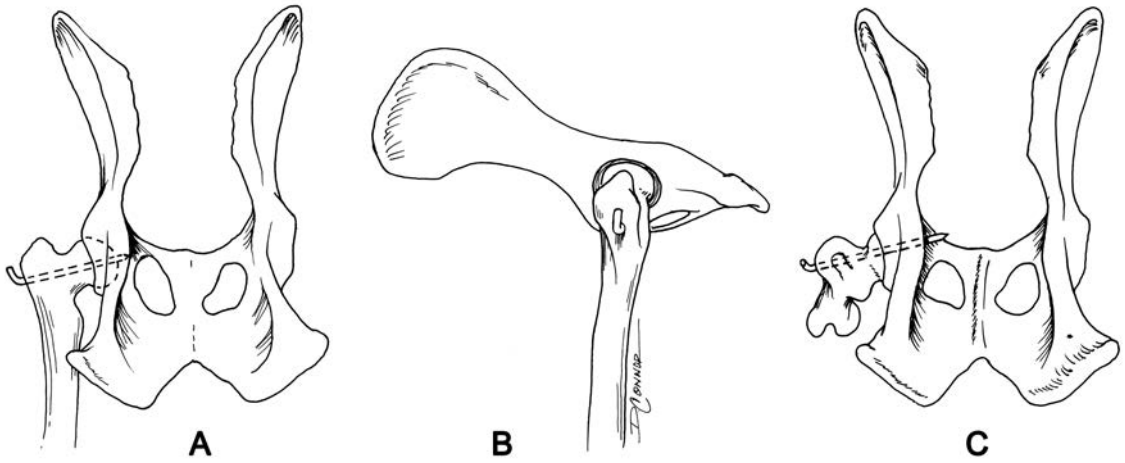


Figure 60-32. A-C. Final placement of transacetabular pin after reduction of joint. Note that the pin extends about 1 cm into the pelvic canal for a large dog and that the end of the pin in bent over to prevent medical migration of the pin.

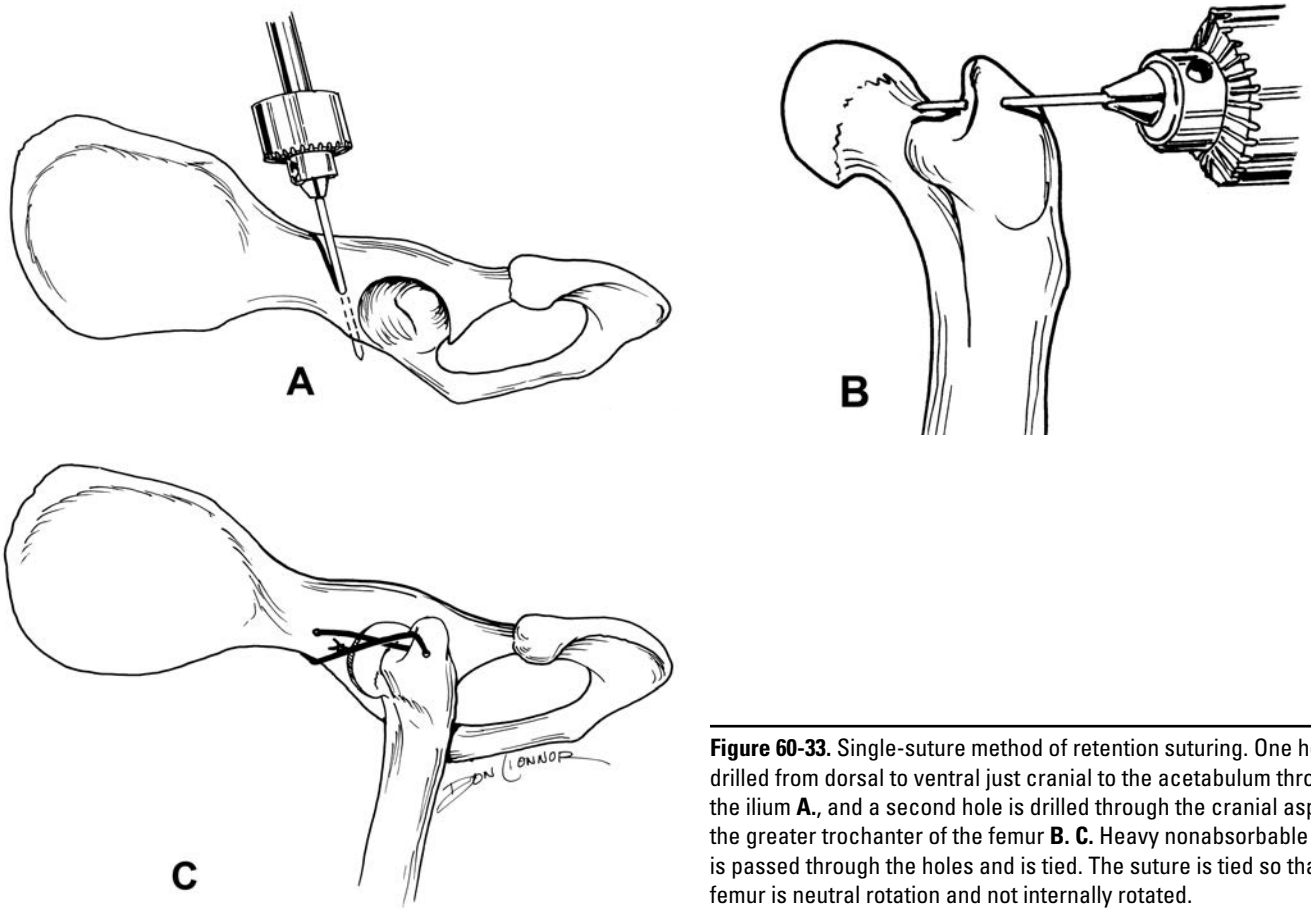


Figure 60-33. Single-suture method of retention suturing. One hole is drilled from dorsal to ventral just cranial to the acetabulum through the ilium **A.**, and a second hole is drilled through the cranial aspect of the greater trochanter of the femur **B. C.** Heavy nonabsorbable suture is passed through the holes and is tied. The suture is tied so that the femur is neutral rotation and not internally rotated.

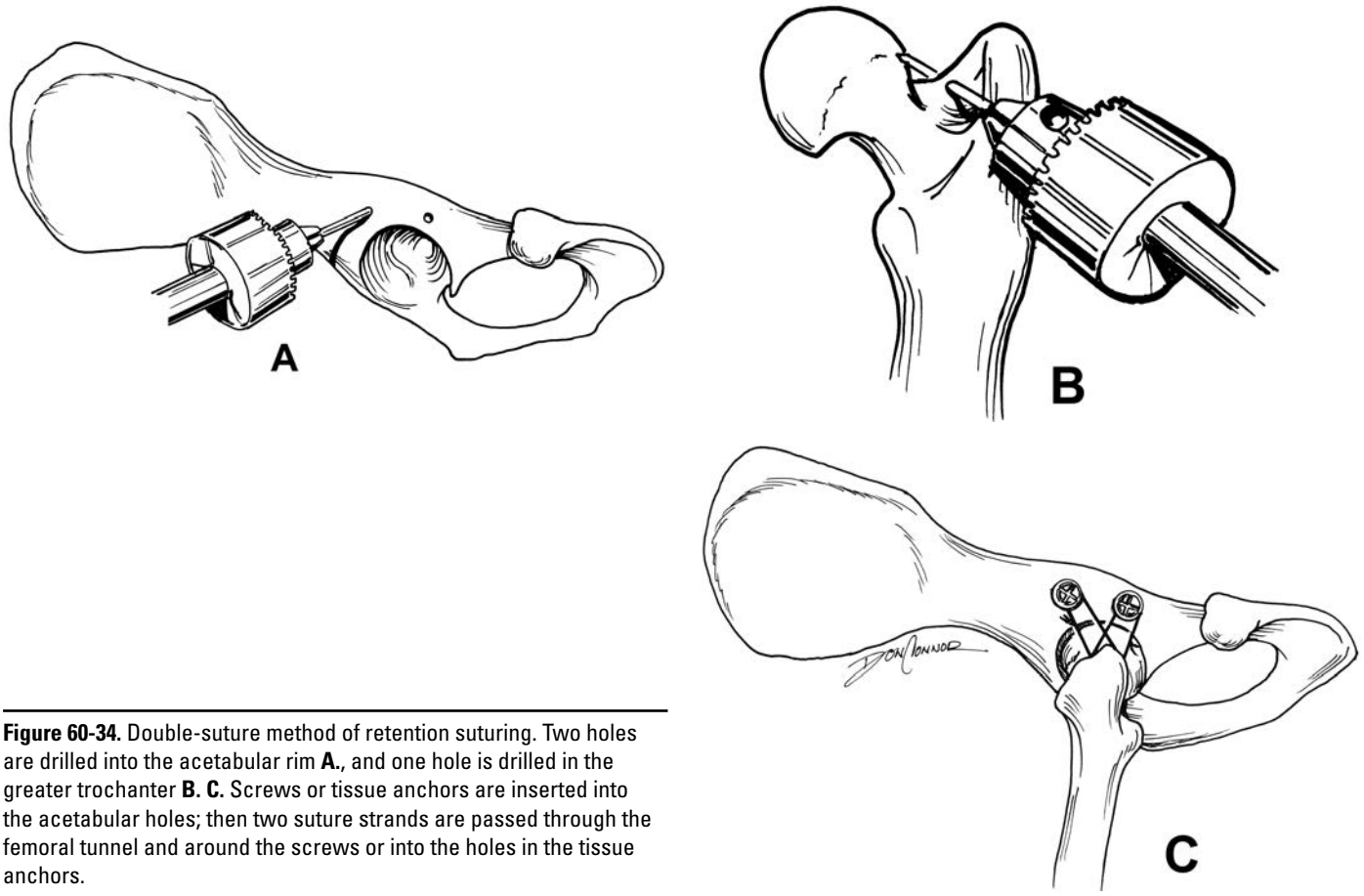


Figure 60-34. Double-suture method of retention suturing. Two holes are drilled into the acetabular rim **A.**, and one hole is drilled in the greater trochanter **B. C.** Screws or tissue anchors are inserted into the acetabular holes; then two suture strands are passed through the femoral tunnel and around the screws or into the holes in the tissue anchors.

tightened (Figure 60-33C). The suture should not be tightened to the extent that flexion and extension of the hip are restricted or that the leg is internally rotated. Over tightening of the suture will result in poor leg function and suture breakage.

In the double-suture method, two sutures are passed from the greater trochanter to the dorsal rim of the acetabulum.[6] Two holes are drilled in the dorsal acetabular rim at the 11 and 1 o'clock positions (Figure 60-34A) and a third hole is drilled cranially to caudally through the greater trochanter of the femur (Figure 60-34B). After screws or tissue anchors are inserted into the holes in the acetabular rim, two strands of heavy nonabsorbable suture material are passed through the femoral tunnel. One strand is passed around the cranial acetabular screw or through the hole in the tissue anchor and the other around the caudal screw or hole in the tissue anchor. The sutures are then tightened (Figure 60-34C). Spiked washers (Synthes, Paoli, PA) may be needed to hold the sutures in place if screws are used. The greater trochanter is reattached with two Kirschner wires and a tension band wire.

With either retention suture technique, the animal is placed in a non weight bearing sling for 2 to 3 weeks postoperatively with exercise restriction. Once the sling is removed, the animal is slowly returned to normal exercise over the next month.

References

1. Bone DL, Walker M. Cantwell RD. Traumatic coxofemoral luxation in the dog. Vet Surg l3:263, 1984.

2. Dobbelaar MJ. Dislocation of the hip in dogs. J small Anim Pract 4:101, 1963.

3. Pierrnattei DL, Greeley RG. An atlas of surgical approaches to the bones of the dog and cat. Philadelphia: WB Saunders, 1979.

4. Beckham HP, Smith MM, Kern DA. J Am Vet Med Assoc 208(1):81-84, 1996

5. Slocum B, Devine T. Dislocation of the canine hip: treatment of the normal and dysplastic hip. Am Anim Hosp Proc 372, 1987.

6. Allen SW, Chambers JN. Extracapsular suture stabilization of canine coxofemoral luxation. Compend Contin Educ Pract Vet 8:457, 1986.

Hip Dysplasia
Algorithms for Treatment

Barclay Slocum and Theresa Devine Slocum

Figures 60-35 through 6-39 are algorithms for treatment of hip disorders.

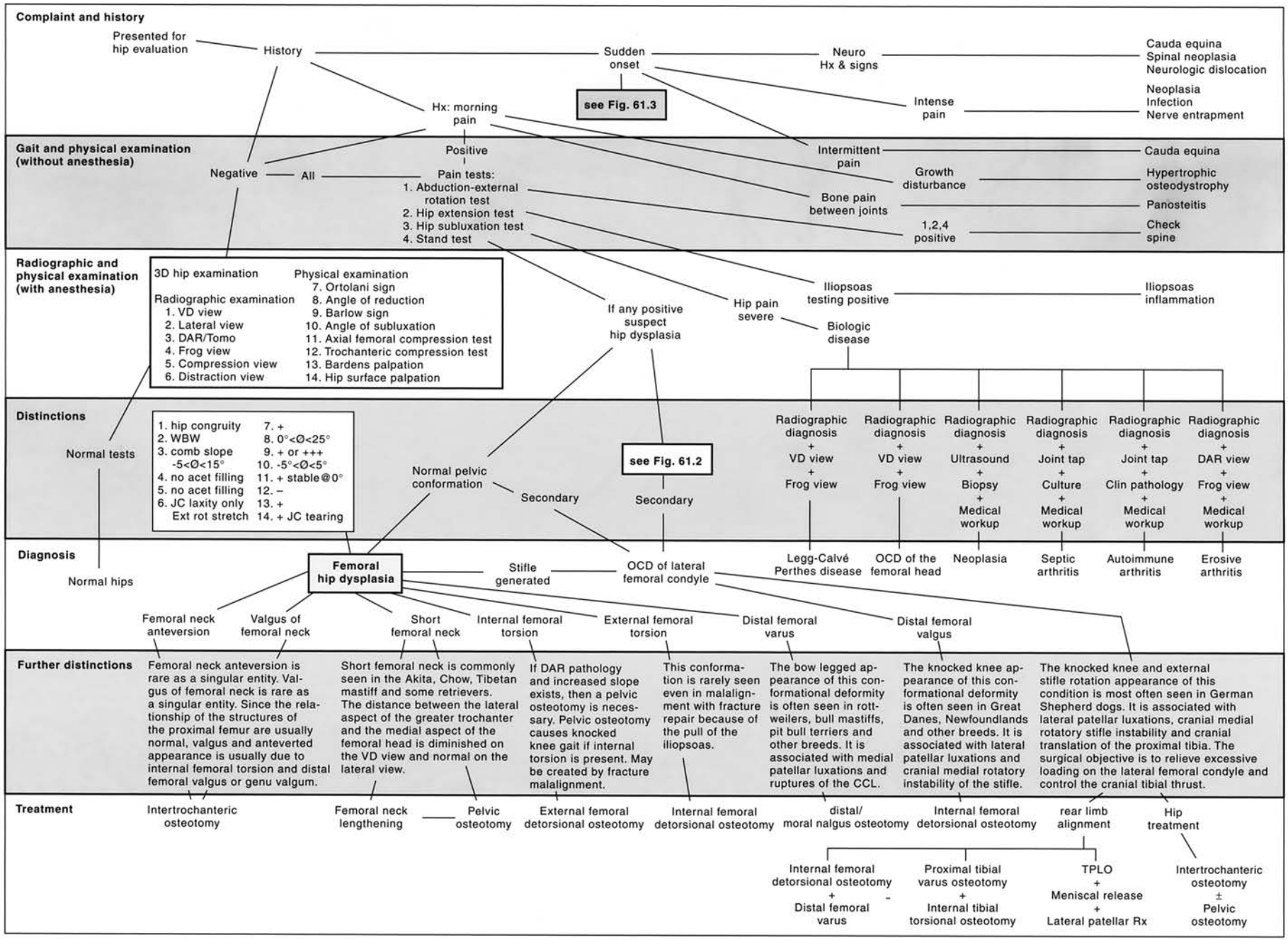


Figure 60-35. General hip algorithm. *CCL*, cranial cruciate ligament; *DAR*, dorsal acetabular rim; *JC*, joint capsule; *OCD*, osteochondritis dissecans; *TPLO*, tibial plateau leveling osteotomy; *VD*, ventrodorsal; *WBW*, white, black, white on lateral radiograph.

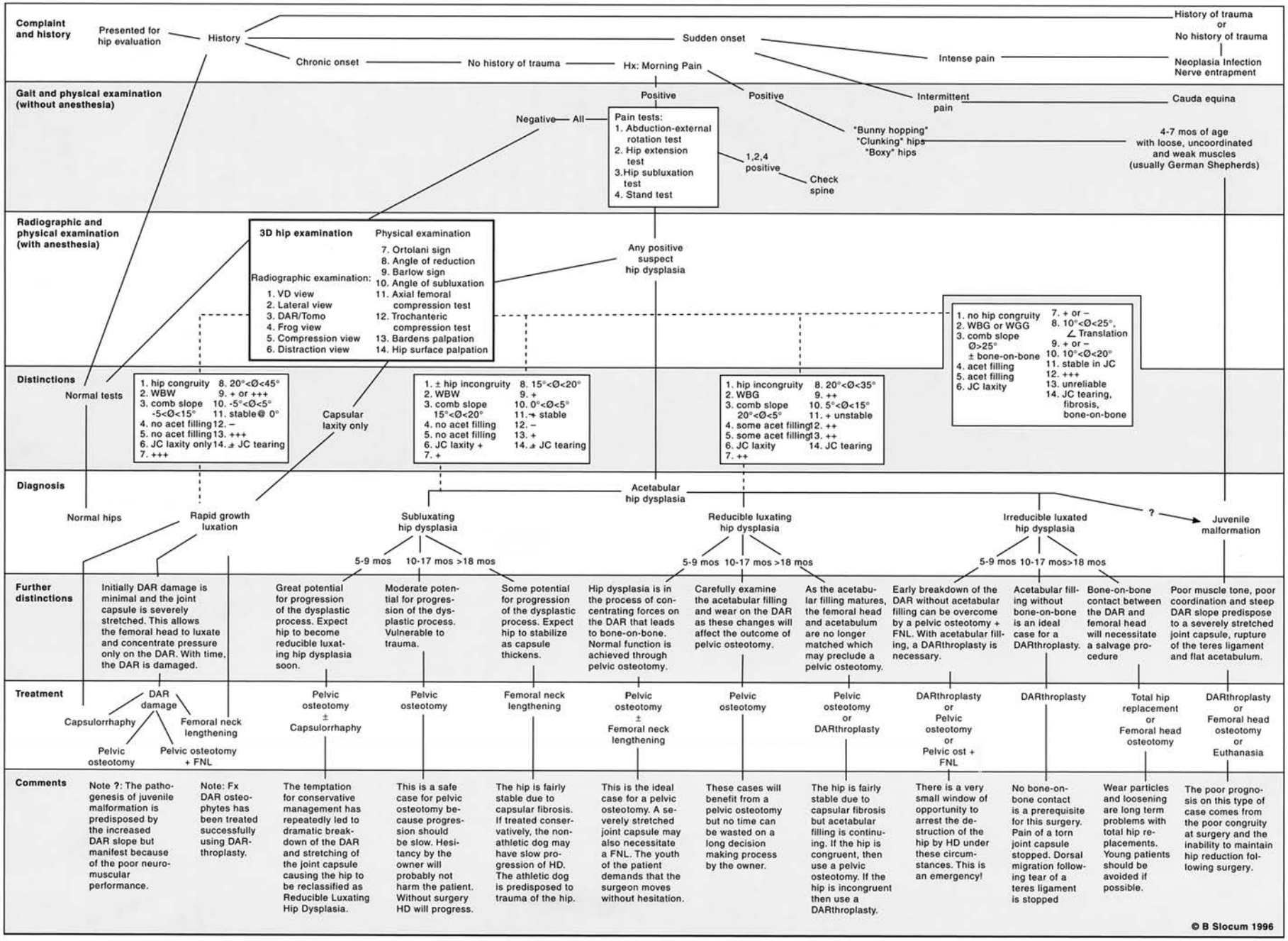


Figure 60-36. Acetabular hip dysplasia algorithm. *DAR*, dorsal acetabular rim; *FNL*, femoral neck lengthening; *JC*, joint capsule; *VD*, ventrodorsal; *WBG*, white, black, gray; *WBW*, white, black, white.

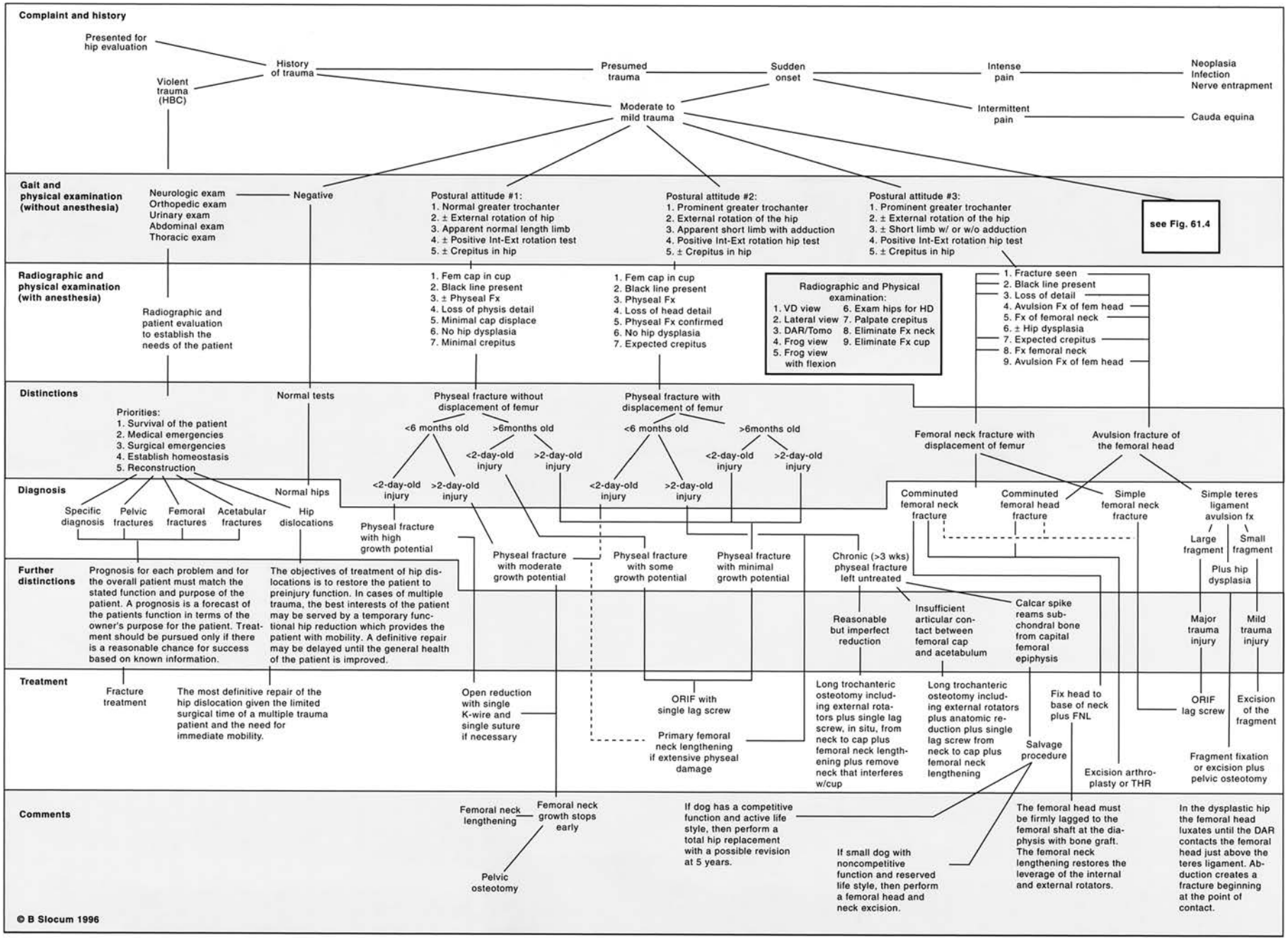


Figure 60-37. Algorithm for trauma to the hip. *DAR*, dorsal acetabular rim; *FNL*, femoral neck lengthening; *HBC*, hit by car; *HD*, hip dysplasia; *ORIF*, open reduction with internal fixation; *THR*, total hip replacement; *VD*, ventrodorsal.

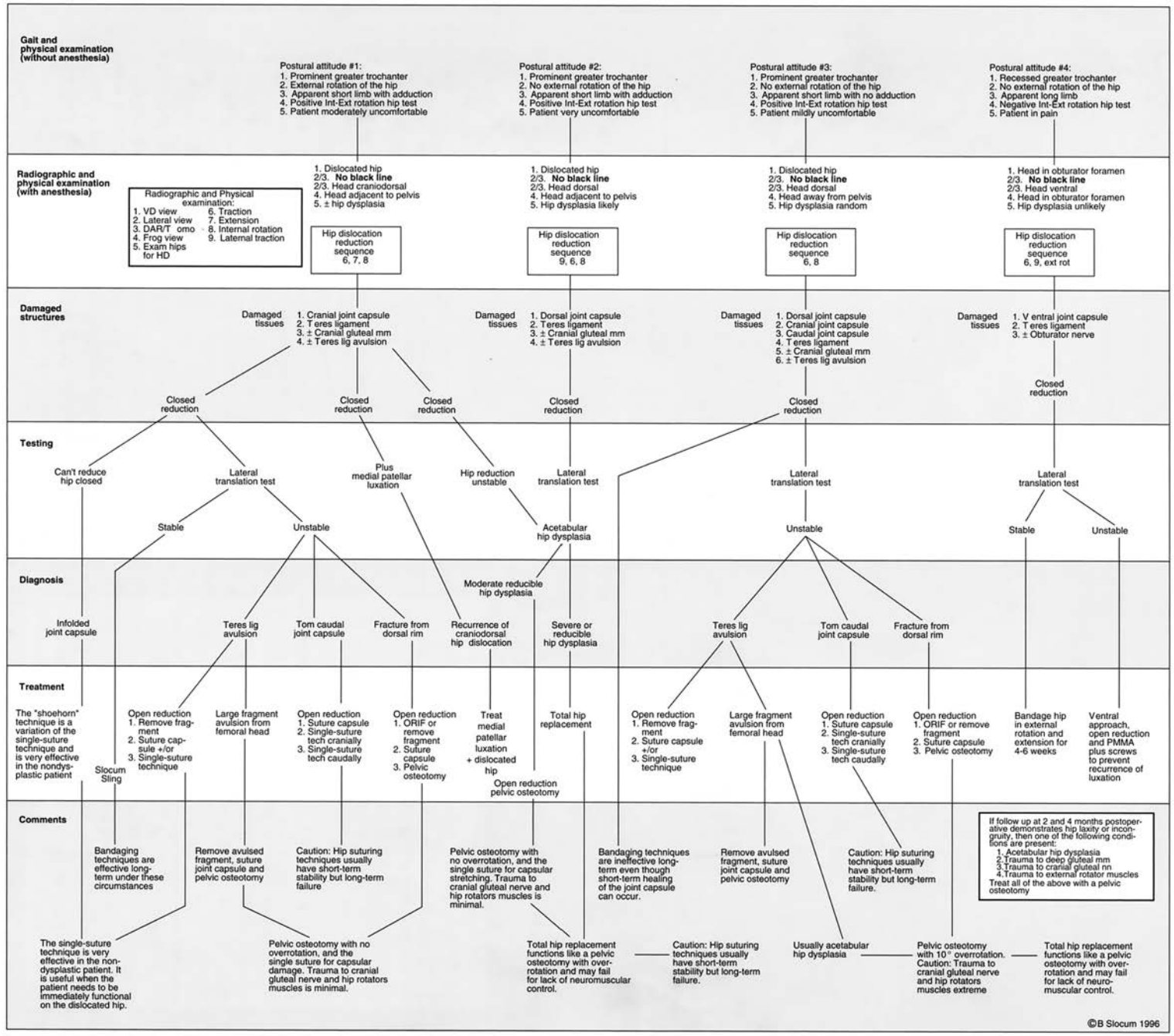


Figure 60-38. Hip dislocation algorithm. *DAR*, dorsal acetabular rim; *HD*, hip dysplasia; *ORIF*, open reduction with internal fixation; *PMMA*, polymethylmethacrylate; *VD*, ventrodorsal.

Normal Hip	
V-D Rads	congruent
Frog	thin cartilage
Cupping	none
Lat Rads	WBW
DAR	<7.5°
Dors Osteo	none
Distract Index	<0.30
Red/Sub	none/none
Cartilage	ok
Joint Caps	ok
Acetabulum	no filling
ROM	ok
AM Pain	ok
Activity	ok
Abd-Ext Rot	no pain
Jumping	ok
Stand Test	ok
Treatment 1	none
Treatment 2	
Treatment 3	

Subluxating Hip Dysplasia	
V-D Rads	congruent + cup
Frog	thin cartilage
Cupping	±
Lat Rads	WBW
DAR	8° to 10°
Dors Osteo	none
Distract Index	0.30>DI>0.40
Red/Sub	20°/5°
Cartilage	ok
Joint Caps	stretched (or torn)
Acetabulum	no filling
ROM	ok
AM Pain	ok
Activity	ok
Abd-Ext Rot	occasional pain
Jumping	ok
Stand Test	ok
Treatment 1	reevaluation 6 mo
Treatment 2	FNL
Treatment 3	

Mild Reducible Hip Dysplasia	
V-D Rads	incongruity + cup
Frog	usually thin cart
Cupping	+
Lat Rads	WB ± G
DAR	10°<slope<20°
Dors Osteo	slight
Distract Index	0.40>DI>0.75
Red/Sub	>25°/<15°
Cartilage	ok or fibrillation
Joint Caps	torn or fx labrum
Acetabulum	maybe some filling
ROM	abduction ok
AM Pain	slow to rise
Activity	bursts, quits early
Abd-Ext Rot	pain
Jumping	some difficulty
Stand Test	some positive
Treatment 1	PO 20°
Treatment 2	PO 20°+FNL
Treatment 3	

Severe Reducible Hip Dysplasia	
V-D Rads	incongruent
Frog	incr cartilage space
Cupping	cupping or deform
Lat Rads	WGG
DAR	15°<slope<30°
Dors Osteo	significant
Distract Index	0.30>DI>1.0
Red/Sub	25°-35° / 20°-25°
Cartilage	worn or eburnation
Joint Caps	torn, fx labrum & fibrosis
Acetabulum	almost filled
ROM	restricted abduction
AM Pain	slow to rise + handstands
Activity	sleeps lots
Abd-Ext Rot	restricted
Jumping	difficult or refuse
Stand Test	positive
Treatment 1	DARthroplasty
Treatment 2	THR
Treatment 3	

Rapid Growth Hip	
V-D Rads	congruent or not
Frog	thin cartilage
Cupping	none
Lat Rads	WBW or G
DAR	<7.5°
Dors Osteo	none
Distract Index	0.30>DI>0.75
Red/Sub	15° to 45°/-7° to 5°
Cartilage	ok
Joint Caps	stretched (or torn)
Acetabulum	no filling
ROM	ok
AM Pain	ok
Activity	ok
Abd-Ext Rot	occasional pain
Jumping	ok
Stand Test	ok
Treatment 1	FNL
Treatment 2	abduction brace
Treatment 3	reevaluation

Intermittent Hip Dysplasia	
V-D Rads	± congruent + cup
Frog	thin cartilage
Cupping	+
Lat Rads	WB ± W
DAR	>10°
Dors Osteo	none
Distract Index	0.40>DI>0.50
Red/Sub	>20°/<10°
Cartilage	ok
Joint Caps	stretched or torn
Acetabulum	little or no filling
ROM	ok
AM Pain	occ slow to rise
Activity	may quit early
Abd-Ext Rot	some pain
Jumping	usually ok
Stand Test	ok, some positive
Treatment 1	PO 20°
Treatment 2	FNL
Treatment 3	

Moderate Reducible Hip Dysplasia	
V-D Rads	incongruent
Frog	incr cartilage space
Cupping	+
Lat Rads	W ± BG
DAR	15°<slope<30°
Dors Osteo	moderate
Distract Index	0.40>DI>0.75
Red/Sub	25°-30°/15°-20°
Cartilage	fibrillation or worn
Joint Caps	torn, fx labrum & fibrosis
Acetabulum	incomplete filling
ROM	abduction reduced
AM Pain	slow to rise
Activity	sleeps more, burst of activity
Abd-Ext Rot	pain
Jumping	usually difficult
Stand Test	usually positive
Treatment 1	PO 20°
Treatment 2	PO 20°+FNL
Treatment 3	PO 30°

Irreducible Hip Dysplasia	
V-D Rads	incongruent
Frog	thick cart space
Cupping	cupping or deform
Lat Rads	WGG
DAR	25°<slope<40°
Dors Osteo	large
Distract Index	0.30>DI>1.0
Red/Sub	25°-40°/20°-30°
Cartilage	eburnation
Joint Caps	fibrosis
Acetabulum	filled
ROM	restricted abduction
AM Pain	slow to rise + handstands
Activity	sleeps lots
Abd-Ext Rot	restricted
Jumping	difficult or refuse
Stand Test	positive
Treatment 1	THR
Treatment 2	DARthroplasty
Treatment 3	excision arthroplasty

Figure 60-39. Summary of examination findings *(left column)* for clinical classification of hip dysplasia. The *right column* indicates the radiographic features corresponding to the clinical findings. *Abd-Ext Rot,* abduction with external rotation; *DAR,* dorsal acetabular rim; *FNL,* femoral neck lengthening; *PO,* pelvic osteotomy; *Red/Sub,* reduction/subluxation; *ROM,* range of motion; *THR,* total hip replacement; *VD,* ventrodorsal; *WGG,* white, gray, gray; *WBW,* white, black, white.

Diagnostic Tests

Barclay Slocum and Theresa Devine Slocum

Clinical Observations

"Boxy" Hips

The observation of gait is important to distinguish between functional abnormalities such as ataxia, and conformational abnormalities. "Boxy" hips are a change in shape of the rump from smooth and rounded to that of a rounded square (Figure 60-40), caused by a luxated hip.

Observation Procedure

The patient is observed from behind during walking. The examiner notes the width between the animal's feet in the transverse plane. The normal patient places the foot beneath the hip joint, which is 7 to 10 cm apart on a dog the size of a Labrador retriever. This is called base normal. On the same dog with boxy hips, the feet will be 2 to 5 cm apart, which is called base narrow. Some patients walk base narrow, convert to base wide (feet are 12 to 15 cm apart), and oscillate between the two (Figure 60-41).

The second characteristic to notice is the contour of the rump from behind. The rump of the normal dog is smooth and rounded, sloping ventrally from the caudal vertebrae, as the contour is traced laterally. The dog with "boxy" hips has minimal or no slope from the caudal vertebrae as the contour of the rump is traced laterally, and then it is round (with a smaller radius of curvature) as the contour curves around the greater trochanter to continue along the lateral thigh. Occasionally, the trochanter intermittently protrudes, causing the shape to change between the two contours (Figure 60-42).

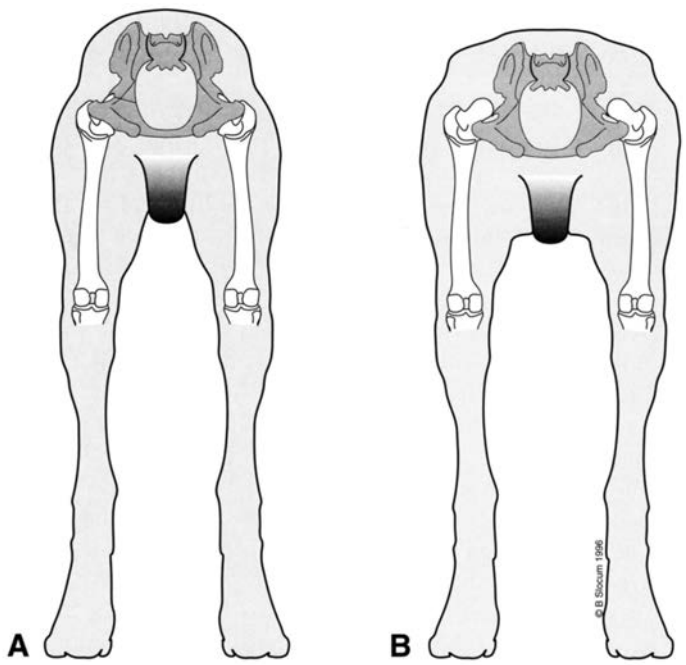


Figure 60-40. A. The contour of the normal rump is like a beautifully arched doorway. **B.** The contour of the rump of a dysplastic dog with luxated hips is like a rectangular doorway.

The difference between normal and "boxy" hips is the difference between a normally reduced femoral head and a luxated femoral head. In the luxated hip, the femoral head has translated laterally and dorsally. This projects the greater trochanter laterally and dor-sally and gives the contour of the rump the "boxy" appearance of a rounded square. The luxated hip is supported by the joint capsule, rather than by the acetabulum. Abduction is limited because the adductor muscles, especially the pectineus, are excessively lengthened by the amount of displacement of the femoral head when abduction occurs. This abduction of the luxated femoral head creates extra forces on the already stretched and inflamed joint capsule, which causes the patient pain. The dog limits the amount of this abduction by walking base narrow (See Figure 60-41).

The reduced or normal position of the hip in the acetabulum is nonpainful. Because the increased slope of the acetabulum in the dysplastic hip allows the femoral head to drift into the luxated position, the patient has two means of reducing the femoral head into the acetabulum. The combined muscle forces of the hip abductors and rotators can create sufficient pull to reduce the femoral head, but this force must be sustained to maintain reduction. These muscles are not created with the purpose of maintaining the reduced hip. As these muscles fatigue, the hip again luxates.

The second means of creating hip reduction is to abduct the hip, a maneuver that redirects the axial muscle forces of the femur into the acetabulum. This requires minimal abductor forces to hold the hip in the reduced position, but the foot is not under the femoral head. The patient must walk base wide to maintain reduction of the luxated hip (See Figure 60-41). This base wide effect has been observed in several circumstances. Some dogs shift from a base narrow gait to a base wide gait and back, as the discomfort of luxation dictates a base wide configuration for comfort. Some dogs shift to base wide to go up stairs. Some dogs hesitate slightly before jumping into a car or the bed of a pickup truck, to go base wide and relocate the hip before jumping.

The presence of "boxy" hips indicates that the hips are luxated and are in a severe and rapid stage of degeneration. If the dog is young, these hips may be saved and made functional by a pelvic osteotomy. Most frequently, dogs are presented beyond this stage.

"Bunny Hopping" Gait

The observation of gait is important in the determination of functional abnormalities such as ataxia and conformational abnormalities. "Bunny hopping" gait is a running gait in which the patient runs with both feet in adduction, simultaneously.

Observation Procedure

The patient is observed from behind during running. The examiner notes the width between the feet in the transverse plane. The normal patient places the foot beneath the hip joint, which is 7 to 10 cm apart on a dog the size of a Labrador retriever. On the same dog with a "bunny hopping" gait, the feet are 2 to 5 cm apart, and use of the hind limbs is simultaneous (Figure 60-43).

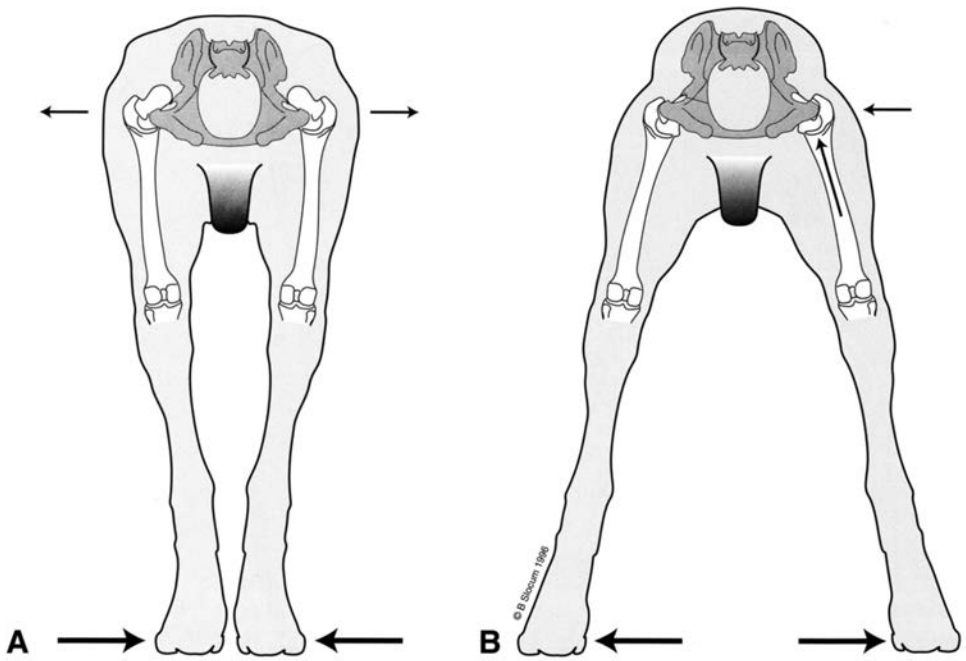


Figure 60-41. A. The dysplastic dog with luxated hips is likely to stand with the feet together, base narrow. **B.** The dysplastic dog with reduced hips stands with the feet apart, base wide, to direct the axial femoral force into the acetabulum and ease hip reduction.

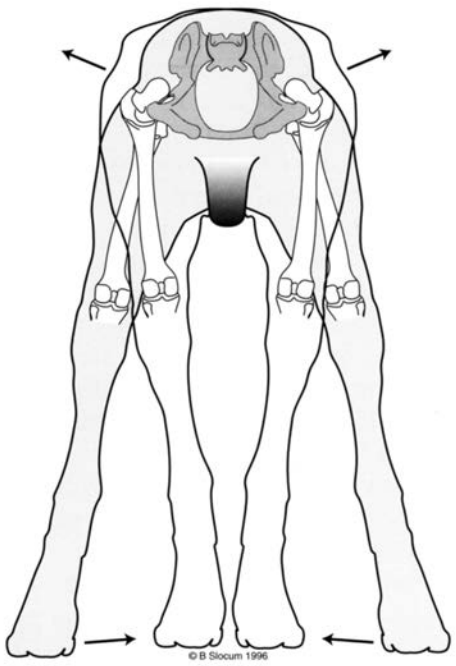


Figure 60-42. As the dog goes from a base wide to a base narrow stance, the width of the rump may increase as the hips luxate. As the dog goes from a base narrow to a base wide stance, the width of the rump may decrease as the hips reduce. This is called a base shift.

The difference between the normal running and "bunny hopping" gait is that, in the normal gait, the feet are apart by approximately the width of the hip joints, and one hind foot is used slightly before the other. In the "bunny hopping" gait, the feet are placed close together and are used together, with the back performing the greater part of extension. The difference between the hips in the normal and "bunny hopping" gait is the difference between a normally reduced femoral head and a luxated femoral head. The luxated hip is supported by the joint capsule rather than by the acetabulum and is therefore limited in its abduction. When the femoral head is laterally displaced, the adductor muscles are excessively lengthened. Abduction of the luxated fem oral head creates large forces on the already inflamed joint capsule. This causes the patient pain and a base narrow gait. The patient seems to be incapable of reducing the femoral head into the acetabulum by either abductor and rotator muscle forces or abduction of the hip. By using both limbs together, the forces are greatly reduced in each hip.

The presence of a "bunny hopping" gait indicates that the hips are luxated and are in a severe and rapid stage of degeneration. These hips are usually beyond reconstruction by means of a pelvic osteotomy unless the patient is young and the severe luxation is a recent occurrence.

"Clunking" Hips

The observation of gait is important in the determination of functional abnormalities. "Clunking" hips are a result of the hip relocating from the luxated position to the reduced position during ambulation.

Observation Procedure

The client often brings the "clunking" of the hips to the attention of the orthopedist. The patient is observed during walking. The examiner's hand can be placed on the animal's rump to feel the hip being reduced during ambulation. One can also hear the "clunk" of reduction (Figure 60-44). A positive observation of "clunking" hips is to experience the feel of the "clunk" and to hear the "clunking" sound.

The presence of a "clunk" in a hip means that the hip begins in a luxated position, and the femoral head falls into an acetabulum of some depth. The combined muscle force of the hip abductors

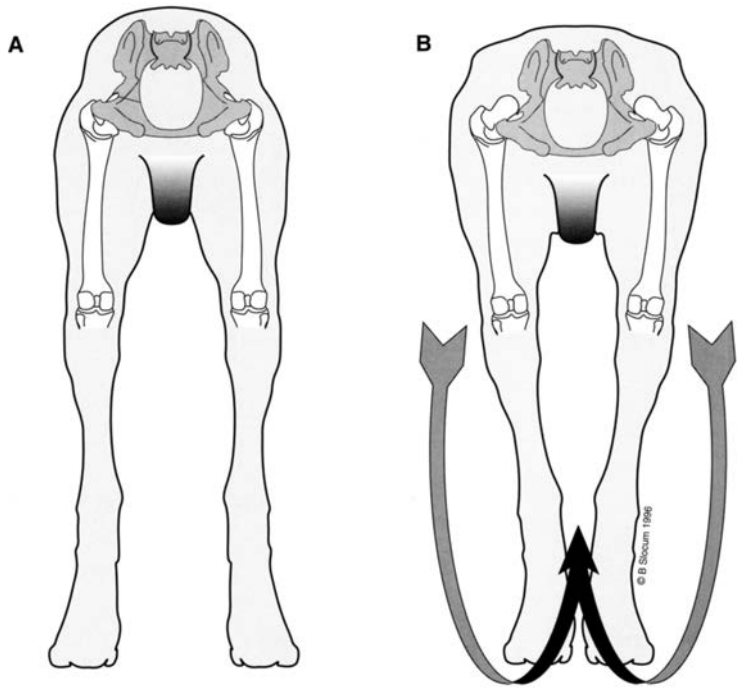


Figure 60-43. A. Normal. **B.** "Bunny hopping" is an abnormality of gait that occurs when hips are luxated. Both rear limbs are used simultaneously during extension to limit hip pain. The back is hyperextended, to assist in lengthening the stride.

and rotators can create sufficient pull to reduce the femoral head, but this force must be sustained to maintain reduction. Because these muscles are not created with the purpose of maintaining hip reduction, they soon fatigue, and the hip again luxates. The reduced or normal position of the hip in the acetabulum is nonpainful, but the increased slope of the acetabulum in the dysplastic hip allows the femoral head to drift into the luxated position.

The presence of a "clunking" hip, whether by direct observation or by client observation, clearly indicates an orthopedic emergency in which the patient should be placed under absolute rest conditions until the hips can be evaluated and treated. If the hips are "clunking," then usually enough acetabulum is left to reseat the femoral head. A pelvic osteotomy will be successful if the acetabulum has not filled with osteophytes and the dorsal acetabular rim (DAR) still has sufficient integrity and depth to maintain the femoral head in the acetabulum after pelvic osteotomy.

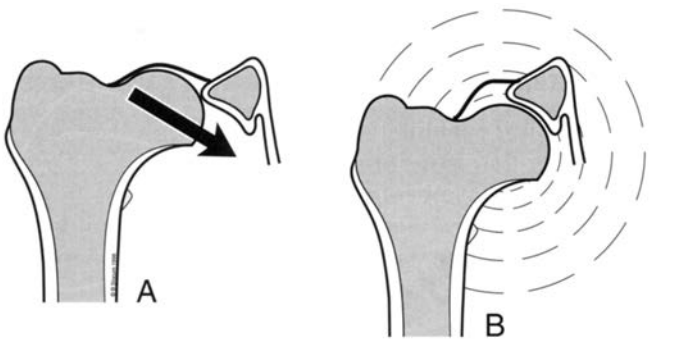


Figure 60-44. A. The "clunking" sound emanating from the hip is generated by the luxated hip, rapidly returning to the acetabulum *(arrow)* during ambulation. **B.** When the femoral head seats in the bottom of the acetabulum, a "clunking" sound is heard, and this corresponds to the vibration felt as the medial translation of the greater trochanter is palpated during ambulation.

The DAR is under immediate trauma by the femoral head because the femoral head just proximal to the ligament of the femoral head is incongruent with the acetabulum and is concentrating forces on the DAR and the adjacent joint capsule. If the DAR breaks down, then the "clunk" will cease. The femoral head remains permanently in the luxated position in the dorsal joint capsule. Acetabular filling follows breakdown of the DAR because it is secondary to the inflammation generated by the breakdown process at the DAR. The hip will stop "clunking" if the hip is neglected because acetabular filling occurs. The window of opportunity to correct this patient's acetabular hip dysplasia by pelvic osteotomy is lost if dorsal acetabular breakdown or acetabular filling occurs. Under these circumstances, the attending veterinarian has lost the chance to reconstruct the patient's hip.

The presence of "clunking" hips indicates that the hips are luxated and are in a severe and rapid stage of degeneration. If the dog is young, these hips may be saved and made functional by a pelvic osteotomy; however, immediate action must be taken to identify the source of damage accurately and to correct the incongruity.

Stand Test

The stand test creates extension of the hip and lordosis of the spine (Figure 60-45). This test is a functional exercise that stresses the spine (especially the L7-S1 with cauda equina impingement) and hip in extension. Because the interaction to perform this test is between the owner and the patient, resistance to the test is

minimal, and the results are reliable. If the owner is unable to handle the patient, or if the patient intimidates the owner, then the test should be bypassed to avoid injury.

Testing Procedure

Clear and specific instructions to the owner are the basis of this test:

1. "Allow your dog to stand on all four legs and face you."
2. "Pick up your dog by the front legs as if you are going to dance with him or her. All the way up."

The patient and owner are observed from the side. Some patients (but few) refuse to stand facing the owner because they have been disciplined for jumping up on the owner.

The normal dog stands in this position without discomfort and enjoys the attention. The dog does not attempt to get down. The dog extends to be closer to the owner. The dog's back and hips are extended and flat as the dog stretches to reach the owner's face.

The abnormal dog stands in this position with discomfort and does not enjoy the test. The dog attempts to get down. The dog does not extend to be closer to the owner and shifts body weight to the side to return to the ground. The dog's back and hips are maintained in flexion, and the dog attempts to disengage from this activity. The dog may even mock bite at the owner's hand as the owner holds the dog's forelimbs.

The stand test stresses the hips and spine of the patient by forced extension. Dogs with abnormal hips respond differently, depending on the degree of inflammation and fibrosis. Young dogs with stretched joint capsules that have little inflammation give the response of a normal dog. The young dog with highly inflamed joints and joint capsules adamantly resists the test. Older dogs with capsular fibrosis of chronic hip dysplasia simply cannot flex at the hips and stand with their rump sticking out.

Dogs with an abnormal spine also vary in their response, depending on the degree of inflammation. The patient with a highly inflamed spine from a disease such as discospondylitis fights this test violently. Dogs with cauda equina syndrome resist to a lesser degree. Patients with mild spondylosis do not fight the test, but they prefer to stand with their rump sticking out.

Even though the stand test is not pathognomonic for a disease, it consistently regionalizes the problem to the back or hip. It is an easy test to perform to demonstrate a problem in these regions.

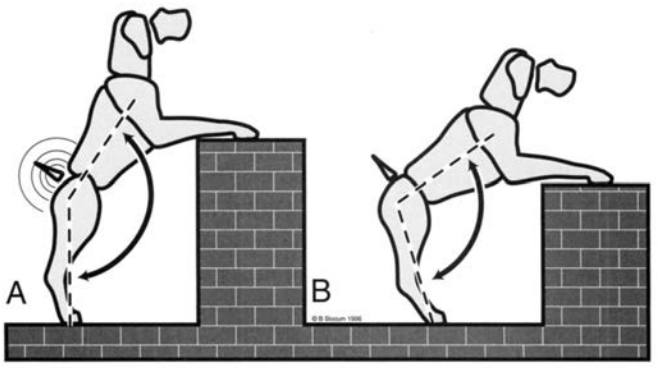


Figure 60-45. The stand test is performed by picking up the front legs of a standing dog. **A.** A normal dog extends the hips and back to relish the attention of the owner. **B.** The abnormal dog protrudes the rump in an attempt to maintain flexion of the hip and back. The abnormal dog usually attempts to return to the standing on all four legs and may even mock bite the hands holding the dog.

Physical Examination in an Awake Patient

Abduction External Rotation Test

The physical examination is the primary means of demonstrating that a patient's lameness or soreness is coming from the hip, lower lumbar spine, or lumbosacral disc. The abduction external rotation test is not specific to hip dysplasia, but it suggests dorsal joint capsule inflammation. Because this test creates discomfort in the hip, the owner should be forewarned of the patient's possible pain response. Only enough external rotation to elicit a response is necessary. This should be the last test performed on the caudal portion of the dog if patient cooperation is expected.

Testing Procedure

The orthopedist is caudal to the patient while an animal health technician restrains the patient's head. The right and left hips are tested independently. The examiner's right hand holds the patient's right stifle. The stifle is used to flex and externally rotate the right hip. The hip is abducted, externally rotated, and extended simultaneously. A negative response from the patient is indifference. A positive response from the patient varies, depending on the dog's personality, from guarding the hip against manipulation, to vocalization, to attempting to bite the operator.

The abduction external rotation test stresses the attachment of the joint capsule at the DAR, to stimulate a pain response in the inflamed hip. The hip inflammation is caused by repeated tearing of the joint capsule as the femoral head translates laterally and dor-sally. The final dorsal migration of the femoral head creates the capsular tearing. After the repeated tearing of the capsule dorsally, the capsule thickens and attempts to heal by fibrosis. The normal joint capsule at the DAR is thin and almost transparent, but it is stout cranially and caudally.

A positive response from the patient indicates that inflammation is present. This test does not quantify the amount of inflammation. The acute tearing of the young patient is usually painful, because it is complete and creates a tremendous stretching on the cranial and caudal capsule. The tearing of the older patient's joint capsule is usually not so extensive. The joint capsule with a more chronic disorder supports the femoral head by hypertrophy and fibrosis. This test is also positive if the lower lumbar spine or lumbosacral disc is inflamed by causing a torsion of the affected inflamed disc.

Hip Extension Test

This physical examination is a primary means of demonstrating that lameness is emanating from the hip or back. This test is not specific to the hip because it tests the dog's response not

only to the inflamed and thickened joint capsule, but also to the contracted iliopsoas and lower back inflammation. Because the hip extension test creates discomfort, the owner should be forewarned of the possibility of aggressive or painful behavior.

Testing Procedure
The orthopedist is caudal to the patient while an animal health technician restrains the patient's head. The right and left hips are tested independently. For testing a small dog's right hip, the operator places his or her fingers around the cranial thigh and the thumb on the dorsal ischial table. The patient's hip is extended by pulling the examiner's fingers to the thumb. For large dogs, the fingers of the right hand are placed around the cranial right thigh at the stifle, and the left hand is placed over the dog's rump. The operator extends the dog's hip by pulling the femur caudally, while the left hand prevents the dog moving away from the doctor. The left hip is similarly tested. A negative response from the patient is indifference. A positive response from the patient varies, depending on the dog's personality, from guarding the hip against manipulation, to vocalization, to attempting to bite the operator.

The hip extension test tightens the joint capsule around the neck of the femur. This stretches an inflamed joint capsule like wringing a mop. The hip inflammation is present because of repeated tearing of the joint capsule as the femoral head translates laterally and dorsally. After the repeated tearing of the capsule dorsally, the inflamed capsule thickens and attempts to heal by fibrosis. A positive response from the patient indicates that hip joint capsule inflammation is present. This test does not quantify how much inflammation is present, only that it is present. This test may show discomfort of the lower lumbar spine or lumbosacral disc inflammation by extending the lower back.

The stand test creates similar conditions of hip extension and lordosis (back extension), but in the stand test, the patient extends only as far as comfort allows. Interpretation of the hip extension test and the stand test is similar.

Hip Subluxation Test

This physical examination is a primary means of demonstrating that a patient's lameness or soreness is coming from the hip. This test is specific to the dysplastic hip because it tests the dog's response to the inflamed dorsal joint capsule. The owner should be forewarned that the patient may create its own discomfort by contracting the muscles that force the femoral head against the irritated joint capsule. This should be the last test performed on the caudal portion of the dog, if patient cooperation is expected.

Testing Procedure
The orthopedist is on the side of the hip to be tested, while an animal health technician restrains the patient's head. The right and left hips are tested independently. For the right hip, the fingers of the examiner's right hand are placed medial to the proximal femur from cranially, and the right thumb is placed on the right ilium. For large dogs, it may be helpful to prevent the hip from abducting by placing the left hand on the lateral stifle. The examiner pulls laterally on the femur and pushes medially on the ilium with the thumb at the same time. A negative response from the patient is indifference. A positive response from the patient varies from guarding the hip against further manipulation, to vocalization, to attempting to bite, depending on the dog's personality. The left hip is similarly tested.

The hip subluxation test stresses the attachment of the joint capsule at the DAR. As the hip subluxates laterally by the examiner's lateral pressure on the proximal femur, the patient contracts the thigh muscles to protect the hip against the anticipated pain. This muscular contraction causes the hip to translate dorsally into the inflamed dorsal joint capsule. This causes a positive pain response. The hip inflammation is present because of repeated stretching of the joint capsule as the femoral head translates laterally. The dorsal migration of the femoral head after lateral translation creates the capsular tearing and high inflammation in the diseased hip.

The normal joint capsule at the DAR is thin and almost transparent, but it is stout cranially and caudally. After repeated stretching and tearing of the capsule dorsally, the capsule thickens and attempts to heal by fibrosis. A positive response from the patient indicates that inflammation is present. This test does not quantitate the amount of inflammation. The acute stretching in the young patient is usually painful because it creates a tremendous stretching on the cranial and caudal capsules. The acute tearing of the dorsal joint capsule resulting from dorsal translation in the young patient is usually painful because it lacks capsular support of the more chronic cases. The per incident tearing of the older patient joint capsule is usually not so extensive, and the joint capsule with a more chronic disorder has the support of hypertrophy and fibrosis cranially and caudally.

The hip subluxation test is useful in distinguishing between hip and back pain because it is specific to the hip and independent of the lower lumbar spine or lumbosacral disc inflammation.

Iliopsoas Testing

This physical examination is a primary means of demonstrating that lameness is emanating from the iliopsoas muscle. This test is specific to the iliopsoas because it tests the dog's response to the inflamed iliopsoas muscle. Because iliopsoas testing creates discomfort, the owner should be forewarned of the possibility of aggressive or painful behavior.

Testing Procedure
The orthopedist is lateral to the patient while an animal health technician restrains the patient's head. The right and left hips are tested independently. For testing a dog's right iliopsoas muscle, the operator places his or her fingers around the patient's cranial thigh and applies digital pressure over the iliopsoas just caudal to the origin of the pectineus muscle. The iliopsoas muscle is further tested by extending the hip and digital palpation. In addition, the iliopsoas muscle is tested further by extending the hip plus digital palpation of the muscle with internal rotation of the hip. The left hip is similarly tested. A negative response from the patient is indifference. A positive response from the patient varies, depending on the dog's personality, from guarding the hip against manipulation, to vocalization, to attempting to bite the operator.

The direct digital palpation of the iliopsoas muscle causes pain in the inflamed muscle. Extension of the hip causes pain by stretching the inflamed muscle. The internal rotation of the hip also lengthens the inflamed iliopsoas muscle. The pain experienced by the patient is in direct proportion to the amount of inflammation, digital pressure, and stretching of the muscle. This test does not quantify the degree of inflammation. The digital test and internal rotation test are specific to the iliopsoas muscle.

Physical Examination in an Anesthetized Patient

Angles of Reduction and Subluxation

The meaning of hip palpation has been incompletely understood because of imprecise definition and measurement. The Ortolani sign occurs during hip abduction and is created when the femoral head is reduced into the acetabulum from a luxated position with a "shift" or "clunk." The angle of reduction is the measurement of the angle of abduction from the sagittal plane to the physical position at which hip reduction occurs.

The Barlow sign is a palpation event during which the femoral head is luxated from the acetabulum. The Barlow sign occurs during hip adduction and is created when the femoral head is luxated from the acetabulum into a position of joint capsular support with a "shift." The angle of subluxation is the angle between the sagittal plane and the physical event of hip luxation at which the hip first begins to luxate. By definition, the angle of subluxation is measured as positive if the hip is lateral to the sagittal plane when subluxation occurs (Figure 60-46) and negative if the hip is medial to the sagittal plane when subluxation occurs.

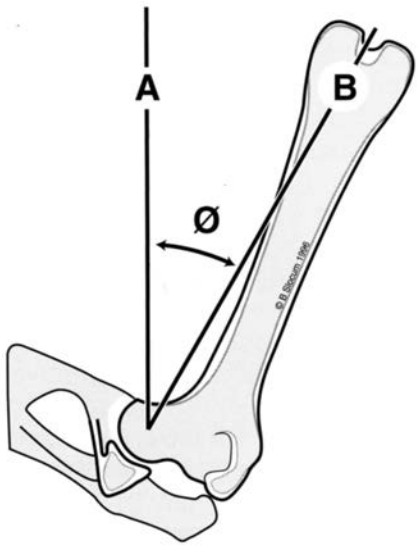


Figure 60-46. Measuring hip angle *(Ø)* is done in dorsal recumbency with the sagittal plane *(A)* as vertical. The femoral axis *(B)* is between the center of the femoral head and the center of the intercondylar notch where it meets the articular surface of the trochlear sulcus. Ø is positive when the hip is abducted; that is, the distal femur is lateral to the sagittal plane as shown; Ø is negative when the hip is adducted, and the distal femur is medial to the sagittal plane.

Techniques of Measurement

The patient is anesthetized and is placed in dorsal recumbency.

Angle of Reduction

The stifle is brought to the starting position of vertical, without hip flexion or extension, by using a medially directed force of the operator's hand on the lateral stifle. Axial femoral compression by the operator is not necessary in the immature patient, although it may clarify the angle at which reduction occurs in a patient with a chronic case. The hip is then abducted slowly by reducing the medially directed force at the stifle. When hip reduction occurs, abduction is stopped. Reduction of the hip is detected in three possible ways: a "clunk" is heard; a shift of the patient's limb is seen or palpated; or the event can be recorded by cineradiography. In chronic hip dysplasia, a "fast spot" or rapid abduction is palpated, instead of a "clunk," as the hip reduces under the influence of abduction.

The angle of reduction is measured by the Canine Electronic Goniometer (Slocum Enterprises, Eugene, OR), which was designed for this purpose. The probe is placed just caudal to the attachment of the pectineus on the iliopectineal eminence. The side of the goniometer is touched to the medial side of the stifle (Figure 60-47 and 60-48). The angle of reduction is read directly from the digital readout with accuracy to 0.1° (Figure 60-49).

Angle of Subluxation

To obtain the angle of subluxation, the stifle is slowly returned to vertical from the abducted position at which the angle of reduction was taken. The hip is adducted slowly by increasing the medially directed force at the stifle. When the hip begins to luxate (subluxate), adduction is stopped. Here again, axial femoral compression by the operator is not necessary, but it may clarify the angle at which subluxation occurs in patients with a chronic disorder.

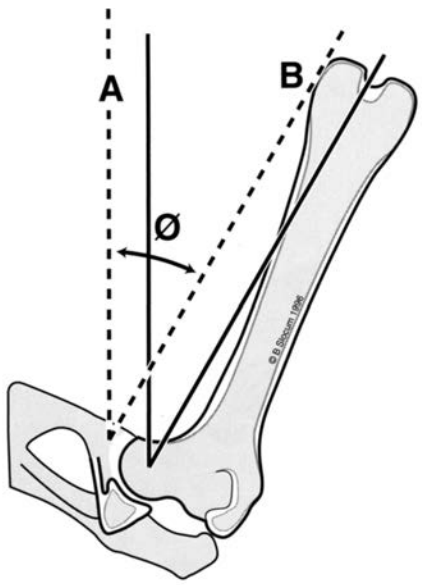


Figure 60-47. The axis of measurement for the Canine Electronic Goniometer *(dotted line, B)* is parallel to the defined axis (solid line). Because the sagittal plane *(A)* is defined by gravity, the angle Ø remains the same.

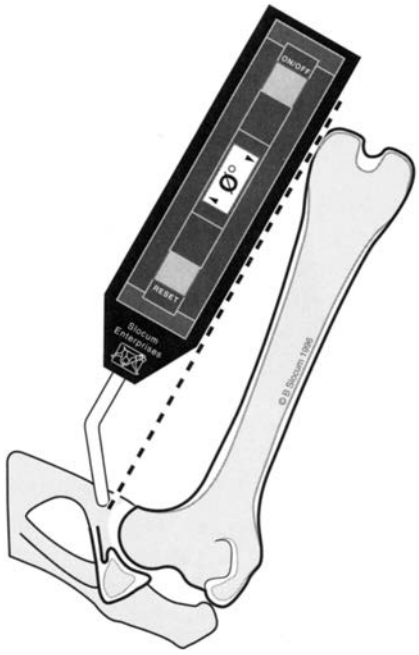


Figure 60-48. The Canine Electronic Goniometer measures the angle with respect to gravity, the sagittal plane is 0°, obtained in dorsal recumbency of the patient. The probe is placed just caudal to the iliopectineal eminence; the body of the goniometer is touched to the medial femoral condyle, and the angle Ø is recorded from the digital readout.

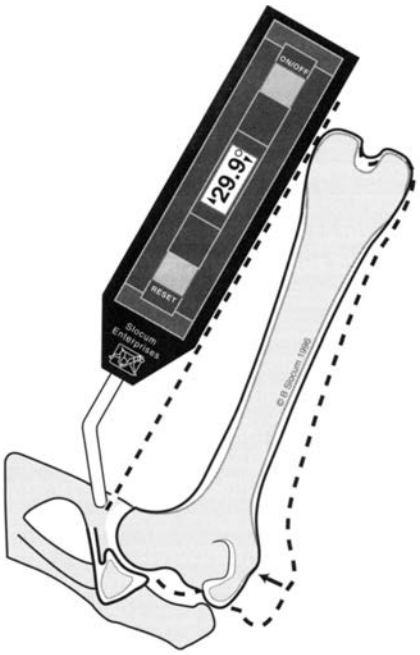


Figure 60-49. The angle of reduction is measured, 29.9° in this example, immediately after the abduction event of hip reduction *(arrow)*.

Luxation of the hip is detected in three ways: a "shift" is palpated; a "shift" is seen; or the event can be recorded by cineradiography. In cases of chronic hip dysplasia, a "fast spot" or rapid abduction is palpated, instead of a "shift," as the hip luxates under the influence of adduction. The angle of subluxation is measured by the Canine Electronic Goniometer. The probe is placed just caudal to the attachment of the pectineus on the iliopectineal eminence. The side of the goniometer is touched to the medial side of the stifle (Figure 60-50), and the measurements are recorded. The measurements of the angles of reduction and subluxation are repeated on the other hip.

Two angles are measured for each hip, the angle of reduction and the angle of subluxation. The format for recording this information is (angle of reduction/the angle of subluxation), that is, AR/AS = 29.9°/14.5°. The angle of reduction is always greater than the angle of subluxation.

The angle of reduction represents joint laxity, that is, the stretching of the joint capsule and its tearing from the DAR. The greater the angle of reduction, the greater is the stretching of the joint capsule dorsally. The stretching of the joint capsule dorsally determines where the DAR will contact the femoral head. The physical contact point between the rim and the femoral head determines the amount of abduction necessary before the axial force of the femur (the direction not the magnitude) is directed medial to that contact point. The femoral head falls into the acetabulum when that condition exists (Figure 60-51). For this reason, abduction is necessary to create hip reduction.

When the stretching of the joint capsule is small, the contact point is almost dorsal on the femoral head when the limb is in the sagittal plane. As the joint capsule stretches, the femoral head is allowed to translate laterally and then dorsally, and the point of contact between the DAR and the head moves further medially on the femoral head. The lateral and dorsal translation of the femoral head is limited by the ligament of the femoral head. This causes the contact point of the DAR and the femoral head to be just dorsal to the fovea capitis. This is the outer limit of capsular stretching without damage to the teres ligament. When the femoral head rests in this position, all the forces transmitted to the DAR from the femoral head have to do so through

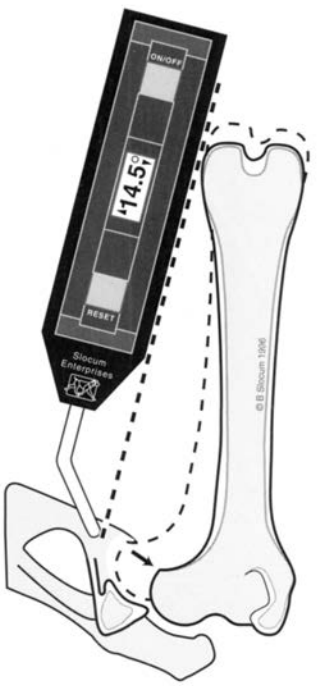


Figure 60-50. The angle of subluxation is measured, 14.5° in this example, immediately after the adduction event of hip luxation *(arrow)*.

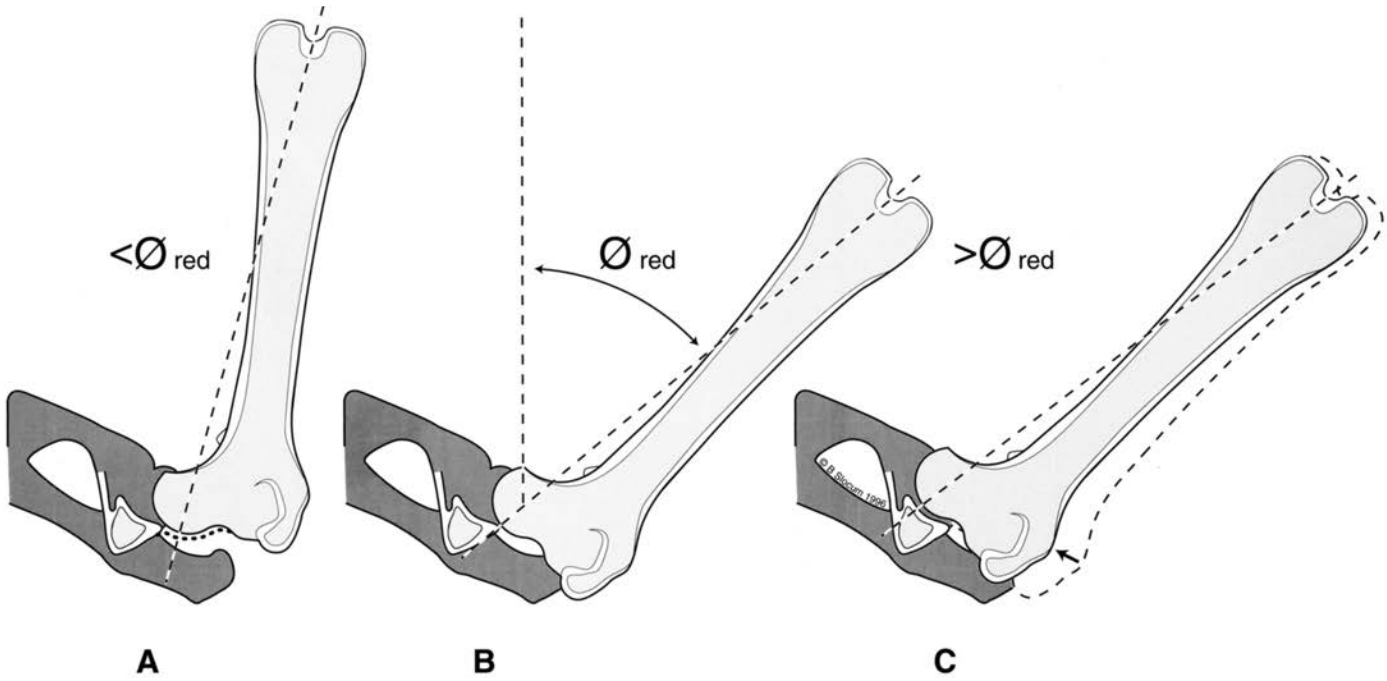


Figure 60-51. A. Hip reduction by abduction begins (less than $Ø^{red}$) with the femoral head resting and stable in the dorsal joint capsule *(dotted line)* (hip luxated) and the acetabulum contacting the femoral head medial to the axial line of femoral force between the joints *(dashed line)*. **B.** As the hip is abducted, the joint capsule supporting the femoral neck through the cranial and caudal ligaments causes the femoral head and the dorsal acetabular rim to contact along the axial line at angle $Ø^{red}$, which makes the hip unstable. **C.** Any further abduction (greater than $Ø^{red}$) causes the femoral head to contact the dorsal acetabular rim lateral to the axial line of force, and the femoral head shifts into the acetabulum *(arrow)*. The femoral head is now stable within the confines of the acetabulum when greater than $Ø^{red}$.

a reduced area of contact. This extreme force per unit area of contact between the femoral head and the DAR damages the cartilage of the femoral head just above the fovea capitis. This damage begins with fibrillation of the cartilage and ends with bone rubbing on bone and distortion of both the femoral head and acetabulum as end-stage events. The angle of reduction increases further only with stretching of the teres ligament or breakdown of the dorsal acetabulum. The angle of reduction decreases with capsular fibrosis and osteophyte production on the DAR that initiates capsular stabilization by resisting further dorsal translation.

The angle of subluxation represents the functional slope of the acetabulum beneath the dorsal rim. The actual slope of the DAR may be less than the angle of subluxation, if the ligament of the femoral head is redundant or the acetabulum is filling with osteophytes. For subluxation of the hip to occur, the femoral head and the acetabulum must interact, but not the joint capsule (Figure 60-52). The direction of the axial femoral force is into the acetabulum following the measurement of the angle of reduction. As the hip is adducted, the axial femoral force becomes normal to the DAR slope that was the last position of stability. Any further adduction of the hip directs the axial femoral force lateral to the perpendicular of the DAR surface, and so the femoral head translates laterally to rest in the joint capsule. In the normal hip, no significant joint capsule laxity exists to allow enough lateral translation of the femoral head for subluxation. All hips have some laxity, as clearly established by Penn-Hip. PennHip is a commercial registry which reads distraction and compression hip radiographs for hip laxity. The laxity is normalized to the femoral head and expressed as the Compression Index, C.I. (C.I. = displacement of the femoral head divided by the radius of the femoral head.) C.I. < 0.30 is normal for most breeds.

As some normal puppies undergo rapid growth between 4 and 6 months of age, the adductor muscle mass (and moment) overpowers the abductor muscles because of the temporary lack of adductor muscle length. As a consequence, the relative hip adduction directs the axial femoral force lateral to the DAR, and the femoral head is contained in its lateral translation by the joint capsule. The joint capsule is stretched, producing joint laxity. The result is an increased angle of reduction and distractive index of PennHip. In such patients, the angle of reduction is high because of the lax joint capsule, but the DAR angle is normal. The angle of subluxation may be 0° or negative because the DAR slope is normal. Such laxity is not hip dysplasia, because the conformation of the hip is normal and the stretched capsule is temporary, whereas hip laxity, caused by capsular stretching that accompanies acetabular hip dysplasia, is secondary to an increased slope of the DAR (the cause of stretching) and remain until the slope of the DAR is normalized by a pelvic osteotomy. This example of rapid growth syndrome in puppies with lax capsules that allow hip luxation confirms our clinical experience that hip joints can be lax without being pathologic. In addition, these puppies have become certified by OFA as normal when trauma to the hip is prevented by conservative management during 5 to 12 months of age. The angle of subluxation may even be a negative number in the nonpathologic hip or after a pelvic osteotomy.

In the pathologic hip, the angle of reduction is easily palpated in the young patient (6 months), but it may be difficult to palpate in

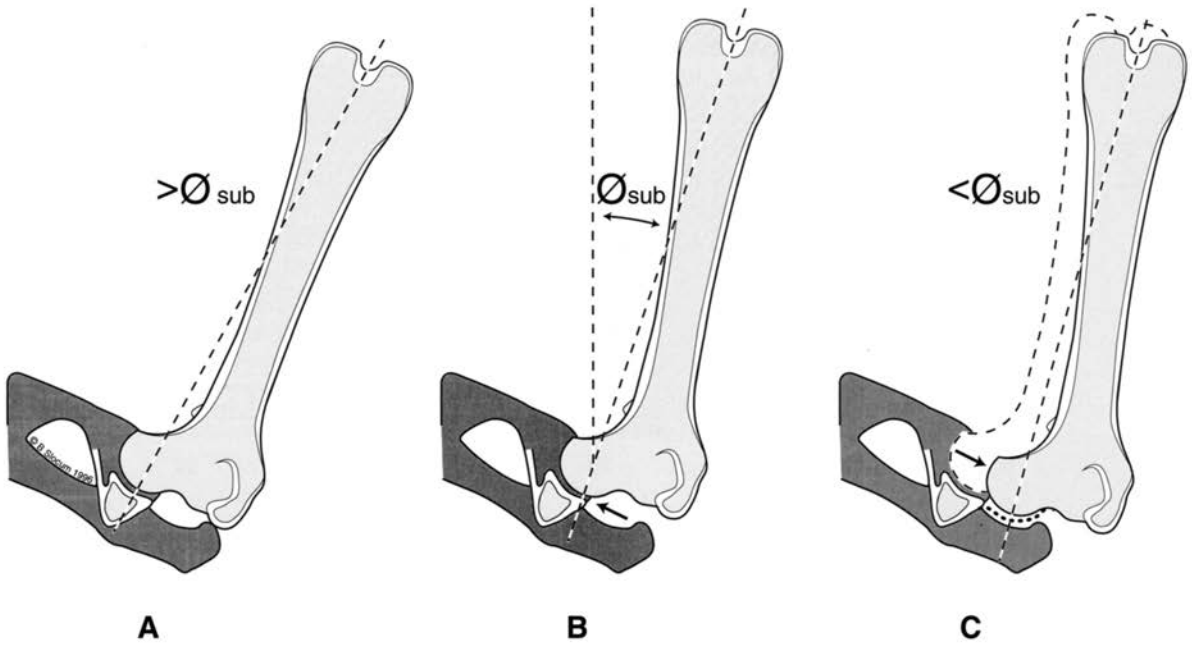


Figure 60-52. A. Hip luxation by adduction begins (greater than $Ø^{sub}$) with the femoral head resting and stable in the acetabulum and the femoral head contacting the dorsal acetabular rim lateral to the axial line of femoral force between joints *(dashed line).* **B.** As the hip is adducted, the femoral head contacts the dorsal acetabular rim at $Ø^{sub}$ along the axial line, and the hip is unstable. **C.** Any further adduction (less than $Ø^{sub}$) causes the femoral head to contact the dorsal acetabular rim medial to the axial line of force, and the femoral head luxates *(arrow)* into the joint capsule *(dotted line).*

the older patient (often by 2 years). The angle of reduction usually increases until the patient reaches the limit of stretching of the teres ligament and the joint capsule. Once the femoral head rests in the luxated position, the acetabulum fills with osteophytes, even though the femoral head may occasionally reduce. The joint capsule becomes fibrotic and thickened. As this dysplastic process progresses, the angle of reduction begins to decrease and finally becomes difficult to palpate.

In the pathologic hip, the angle of subluxation is greater than 0° and slowly increases, but it never decreases. This increasing angle is caused by the increased DAR slope because of acetabular filling and teres ligament redundancy. As the angle of reduction decreases and the angle of subluxation increases, one sees a single angle at which the femoral head shifts between capsular support and acetabular support. This is called the angle of translation (Figure 60-53).

Simply stated, a great difference between the angle of reduction and the angle of subluxation (i.e., 40/5) indicates a healthy hip with a stretched joint capsule, or a young dog's hip in the early stages of hip dysplasia that can be readily repaired with good results and no arthritis. A moderate difference between the angle of reduction and the angle of subluxation (i.e., 30/15) indicates a hip in immediate need of a pelvic osteotomy, but the status of the articular cartilage and acetabular filling needs to be assessed. A small difference between the angle of reduction and the angle of subluxation (i.e., 25/22) indicates a hip that is filling with osteophytes and is no longer a candidate for a pelvic osteotomy. A small difference between the angle of reduction and the angle of subluxation in the near-0° range (i.e., 10/0) indicates a normal hip with some capsular stretching with no need for surgical intervention.

The angle of reduction and the angle of subluxation are critical parts of the hip evaluation and are excellent indicators of status of hip health, especially at 6 months of age. Hip palpation at the time of neutering is a perfect opportunity to assess the patient for future hip problems, because it gives the owners information about whether their pet is at risk for hip dysplasia.

Ortolani Sign

The Ortolani sign is a palpation finding which was originally used in human medicine as an indicator of hip dysplasia. This sign occurs when the luxated hip enters the acetabulum with a "clunk."

Testing Procedure

The anesthetized patient is placed in dorsal recumbency. The palm of the operator's left hand is lightly placed on the lateral side of the patient's flexed right stifle. The left thumb is placed over the medial femoral condyle adjacent to the patella. The starting position is hip adduction without flexion or extension. In this position, the hip luxates from the acetabulum. The hip is slowly abducted.

If a "shift" or "clunk" in the hip is palpated, then the Ortolani sign is positive. If no "shift" or "clunk" in the hip is palpated, then the Ortolani sign is negative. The process is also repeated for the left hip by using the operator's right hand on the patient's left stifle.

The "shift" or "clunk" palpated in the hip is the reduction of the femoral head. Reduction of the femoral head into the acetabulum can only occur if the joint capsule has been stretched. A positive Ortolani sign means that the joint capsule is stretched. A negative Ortolani sign means either that the joint capsule is not

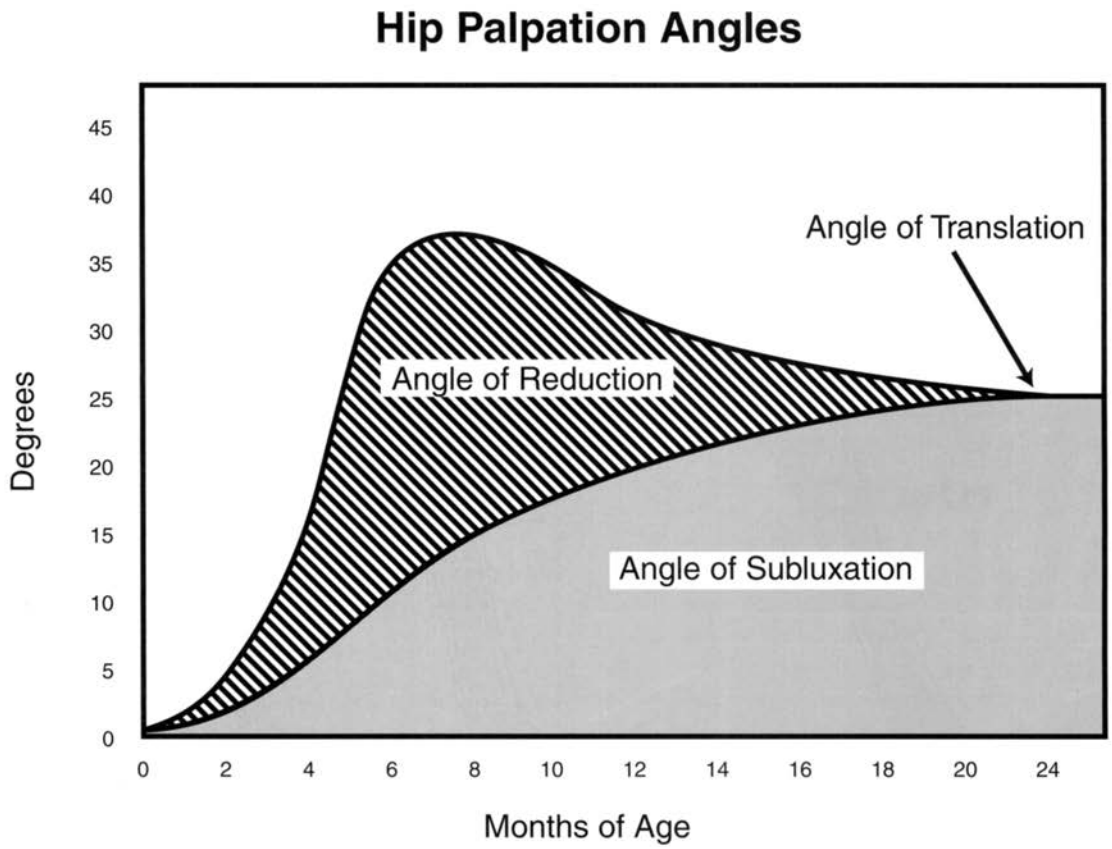


Figure 60-53. The natural progression of the angles of reduction and subluxation over time in the moderately dysplastic dog has repeatable characteristics. Early (0 to 7 months) joint capsular stretching is accompanied by a rapid increase in the angle of reduction. As time passes, the capsule becomes thickened and stabilizes the hip. The angle of subluxation, which is a function of femoral head and acetabular interaction, represents dorsal acetabular damage, acetabular filling, and ligamentum teres redundancy. The angle of subluxation increases most rapidly in the early adolescent period (5 to 8 months), when the acetabulum is subjected to high force per unit area by the luxating femoral head in the lax joint capsule. As filling of the acetabulum occurs by osteophytes forming under the influence of inflammation within the joint and the joint capsule thickens, the rate of increase of the angle of subluxation slows. The angle of subluxation continues to increase until the angle of reduction equals the angle of subluxation, called the angle of translation (AT). At the AT, the femoral head is supported by the capsule when Ø is less than AT, and the femoral head is supported by the acetabulum when Ø is greater than AT.

stretched or that the hip is not reducible into the acetabulum. Chronic fibrosis of the joint capsule often makes the transition from luxation to reduction so subtle as to go undetected.

The Ortolani sign does not represent hip dysplasia, but it indicates joint capsule stretching, which often accompanies hip dysplasia. Joint laxity is not hip dysplasia, but it is one secondary manifestation of the hip dysplastic process. Joint laxity occurs when the joint capsule is stretched. Joint capsule stretching has many causes, the most common being hip dysplasia.

To reduce the hip, the femoral head must enter the acetabulum. The angle of abduction at which the head begins to enter the acetabulum during hip abduction is the angle of reduction. This angle is the angle at which the femoral head becomes stable and relocates because of the axial compressive force direction. The angle of reduction depends on the amount of stretching of the joint capsule.

Barlow Sign

The Barlow sign is a palpation finding originally used in human medicine as an indicator of hip dysplasia. This sign occurs when the reduced hip leaves the acetabulum.

Testing Procedure

The anesthetized patient is placed in dorsal recumbency. The palm of the operator's left hand is placed lightly on the lateral side of the patient's flexed right stifle. The left thumb is placed over the medial femoral condyle adjacent to the patella. The starting position is hip abduction without flexion or extension. This position reduces the hip into the acetabulum. The hip is slowly adducted.

If a "shift" of the femoral head is palpated, then the Barlow sign is positive. If no "shift" of the femoral head is palpated, then the Barlow sign is negative. The process is also repeated for the left hip by using the operator's right hand on the patient's left stifle.

The "shift" palpated with the Barlow sign is luxation of the femoral head. Luxation of the femoral head from the acetabulum can only occur if the joint capsule has been stretched. A positive Barlow sign means that the joint capsule is stretched. A negative Barlow sign means either the joint capsule is not stretched or the hip will not reduce into the acetabulum. If the hip has chronic disease with a thickened joint capsule, the shift may be so subtle that it is missed by the operator.

The Barlow sign does not represent hip dysplasia, but it indicates joint capsule stretching, which often accompanies hip dysplasia. Joint laxity is not hip dysplasia, but it is a secondary manifestation of the hip dysplastic process. Joint laxity occurs when the joint capsule is stretched. Joint capsule stretching has many causes, and the most common cause of joint laxity is hip dysplasia.

To luxate the hip, the femoral head must leave the acetabulum. The angle of adduction at which the head begins to leave the acetabulum during hip adduction is the angle of subluxation. This angle is the angle at which the femoral head becomes unstable because of the axial compressive force direction and luxates. The angle of subluxation depends on the functional slope of the DAR.

Bardens Palpation

Bardens recognized laxity in the hip joints of 8-week-old puppies and discovered that those puppies were dysplastic as adults. Later, Brown studied the laxity of hips in rottweiler puppies by the Bardens method and confirmed that laxity and hip dysplasia were associated. Recently, laxity testing has been addressed by radiography and statistical analysis and has been shown to be present in hip dysplasia.

Bardens Palpation

The anesthetized 6- to 8-week-old puppy is placed in right lateral recumbency for testing of the left (up) hip (Figure 60-54). The operator's right hand is the measuring hand and the left hand is the testing hand. The thumb of the operator's right hand is placed on the left lateral prominence of the patient's tuber ischiadi-cum. The middle finger of the operator's right hand is placed on the left wing of the ilium. The index finger of the operator's left hand is placed on the left greater trochanter. The patient's left femur is grasped just below the greater trochanter by the left hand of the operator. A medial to lateral force is exerted on the proximal femur by the left hand that translates the greater trochanter laterally. This translation is recorded and measured.

For testing of the right hip, the operator's left hand is the measuring hand and the right hand is the testing hand. The experienced operator can distinguish among four groups of lateral hip translation: 1 to 2 mm; 3 to 4 mm; 5 to 6 mm; and greater than 6 mm:

Normal hip: 1 to 2 mm
Borderline hip: 3 to 4 mm
Dysplastic hip: 5 to 6 mm
Severely dysplastic hip: more than 6 mm

Although the Bardens palpation has never been well accepted as a definitive index of hip dysplasia, it is useful as a general indicator of hip dysplasia. The Bardens palpation has four main objectives. First, the method requires a skilled operator who can detect and measure the lateral laxity accurately. This makes the test difficult to generalize to all veterinarians. Second, the patient must be between 6 and 8 weeks of age to achieve uniformity in the population and the dysplastic process. Third, the scientific correlation of confirmation between the Bardens palpation and degree of hip dysplasia in the mature patient has not been clearly established. Fourth, hip laxity is not hip dysplasia but rather one measurable aspect of hip dysplasia and is dependent on joint capsule stretching. As we develop better means of measuring the lateral translation with accuracy and repeatability, this test may become the basis for future decisions about hip dysplasia.

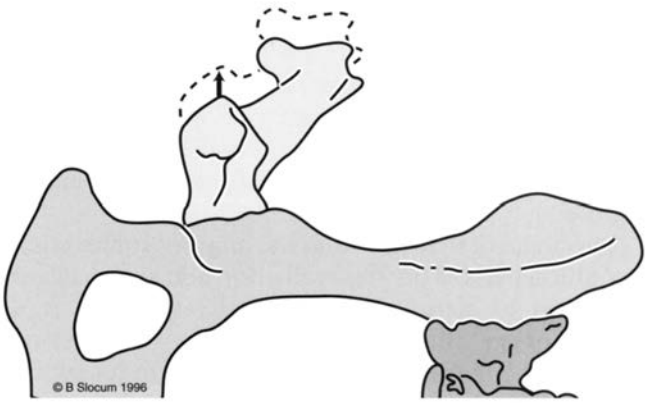


Figure 60-54. Bardens palpation of the left hip (up) requires the patient to be in right lateral recumbency. The left proximal trochanter is translated laterally *(dotted femur)* by a medial-to-lateral force on the proximal femur with the left hand. The right hand calibrates the amount of translation *(arrow)*.

Axial Compression Test of the Hip

The axial compression test is an intraoperative test for hip stability. Hip stability is achieved when the reduced hip remains in the acetabulum on axial compression of the femur in the sagittal plane.

Testing Procedure

To test the left hip, the patient is placed in right lateral recumbency. The examiner's right hand is placed on the dorsal rump of the patient. The left hand gently grasps the stifle and applies axial compression of the femur in the sagittal plane to the reduced hip (Figure 60-55).

If a "shift" of the femoral head is palpated as the hip luxates from the acetabulum, then the axial compression test is positive and the hip is unstable. If no "shift" of the femoral head is palpated, then the axial compression test is negative and the hip is stable. When the test is applied to the right hip, the operator's right hand is on the patient's stifle, and the left hand is on the rump.

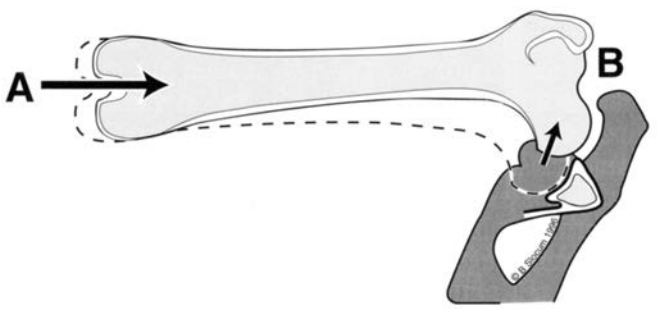


Figure 60-55. The axial compression test *(A)* is positive and the hip is unstable if a dorsolateral translation of the femoral head *(small arrow)* is detected by a lateral movement of the greater trochanter *(B)*. The test is negative, and the hip is stable, if no translation is noted.

The palpated "shift" is luxation of the femoral head. Luxation of the femoral head from the acetabulum can only occur if the slope of the DAR is too great to contain the head, if acetabular filling is present, or if the femoral head has a redundant ligament. No "shift" means that the DAR is able to contain the femoral head. Surgically, it means the axial rotation of the acetabular segment by pelvic osteotomy is sufficient. A hip joint is either stable or unstable to axial compression in the sagittal plane. If a hip is stable in the sagittal plane, additional rotation of the acetabular segment by pelvic osteotomy will only limit abduction of the hip and cause hip degeneration.

Suggested Readings

Bardens JW. Palpation for the detection of joint laxity. In: Proceedings of the Canine Hip Dysplasia Symposium and Workshop. St. Louis: Orthopedic Foundation for Animals, 1972:105-109.

Bardens JW, Hardwick H. New observations in the diagnosis and cause of hip dysplasia. Vet Med Small Anim Clin 1968:63:238.

Belkoff SM, Padgett G, Soutas-Little RW. Development of a device to measure canine coxofemoral joint laxity. VCOT 1989;1:31-36.

Slocum B, AVORE. Pelvic osteotomy: the results of 285 pelvic osteotomies (abstract). Vet Surg 1986; 15:134.

Slocum B, Devine T. Pelvic osteotomy in the dog as treatment for hip dysplasia. Semin Vet Med Surg 1987;2:107.

Slocum B, Devine T. Femoral neck lengthening for hip dysplasia in the dog. Vet Surg 1989; 18:81.

Slocum B, Devine T. Pelvic osteotomy. In: Whittock W, ed. Canine orthopedics. 2nd ed. Philadelphia: Lea & Febiger, 1990:471.

Slocum B, Devine T. Pelvic osteotomy for axial rotation of the acetabular segment. Vet Clin North Am 1992,22:645.

Slocum B, Slocum TD. Slope of the dorsal acetabular rim for hip evaluation in the dog. In: 17th annual conference of the Veterinary Orthopedic Society. Jackson Hole, WY: Veterinary Orthopedic Society, 1990:12.

Smith G, Biery D, Gregor T. New concepts of coxofemoral joint stability and the development of a clinical stress-radiographic method for quantitiating hip joint laxity in the dog. J Am Vet Med Assoc 1990;196:59-70.

Wright PJ, Masson TA. The usefulness of palpation of joint laxity in puppies as a predictor of hip dysplasia in a guide dog breeding programme. J Small Anim Pract 1977; 18:513.

Radiographic Characteristics of Hip Dysplasia

Theresa Devine Slocum and Barclay Slocum

Evaluation of the canine hip for hip dysplasia involves gathering information on the history and attitude of the dog from the owner, performing a series of hip function assessment tests on the awake and anesthetized dog, and obtaining a three-dimensional view of the hip joint by radiographs. Examination of the dog for hip dysplasia is an important service to predict the physical ability of the young dog (6 months of age and older) to meet the owners' expectations for function and to provide the appropriate treatment for a dysplas-tic dog. Although hip dysplasia is defined by many authors as a congenital, bilateral, degenerative joint disease, or as hip laxity, limitations of these definitions are recognized clinically as we expand our knowledge of the disease and separate acetabular hip dysplasia from femoral hip dysplasia. The most important aspect of any definition is to acknowledge that hip dysplasia is a dynamic process, and any view of the disease is a window at one point in its progression.

Most cases of dysplasia involve acetabular hip dysplasia, which is characterized by excessive slope of the dorsal rim of the acetabulum, and its secondary osteo-arthritic changes. Because the major forces of the hip run parallel to the long axis of the femur, the contact between the femoral head and the acetabulum should be perpendicular to the axial femoral forces for a stable hip joint. In the young puppy, the femoral head presses into the pliable acetabulum to form a deep socket. After 4 months, the formation of the acetabulum is becoming complete. If the acetabulum is shallow because of insufficient magnitude or direction of forces pushing the femoral head into the developing acetabulum, the joint capsule becomes stretched or, worse, the cartilaginous labrum becomes fractured. With insufficient dorsal support to the femoral head, muscular forces must be relied on to stabilize the joint by forcing the head into the acetabulum. As the muscles become fatigued, the joint capsule becomes stretched, and the dorsal rim becomes damaged. The femoral head resides in an incongruent subluxated position. As the restraints to subluxation, the joint capsule and teres ligament, stretch and tear, the vicious cycle of osteoarthritis becomes evident. When the hip cannot be maintained in the acetabulum, yet is within the joint capsule, the hip is considered luxated. When the acetabulum fills with osteophytes and the femoral head cannot be congruent with the acetabulum, the hip has irreducible luxating hip dysplasia. A dislocated hip occurs when the hip is outside the traumatically torn joint capsule. As the stages of acetabular dysplasia progress, the treatment and prognosis for the hip must also match the degenerative process. Physical and radiographic information must be combined to provide the best evaluation of the canine hip.

The hip is a three degree of freedom joint, which means that it allows rotation about three orthogonal axes but no translation along those axes. Normal movements are flexion-extension, internal rotation-external rotation, and adduction-abduction. The dog is examined at a walk, trot, and run. Leg alignment, stride length, and movement in the sagittal plane are all noted. With the dog standing, the hip is slowly flexed and extended. A thickened and inflamed joint capsule causes the patient discomfort, and extension is resisted. Similarly, dysplastic patients usually refuse to stand erect with the hip in an extended position. The leg is abducted and externally rotated. Any apprehension indicates irritation to the inflamed tissue between the femoral neck and the dorsal rim of the acetabulum. Inability to abduct the leg indicates a contracted pectineus muscle. With the patient under anesthesia, the hip is palpated to reveal the viability of the cartilage of the femoral head and the acetabulum. With the dog in dorsal recumbency, the angle of reduction (the angle from vertical when reduction occurs during abduction) is measured; this angle is an indicator of joint capsule laxity. The greater the angle of reduction, the greater is the stretching or tearing from the dorsal acetabular rim (DAR) that has occurred to the joint capsule. The angle of subluxation (the angle from vertical when the luxation occurs during adduction) is measured. This angle increases proportionally to the damage to the dorsal rim of the

acetabulum and acetabular filling. The trochanteric compression test reveals the preferred position of the femoral head with respect to the acetabulum; normally, it is within the acetabulum. A normal dog shows no apprehension or pain during the physical examination and enjoys the attention. Under anesthesia, a dog with normal hips demonstrates no angle of reduction or subluxation and has a negative trochanteric compression test.

Clinically, our radiographic examination uses six radiographic views: ventrodorsal, lateral, DAR, frog, compressed ventrodorsal, and distracted ventrodorsal views. The ventrodorsal, lateral, and DAR views are orthogonal and therefore give a "three-dimensional" study of the hip (Figure 60-56A and B). Because positioning is essential in evaluating these radiographs, the dog is anesthetized for this portion of the examination. In the normal hip, the ventrodorsal view shows the femoral head to be deeply seated under the acetabulum with at least 50% coverage by the dorsal rim. Congruence exists between the subchondral bone of femoral head and the cranial acetabulum. Any torsion of the femur or anteversion of the femoral head is readily recognized with this view. The ventrodorsal view is useful for determining pelvic torsion, which often mimics unilateral hip dysplasia and is usually associated with a transitional vertebra. In the sublux-ated hip, the femoral head is partially covered by the dorsal rim of the acetabulum. One sees incomplete congruence of the joint and cupping of the acetabulum. In the luxated hip, the femoral head resides outside the acetabulum, and there is no congruence of the hip joint. As the disease process worsens, one can see a thickening of the neck of the femur and, occasionally, dorsal acetabular osteophytes forming.

The frog view is useful to determine acetabular filling with osteophytes (Figure 60-57). The examiner must not lever the femoral head out of the acetabulum by abduction beyond 45°. The normal hip joint rests easily in the socket, whereas in the dysplastic hip, the femoral head is unable to seat fully in the acetabulum. This is indicative of filling of the acetabulum with osteophytes or a redundant teres ligament. As the dysplastic process progresses, the frog view demonstrates this condition.

The lateral radiograph of the pelvis and lower lumbar spine is useful for differentiating hip dysplasia from spondylitic bridging at L7-S1, which is often associated with the painful cauda equina syndrome. A normal hip shows congruence and concentricity of the femoral head within the acetabulum. In the dysplastic hip, the concentricity of the femoral head becomes less visible, and rather than a "white-black-white" description of normal congruence, a "white-gray-gray" description is common. Dorsal acetabular osteophytes are often seen as a white line over the femoral head.

Perhaps the most informative radiographic view is the DAR view. The dog is placed in a sternal recumbency with the hind legs pulled cranially to rest along the side of the thorax. A circumferential belt holds the stifles against the torso. Four-inch elevation of the hocks provides hamstring tension that causes enough rotation on most dogs to allow the x-ray beam to pass through the longitudinal axis of the pelvis. This view enables us to see the weightbearing portion of the acetabulum in cross section. In normal dogs, the DAR view shows the dorsal rim of the acetabulum to be sharply pointed. The femoral head is well seated and is covered by the acetabulum. When measured, the DAR angle is 7.5° or less, from a line perpendicular to the long axis of the pelvis. Normal hips have a combined left and right DAR measurement of 15° or less. Congruence of the hip joint is apparent with this view. A dog with normal hips continues to have a normal DAR angle throughout its lifetime.

As the hip is damaged by dysplasia, sclerosis of the rim can be seen on the DAR radiograph. The shape of the rim progresses from slightly rounded to blunted and broken off. Concurrently, the slope of the rim becomes increased. The dorsal acetabular osteophytes, so difficult to visualize on the ventrodorsal radiograph, are obvious with the DAR view. The femoral head moves dorsally and laterally, and filling of the acetabulum occurs. As the process of dysplasia progresses, the osteoarthritic changes can be seen clearly with this view. Lack of congruity and loss of cartilage are easily noted. When measured on the DAR view, dogs with hip dysplasia have a combined DAR slope of 20° or more. The slope continues to increase as the dysplastic changes occur.

The importance of the DAR view is that it corresponds to hip palpation under anesthesia and provides the information necessary to determine the treatment of choice for the individual dog. As stress is placed on the DAR with the early stages of dysplasia, the rim shows slight rounding. On palpation, the hip makes a smooth transition from the subluxated position into the acetabulum, indicating integrity of articular cartilage of the head and acetabulum and minimal stretching of the joint capsule. As frequent intermittent subluxation occurs, palpation reveals smooth cartilage and a stretched joint capsule, noted by a "clunk" as the hip moves from subluxation to reduction. The acutely luxating femoral head causes a bevel to the rim, characteristic of a torn joint capsule and a worn labrum. With palpation, this correlates to a fine granular crepitus of articular cartilage fibrillation and abrupt dorsal translation of the femoral head. In chronic conditions, no distinct transition between reduction and subluxation is palpated because of acetabular filling and capsular fibrosis. The DAR radiograph measurement provides the amount of pelvic rotation for a triple pelvic osteotomy in patients that still have cartilage on the femoral head. This measurement is the amount of rotation necessary for support of the femoral head by the acetabulum. If the DAR measurement shows a 20° slope, then a 20° Canine Pelvic Osteotomy Plate (Slocum Enterprises, Eugene, OR) is necessary for corrective surgery. Postsurgically, a tomogram of the DAR allows visualization of the amount of rotation performed with pelvic osteotomy. Overrotation can be prevented as a result of this radiographic technique.

Femoral dysplasia on physical examination has the same characteristics as acetabular dysplasia; however, it is most easily differentiated radiographically, and with palpation under anesthesia. The ventrodorsal radiograph shows a shortened femoral neck and a lack of coverage and congruity in the hip joint. In the early stages of femoral dysplasia, the hip may have an angle of reduction of less than 10° and an angle of subluxation of less than 0° on palpation. The lateral radiograph shows femoral head anteversion. The DAR view may appear normal if

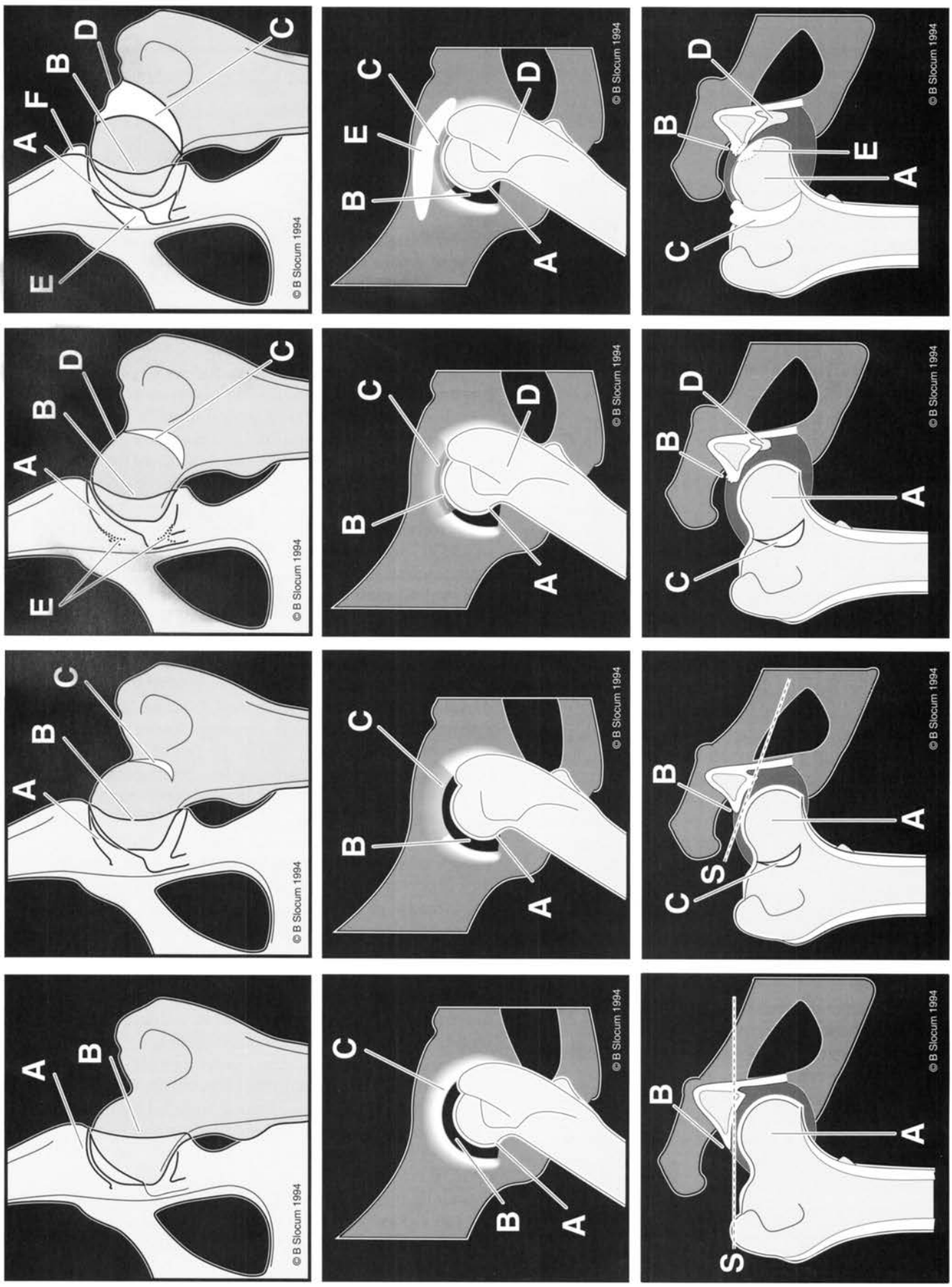


Figure 60-56A. Three-dimensional ventrodorsal, lateral, and dorsal acetabular rim radiographic matrix illustrating the normal hip, subluxating hip dysplasia, reducible luxating hip dysplasia, and irreducible hip dysplasia.

Normal Hip	Subluxating Hip Dysplasia	Reducible Luxating Hip Dysplasia	Irreducible Luxating Hip Dysplasia
A. Congruity between subchondral bone of cranial acetabulum and head	A. Congruity variable with capsule stretching and lateral distraction	A. Hip consistently incongruent	A. Permanent incongruity
B. DAR almost linear	B. DAR cupping (curvature due to repeated subluxation)	B. DAR cupping loses crisp margin	B. DAR deformed and indistinct
	C. Small osteophyte at the margin of the caudal articular surface	C. Osteophyte at the margin of the caudal articular surface	C. Osteophytes at margins of all articular surfaces
		D. Neck thickened by osteophyte production	D. Neck and head deformed by osteophyte production
		E. Acetabular filling prevents deep seating of femoral head	E. Acetabular filling prevents reduction of femoral head
			F. Acetabular osteophyte indicative of severe DJD
Normal Hip	**Subluxating Hip Dysplasia**	**Reducible Luxating Hip Dysplasia**	**Irreducible Luxating Hip Dysplasia**
A. White subchondral bone	A. White subchondral bone	A. White subchondral bone	A. White subchondral bone
B. Black articular cartilage	B. Black articular cartilage	B. Gray articular cartilage dorsally	B. Acetabular filling prevents reduction of femoral head
C. White subchondral bone	C. Gray subchondral bone	C. Gray subchondral bone	C. Gray subchondral bone
		D. Femur may translate dorsally	D. Femur may translate dorsally
			E. Acetabular osteophyte indicative of severe DJD
Normal Hip	**Subluxating Hip Dysplasia**	**Reducible Luxating Hip Dysplasia**	**Irreducible Luxating Hip Dysplasia**
A. Center of femoral head lies medial to the lateral margin of the DAR	A. Center of the femoral head is at the lateral margin of the DAR	A. Center of femoral head is lateral to the margin of the DAR	A. Center of femoral head lateral to DAR
B. DAR is pointed	B. DAR is rounded	B. Osteophytes or beveling evident	B. Well-developed osteophytes dorsally within a deformed DAR
C. Slope of the DAR is less than 7.5°	C. A fine osteophyte at the margin of the caudal articular surface	C. Mature osteophyte at the margin of the caudal articular surface	C. Femoral neck osteophytes deformed neck
	D. Slope of DAR is greater than 7.5°	D. Small acetabular osteophyte developing	D. Acetabular filling prevents reduction of femoral head
			E. Loss of articular cartilage seen by narrowing of joint space

Figure 60-56B. Three-dimensional radiographic matrix findings for normal hip, subluxating hip dysplasia, reducible luxating hip dysplasia, and irreducible hip dysplasia.

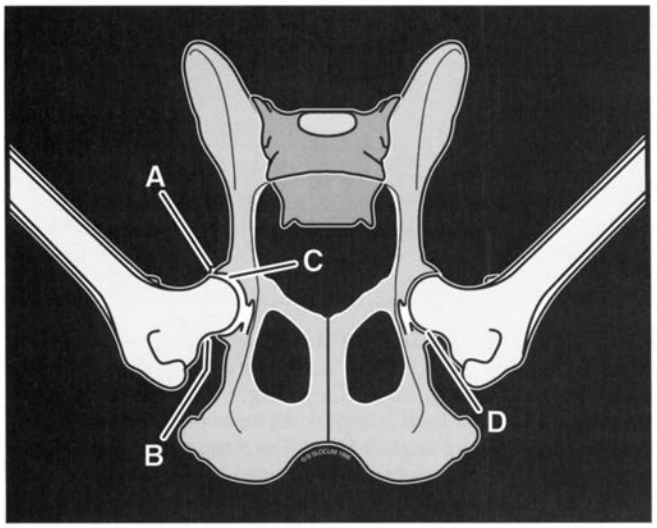


Figure 60-57. A frog view is taken with the hips in 45° of abduction. The normal hip has a narrow cartilage line *(D)* and no osteophytes, whereas the dysplastic hip may have a dorsal acetabular osteophyte *(A)*, a femoral neck osteophyte *(B)*, and a wide cartilage space *(C)*, indicating acetabular filling by osteophytes or redundant ligamentum teres.

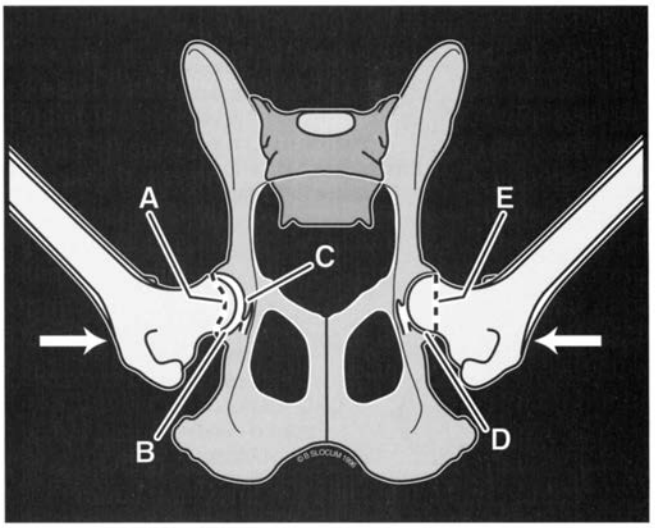


Figure 60-58. A compression view is a ventrodorsal view with the hips in 0° of abduction, no flexion, and a medial force on both greater trochanters *(white arrows)*. The normal hip has a narrow cartilage line *(D)*, no osteophytes, and a linear dorsal acetabular rim *(E)* viewed through the femoral head, whereas the dysplastic hip may have a cupped dorsal acetabular rim *(A)*, a wide cartilage space *(B)*, which indicates acetabular filling by osteophytes or redundant ligamentum teres, and ventral acetabular filling osteophytes *(C)*.

damage to the rim has not yet occurred. As the hip degenerates because of lack of support from the acetabulum, the dorsal rim becomes blunted. As a result, we then observe radiographically the same characteristics as acetabular dysplasia. Correct diagnosis of early femoral dysplasia is critical to the success of surgical treatment. If medially directed muscle force is insufficient to hold the hip in the acetabulum, an excessive amount of pelvic rotation will correct the situation but will lead to femoral neck impingement and reduced abduction. Femoral neck lengthening is the surgical treatment of choice. As the disease process continues, both femoral neck lengthening and pelvic osteotomy are necessary to obtain return of normal function. When both operations are necessary, a much lower rotation of the pelvis is adequate for correct coverage of the femoral head with acetabular stability.

Radiographic views taken using compression (Figure 60-58) and distraction (Figure 60-59) provide information on hip laxity. Bardens[1] first proposed a wedge technique to demonstrate radiographic joint laxity in the early 1960s, along with palpation. Radiographic techniques were further defined by Belkoff and associates in 1989[2], using a distraction device. Although this device allows passive laxity to be seen radiographi-cally, this has been used by Stoll[3] as a measure of the amount of femoral neck lengthening necessary when the dorsal acetabular slope has been reduced to 0°. Because passive capsular laxity is present in both dysplastic and nondysplastic hips, it should be considered a secondary indicator of hip dysplasia (Figures 60-60 and 60-61). The distraction displacement index is an indicator of passive joint laxity. Smith and colleagues[4] determined that a distraction index of 0.30 is the dividing line between normal hips and hips predisposed to hip dysplasia. Some dysplastic hips, however, have a distraction index less than 0.30, and some hips with a distraction index greater than 0.30 fail to show other dysplastic characteristics. The compression displacement index is an indicator of acetabular filling. In the clinical situation, laxity

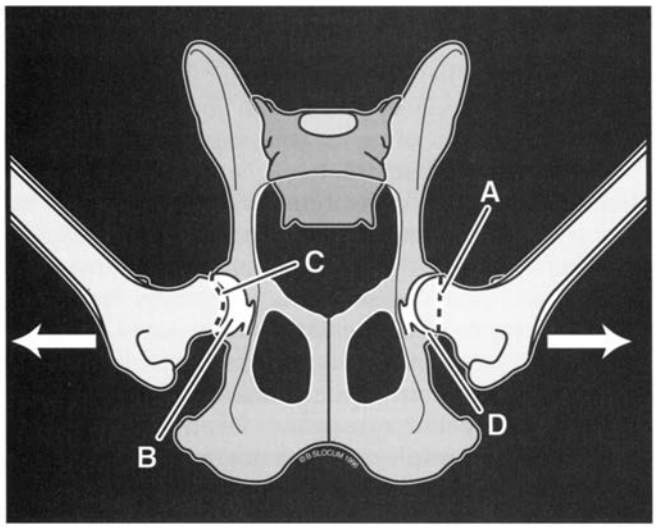


Figure 60-59. A distraction view is a ventrodorsal view with the hips in 0° of abduction, no flexion, and a lateral force on both proximal femurs *(white arrows)*. The normal hip has a narrow cartilage line *(D)*, no osteophytes, and linear dorsal a acetabular rim *(A)* viewed through the femoral head, whereas the abnormal hip may have a cupped dorsal acetabular rim *(C)* and a wide cartilage space *(B)*, which indicates a stretched joint capsule but not necessarily hip dysplasia.

of the joint capsule is palpated and measured as the angle of reduction. The angle of subluxation is a measure of the functional slope of the dorsal acetabulum because it is the result of interaction between the acetabulum and the femoral head.

In summary, correct evaluation of the hip joint is essential to understand the progression of hip dysplasia and to recognize the choice points of intervention. Physical and radiographic examination of dogs 6 months of age and older can provide accurate

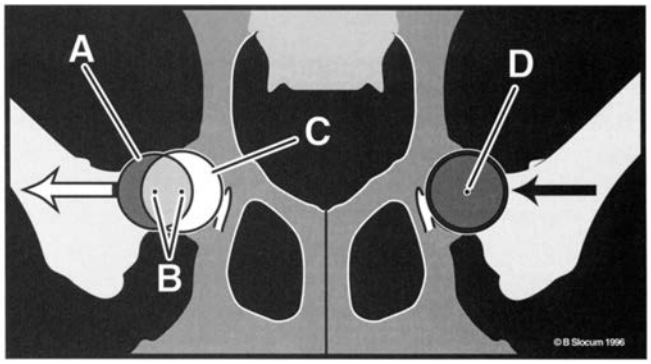


Figure 60-60. Lateral distraction of the femur *(white arrow)* causes lateral translation of the femoral head. The circle that overlies the acetabular subchondral bone *(C)* is larger than the circle that overlies the femoral head subchondral bone *(A)*. The centers of the two circles *(B)* are displaced by *d*. The distraction displacement index is equal to the displacement divided by the radius of *A, r: (DDI = d ÷ r)*. Medial compression of the greater trochanter *(black arrow)* causes the circles overlying the acetabular and femoral head subchondral bone of the hip to be concentric and the centers superimposed *(D)*, indicating that this hip is not abnormal. The compression displacement index is equal to the displacement *(d)* divided by the radius of *A, r. (CDI = d ÷ r)*. In the normal hip, *d* = 0; therefore, *CDI* = *d* ÷ *r* = 0.

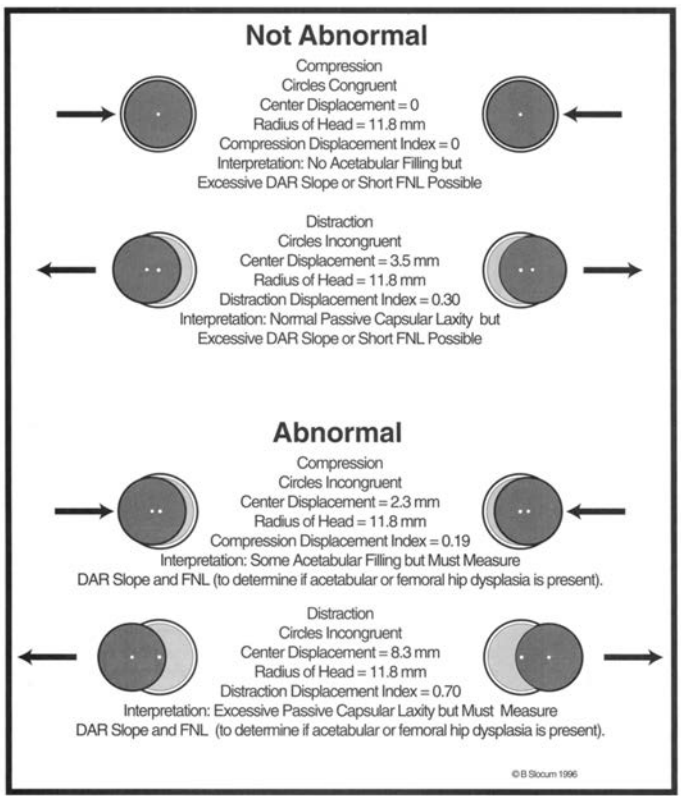


Figure 60-61. Schematic illustration of interpretation of the compression and distraction radiography. *DAR,* dorsal acetabular rim; *FNL,* femoral neck lengthening.

assessment of the hips. The patient can be treated appropriately to provide for the enjoyment and functioning of the dog for the rest of its lifetime.

References

1. Bardens J. Joint laxity as hip dysplasia. In: Canine Hip Dysplasia Symposium. St. Louis: , 1972:71.

2. Belkoff SM, Padgett G, Soutas-Little RW. Development of a device to measure canine coxofemoral joint laxity. Vet Compar Orthop Traumatol 1989;1:31-36.

3. Stoll S. Femoral neck lengthening using distraction measurements. In: American College of Veterinary Surgeons Surgical Forum.: American College of Veterinary Surgeons, 1996.

4. Smith G, Biery D, Gregor T. New concepts of coxofemoral joint stability and the development of a clinical stress-radiographic method for quantitating hip joint laxity in the dog. J Am Vet Med Assoc 1990,196:59-70.

Suggested Readings

Corley EA. Hip dysplasia: a report from the Orthopedic Foundation for Animals. Semin Vet Med Surg 1987;2:141.

Henry J, Park R. Wedge technique for demonstration of coxofemoral joint laxity in the canine. In: Canine Hip Dysplasia Symposium. St. Louis: Arthur Freeman, 1972:117.

Laming F. Canine hip dysplasia and other orthopedic problems. Loveland, CO: Alpine Publications, 1981.

Morgan JP, Stephens M. Radiographic diagnosis and control of canine hip dysplasia. Davis, CA: Venture Press, 1985.

Pappas AM. Congenital hip dysplasia. In: Tronzo R, ed. Surgery of the hip joint. Philadelphia: Lea & Febiger, 1973.

Rendano V, Ryan G. Canine hip dysplasia evaluation: a positioning and labeling guide for radiographs to be submitted to the Orthopedic Foundation for Animals. Vet Radiol 1985:26:170.

Rettenmaier J, Constantinescu G. Canine hip dysplasia. Compend Contin Educ Pract Vet 1991;13:643.

Riser WH. The dog as model for the study of hip dysplasia. Vet Pathol 1975:12:229.

Riser WH, Shirer JF. Hip dysplasia: coxofemoral abnormalities in neonatal German shepherd dogs. J Small Anim Pract 1966:7:7.

Riser WH, Rhodes WH, Newton CD. Hip dysplasia. In: Newton CD, Nunamaker DM, eds. Textbook of small animal orthopedics. Philadelphia: JB Lippincott, 1985.

Sage FP. Campbell's operative orthopedics 4th ed. St. Louis: CV Mosby, 1963:1708-1709.

Slocum B, AVORE. Pelvic osteotomy: the results of 285 pelvic osteotomies (abstract). Vet Surg 1986,15:134.

Slocum B, Devine TM. Dorsal acetabular rim radiographic view for evaluation of the canine hip. J Am Anim Hosp Assoc 1990:26:289-296.

Slocum B, Devine T. Pelvic osteotomy in the dog as treatment for hip dysplasia. Semin Vet Med Surg 1987:2:107.

Slocum B, Devine T. Femoral neck lengthening for hip dysplasia in the dog. Vet Surg 1989; 18:81.

Slocum B, Devine T. Pelvic osteotomy. In: Whittick W, ed. Canine orthopedics. 2nd ed. Philadelphia: Lea & Febiger, 1990:471.

Slocum B, Slocum TD. Slope of the dorsal acetabular rim for hip evaluation in the dog. In: 17th annual conference of the Veterinary Orthopedic Society. Salt Lake City, UT: Veterinary Orthopedic Society, 1990:12.

Slocum B, Slocum TD. Examination of the canine hip. Canine Pract 1991;15:5-10.

Slocum B, Slocum TD. Pelvic osteotomy for axial rotation of the acetabular segment in dogs with hip dysplasia. Vet Clin North Am Small Anim Pract 1992;22:645-682.

Snavely JG. The genetic aspects of hip dysplasia in dogs. J Am Vet Med Assoc 1959;135:201.

Wallace L. Canine hip dysplasia: past and present. Semin Vet Med Surg 1987;2:92.

Definitions of Hip Terms

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Acetabular Hip Dysplasia
Acetabular hip dysplasia is the malorientation of the acetabulum in the presence of normal depth. A slope of the dorsal acetabular rim (DAR) greater than 10.0° is considered to be acetabular hip dysplasia. The slope is usually reported as the sum of both the right and left DAR slopes, so a combined slope greater than 20.0° would be dysplastic. (A combined slope of 15.0 to 20.0° is suspect, whereas a combined slope of 15.0° or less is considered normal.) The minimum depth of the normal hip is 50% coverage of the femoral head by the DAR under ideal circumstances.

Angle of Reduction
The angle of reduction is the angle between the sagittal plane and the longitudinal axis of the femur when a "clunk" or shift is palpated as the femoral head enters the acetabulum during abduction of the hip in the anesthetized patient.

Angle of Subluxation
The angle between the sagittal plane and the longitudinal axis of the femur when a "clunk" or shift is palpated as the femoral head leaves the acetabulum during adduction of the hip in the anesthetized patient.

Barden Palpation
Barden palpation is a test for lateral translation of the hip. The lateral translation is a sign of joint capsule stretching: 1 to 2 mm is normal; 3 to 4 mm is suspicious; 4 mm or more is considered dysplastic.

Barlow Sign
The Barlow sign is the "clunk" or shift palpated as the femoral head leaves the acetabulum during adduction of the hip.

Coxarthrosis
Coxarthrosis is a general term for hip degeneration from nondysplastic sources that include, but are not limited to, rapid growth syndrome, osteochondritis dissecans of the lateral femoral condyle and transitional vertebra at the seventh lumbar vertebra or first sacral vertebral segment, osteochondritis dissecans of the femoral head, neurologic or neuromuscular insufficiency, degenerative myelopathy, intervertebral disc disease, autoimmune arthritis of the hip, infection of the hip joint, and neoplasia of the hip. Secondary manifestations of coxarthrosis are joint capsule laxity, tearing of the joint capsule, increase of synovial fluid, acetabular osteophytes, femoral osteophytes, acetabular filling, destruction of the dorsal acetabular rim, teres ligament hypertrophy or degeneration, and articular cartilage fibrillation or eburnation.

Darthroplasty
A DARrthroplasty is a dorsal acetabular rim arthroplasty. The dorsal rim of the acetabulum is augmented by bone graft that supports the joint capsule in cases that have a luxated hip. In essence, a new acetabulum is created to support the luxated hip.

Dislocation
The femoral head is unsupported by and resting outside the torn joint capsule, the ligament of the femoral head is torn, and the femoral head is outside the acetabulum.

Distraction Index
The distraction index is a ratio of the linear distance between the center of the femoral head and the center of the acetabulum with the hip in distraction, to the radius of the femoral head. In most breeds, normal hips have a distraction index up to and including 0.30.

Dorsal Acetabular Rim (DAR)
The DAR rim is that portion of the lateral rim of the acetabulum of about 30° that is crossed by a line through the centers of motion of the hip and stifle in the normal standing patient as viewed in the sagittal plane (lateral radiograph). This portion of acetabular rim is subjected to trauma by the femoral head during the dysplastic process.

Femoral Anteversion
Femoral anteversion is the cranial position of the femoral head when compared with normal. The femoral neck often has a valgus conformation. However, the relationships of other components of the femur are normal. Femoral ante-version alone is considered one form of hip dysplasia. Femoral anteversion in the presence of osteochondritis dissecans (OCD) of the lateral femoral condyle is considered a growth disturbance secondary to the OCD.

Femoral Hip Dysplasia
Femoral hip dysplasia is malorientation of the femoral head with respect to the greater trochanter when the limb is in the sagittal plane.

Femoral Neck Length
Femoral neck length is the distance from the lateral aspect of the greater trochanter to the medial aspect of the femoral head. A short femoral neck is considered one form of hip dysplasia.

Femoral Torsion
Femoral torsion is malorientation of the proximal femur with respect to the distal femur. However, the relationships of the components of the ends of the femur are normal. Femoral torsion is considered one form of hip dysplasia.

Hip Dysplasia
Hip dysplasia is an inherited condition of the hip that leads to the degeneration of the joint. Several anatomic variations from normal provide the biomechanical prerequisites for predictable

and progressive degeneration of the hip. Acetabular hip dysplasia is caused by malorientation or shallowness of the acetabulum. Femoral hip dysplasia is caused by a short femoral neck, anteversion of the femoral neck, or femoral torsion. Secondary manifestations of hip dysplasia are joint capsule laxity, tearing of the joint capsule, increase of synovial fluid, acetabular osteophytes, femoral osteophytes, acetabular filling, destruction of the dorsal acetabular rim, teres ligament hypertrophy or degeneration, and articular cartilage fibrillation or eburnation. These secondary changes are not hip dysplasia, but rather result from hip disorders. Nondysplastic conditions can cause the same secondary manifestations as hip dysplasia.

Juvenile Hip Malformation
Juvenile hip malformation is the hip deformity in which an extraordinarily shallow acetabulum is elongated and fails to match the femoral head. The pathogenesis of this condition is thought to be of neuromuscular origin because these patients usually have poor muscular tone, muscular weakness, and an uncoordinated movement. The condition is usually seen in young German shepherd dogs. Because of the pathogenesis, one could term the problem "neuromuscular hip dysplasia" or developmental coxarthrosis of neuromuscular origin.

Luxation
The femoral head is supported by and resting in the intact joint capsule and is incongruent with and not supported directly by the acetabulum.

Normal Hip
A normal hip has no appreciable laxity of the hip joint capsule, with a distraction index less than or equal to 0.30, and no angle of reduction is palpated. The hip has normal acetabular orientation (combined dorsal acetabular rim slope of up to 15°), normal acetabular depth (at least 50%), normal sacral conformation, normal femoral neck length, normal white-black-white articular line on the lateral radiograph, and no palpable angle of subluxation. The determination of normal hips can be made at 6 months of age.

Ortolani Sign
The Ortolani sign is the "clunk" or shift palpated as the femoral head enters the acetabulum during abduction of the hip.

Pelvic Osteotomy
A pelvic osteotomy is a surgical procedure in which a triple osteotomy of the pelvis (pubis, ischium, and ilium) frees the acetabular segment for rotation about an axis parallel to a line tangent to the dorsal acetabular rim (DAR). The amount of axial rotation brings the slope of the DAR to 0°. Excessive rotation of the pelvic osteotomy causes interference between the DAR and the femoral neck. If the acetabulum is filled with osteophytes, then the articular cartilage of the femoral head will erode, and congruity of the femoral head and acetabulum is improbable.

Pelvic Torsion
Pelvic torsion is a spiral deformity of the entire pelvis around its median axis. It can be identified in the ventrodorsal, lateral, and dorsal acetabular rim radiographs. Pelvic torsion is associated with transitional vertebrae of the first sacral segment and is considered a secondary manifestation of the vertebral abnormality. One hip is usually considered normal, whereas the other is "dysplastic." Because the origin of the problem is the sacral deformity, one should term the problem "sacral hip dysplasia" or coxarthrosis of sacral origin.

Rapid Growth Syndrome
Rapid growth syndrome is laxity of the hip joint capsule in the presence of normal acetabular orientation (combined dorsal acetabular rim slope up to and including 15°), normal acetabular depth (at least 50%), normal sacral conformation, normal femoral neck length, normal white-black-white articular line on the lateral radiograph, and normal angle of subluxation (up to and including 0°). The distraction index is greater than normal (greater than 0.30), and the angle of reduction is present (none is normal). The pathogenesis of this condition is the maldirection of the axial femoral force during a rapid growth spurt at 4 to 6 months of age. This maldirection of the axial femoral force stretches the hip joint capsule, but it is otherwise harmless to the hip. Restricted nutrition reduces the excessively rapid rate of growth and should have a preventive influence on capsular laxity. If the patient applies excessive axial load to the hip in the luxated position, the joint capsule can tear, the dorsal acetabular rim (DAR) can fracture, or the DAR can deform over time. If caught at the joint capsule stretching stage, strict confinement and elimination of play for 4 to 6 weeks allow the stretched joint capsule to contract. Normal hips are obtained on OFA examination at 2 years of age. A femoral neck lengthening is curative if performed before increase of the DAR slope into the pathologic range. If the affected patient is allowed to damage the DAR, then traumatic coxarthrosis will result and secondary manifestations of trauma will later be misdiagnosed as hip dysplasia. Because the origin of the problem is the rapid growth of the distal femur (12 to 15 mm per week for 6 to 8 weeks), one should term the problem "rapid femoral growth hip dysplasia" or coxarthrosis of rapid growth of distal femur origin.

Slope of the Dorsal Acetabular Rim (DAR)
The slope of the DAR is defined as the angle formed by a line normal to the sagittal plane (horizontal line) and a line created by the intersection of the acetabular subchondral bone at the DAR, and a plane defined by the intersection of the horizontal line and line through the centers of motion of the hip and stifle in the normal standing patient as viewed in the sagittal plane. The slope of acetabular subchondral bone at the DAR is linear, based on a study of 25 normal pelves. Clinically, the slope of the DAR is the angle between the tangent to the reduced femoral head at its first point of contact with the acetabulum and the horizontal line as seen on the DAR radiographic view.

Subluxation
The femoral head is incongruent and supported directly by the acetabulum, and it is allowed some lateral translation, but it is prevented from dorsal translation by the intact joint capsule.

Total Hip Replacement
A total hip replacement is a salvage procedure in which the worn acetabulum is replaced by a high-molecular-weight polyethylene

acetabular cup, and the worn femoral head is replaced by a molybdenum-chromium-stainless steel alloy femoral prosthesis. The components are maintained in position by polymethylmethacrylate. The replaced components are devoid of nerve endings and therefore are pain free. This surgical procedure is best used when the femoral head rubs bone on bone with the acetabulum.

Treatment of Hip Dysplasia

Femoral Neck Lengthening

Barclay Slocum and Theresa Devine Slocum

In the biomechanical sense, the femoral neck length is defined as the distance between the lateral limit of the greater trochanter and the medial limit of the femoral head. Both the internal and external rotator muscles attach to the greater trochanter and exert equal moments about the femoral head. The moment is defined as force times distance. By lengthening the femoral neck, the moments become greater, yet internal and external moments are still equal. This creates a greater medially directed resultant force more capable of holding the hip in the acetabulum.

The primary indication for a femoral neck lengthening is a short femoral neck. Short femoral necks are common in some breeds such as the akita, chow, and Tibetan mastiff. These hips are frequently diagnosed as dysplastic (Figure 60-62). Short femoral necks can also occur secondary to trauma to the growing capital physis (Salter type IV), as well as secondary to the surgical manipulation and fixation of a fracture of the capital physis. In dogs less than 6 months of age, rigid internal fixation of a fractured capital physis is likely to result in degeneration of the hip from a shortened femoral neck. Similar patients have no arthritis if the femoral neck is lengthened. If a nondisplaced capital physeal fracture is left undiagnosed or unattended, the femoral neck often resorbs, and a short femoral neck results.

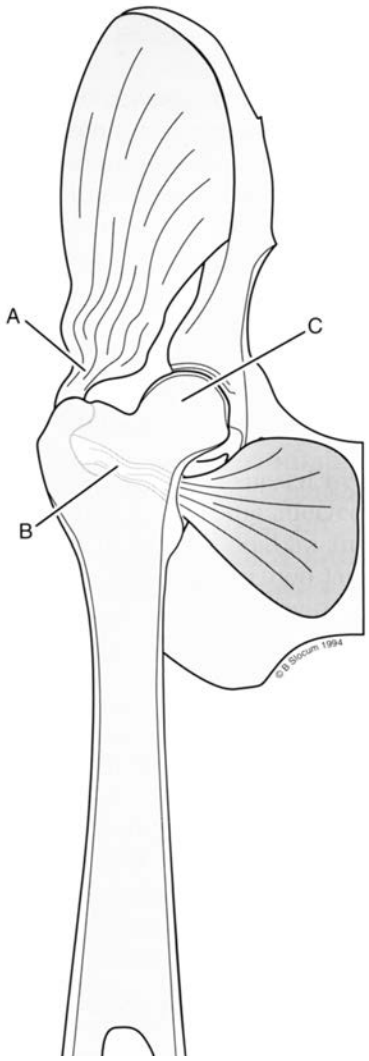


Figure 60-62. In the dysplastic hip, the internal hip rotator group *(A)*, external hip rotator group *(B)*, and joint capsule are lax when the femoral head *(C)* is reduced.

Surgical Technique

The lateral approach to the femur is used to gain access to the lateral, cranial, and medial aspects of the femur. The vastus lateralis is detached from its origin just distal to the greater trochanter and is elevated from the femur as far as the distal lateral circumflex femoral vessels. A small Hohmann retractor is placed beneath the deep gluteal muscle and over the web between the greater trochanter and the femoral head. Two Gelpi retractors are used to separate the biceps femoris and vastus lateralis muscles. External rotation of the hip exposes the proximal femur and the femoral diaphysis for osteotomy.

The greater trochanter is freed from the femoral head by an osteotomy cut in the sagittal plane for two-thirds the length of the femur (Figure 60-63). The cranial cortex of the femur is penetrated by an oscillating saw beginning just proximal to the distal lateral circumflex femoral vessels. The cranial cortical cut is carried prox-imally in the sagittal plane to the Hohmann retractor between the greater trochanter and the femoral head. The cranial cortex is used as a saw guide to direct the osteotomy of the caudal cortex. Because the osteotomy is medial to the external rotator muscle group, little danger exists of traumatizing the sciatic nerve, which lies lateral to these muscles. Considerable hemorrhage is sometimes encountered at the level of the nutrient foramen, but this soon stops with minimal blood loss. If the patient's profile indicates the potential for hemophilia, coagulation potential and von Willebrand factor should be tested before the operation.

Lateralization of the greater trochanter is accomplished by placing a 40-mm cortical screw in only the lateral cortex of the femur at the level of the third trochanter, perpendicular to the sagittal plane. With the limb held in the sagittal plane, the proximal femur is manually moved laterally (Bardens test). The laxity of the Bardens test is decreased by advancement of the screw through the lateral cortex, but not into the medial cortex. Interference of the cancellous surface of the medial segment separates the medial from the lateral cortex, which tightens the rotators as the femoral neck is lengthened. When laxity by Bardens palpation becomes zero, the advancement of the screw is sufficient.

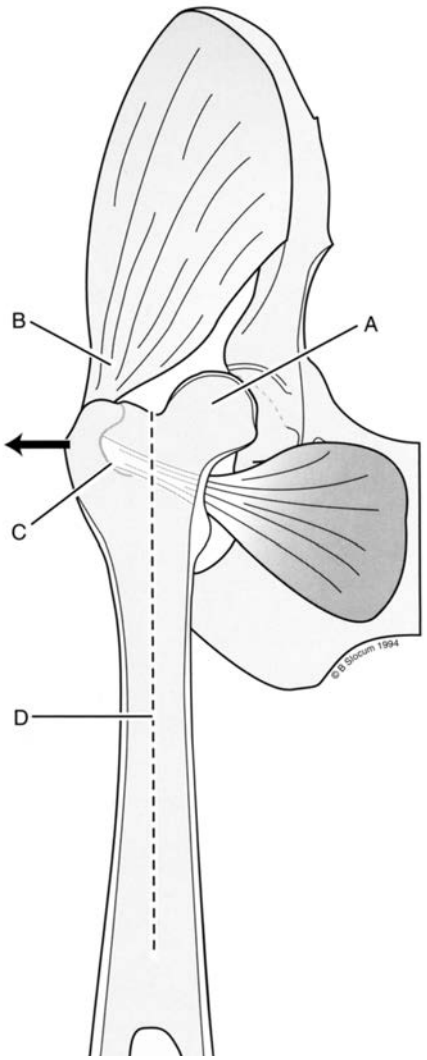


Figure 60-63. When the greater trochanter is moved laterally *(arrow)*, the femoral head *(A)* luxates. The internal *(B)* and external *(C)* hip rotators are no longer lax. A sagittal plane osteotomy *(D)* is made in the femur.

The appropriate Femoral Neck Lengthening Wedge (US Patent No. 4,759,351, Slocum Enterprises, Eugene, OR) is inserted just proximal to the screw to maintain the femoral neck length. A towel clamp or small fragment reduction forceps is used to grasp and manipulate the wedge. The wedge is held in place by predrilling a 2.7-mm (7/64-inch) hole through the lateral cortex, wedge, and medial cortex and then placing a 3.2-mm (1/8-inch) threaded pin into the hole such that the point completely penetrates the medial cortex. A wire passer is used to pass a heavy (1.25-mm or 18-gauge) wire around proximal femur. The wire should be proximal to the lesser trochanter. The point of the pin keeps it from migrating distally. After directly observing the sciatic nerve to ensure that it not entrapped, the wire is securely tightened. The screw is removed.

Another wedge is placed hallway down the osteotomy and is secured in a like manner. Care is taken to avoid driving the wedge distally because this splits the femur. The cerclage wire is proximal to the pin on the lateral cortex and is distal to the pin on the medial cortex, to prevent the pin from migrating. A third pin and cerclage wire are placed at the distal end of the osteotomy (Figure 60-64). No bone graft is necessary because healing takes approximately 5 weeks.

Closure is direct. The vastus lateralis can be reattached with horizontal mattress sutures. Holes can be-drilled in the greater trochanter if greater purchase is necessary. The vastus lateralis is usually attached to the tendon of the deep gluteal muscle cranially.

Procedure for Capital Physeal Fracture

Femoral neck lengthening is indicated for a capital physeal fracture when growth potential has been lost, when chronic capital physeal nonunion has occurred because of the trauma of delayed treatment, or when the young patient has only one opportunity for surgical correction permitted by the owner. In the last circumstance, failure of the capital physis to grow after smooth pin fixation leads to a short femoral neck and degeneration of the hip without opportunity to compensate for this lack of growth surgically. The femoral neck length deficiency may be

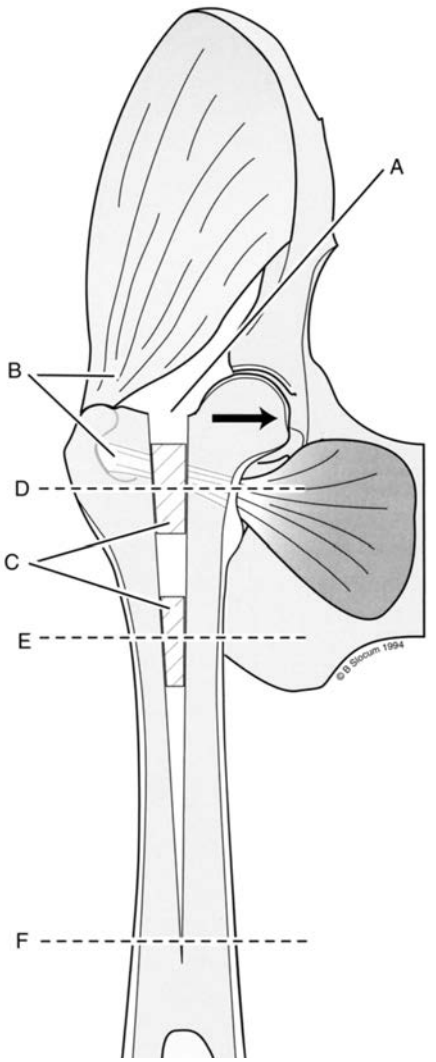


Figure 60-64. The proximal portion of the femoral osteotomy is spread apart *(A)*, which moves the femoral head into the reduced position *(arrow)*. This tightens the hip rotators *(B)*. Femoral Neck Lengthening Wedges are placed into the osteotomy *(C)* to maintain the femoral neck length. Internal fixation is first placed at the level of the third trochanter *(D)*, followed by additional fixation (*E* and *F*).

anticipated, and compensation by fusing the capital physis and adding the anticipated femoral neck deficit may be undertaken at the initial surgical procedure.

A lateral approach to the proximal half of the femur is achieved by unwrapping the origin of the vastus lateralis muscle from the femur as previously described, while leaving the femoral insertion of the deep gluteal intact. A 7.5-cm (3-inch) osteotomy of the greater trochanter in the craniocaudal direction from the web between the greater trochanter and the femoral head to the lateral cortex is made (Figure 60-65). The internal hip rotators (superficial, middle, and deep gluteal muscles) and the external hip rotators (gemelli, internal and external obturator, and quadratus femoris muscles) remain attached to the greater trochanter. The distal end of the trochanteric section is reflected dorsally to expose the hip joint capsule (Figure 60-66).

Subperiosteal elevation of the vastus lateralis from the cranial femoral neck to the joint capsule exposes the femoral side of the capital physis or the capital epiphysis if it is displaced cranially. The joint capsule is minimally opened cranially, to observe the articular surface of the femoral head. The capital epiphysis is anatomically reduced, if possible. If anatomic reduction is not possible because of trauma, then the capital epiphysis is positioned over the femoral neck to be functional for weight-bearing. A lag screw is placed up the femoral neck or remnant of the femoral neck from the surface of the osteotomy to secure the relationship between the head and the neck. The screw head is countersunk only enough to avoid protrusion into the osteotomy kerf; overtightening the screw causes the end of the screw to protrude from the surface of the femoral head (See Figure 60-66). The cranial joint capsule is closed by cranial capsulorrhaphy.

Femoral neck lengthening is performed to establish the adult femoral neck length (Figure 60-67). This length is determined by measuring the neck length in the parent of the same sex (if the patient resembles that parent) or by measuring neck length in another dog of the same breed and body type. A Femoral Neck Lengthening Wedge of the appropriate thickness is placed at the level of the third trochanter. A lag screw is placed in the distal end of the trochanteric segment. The glide hole should be large enough to accommodate lateralization of the greater

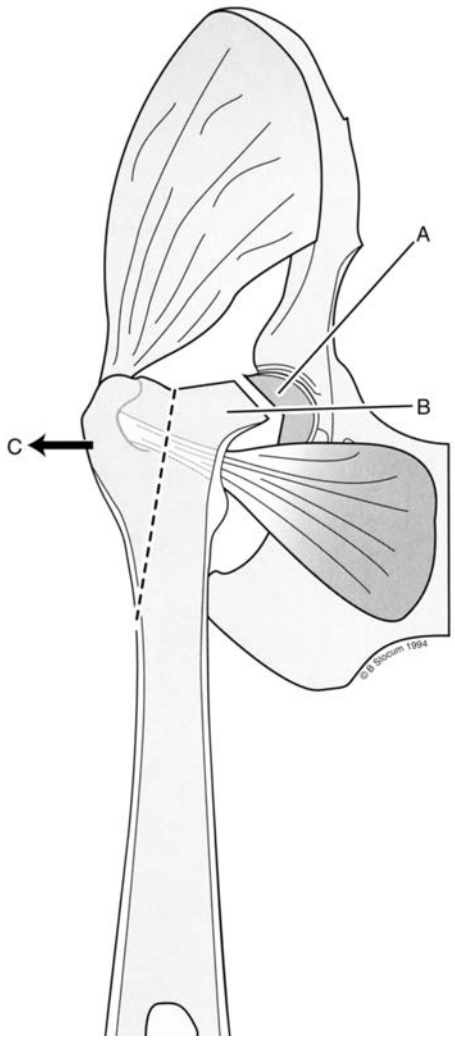


Figure 60-65. Fracture of the capital femoral physis and displacement of the epiphysis *(A)* and the femoral neck *(B)* are often accompanied by lateral movement of the proximal femur *(arrow)* and visual prominence of the greater trochanter *(C)*. A long trochanteric osteotomy *(dashed line)* provides good access for surgical repair.

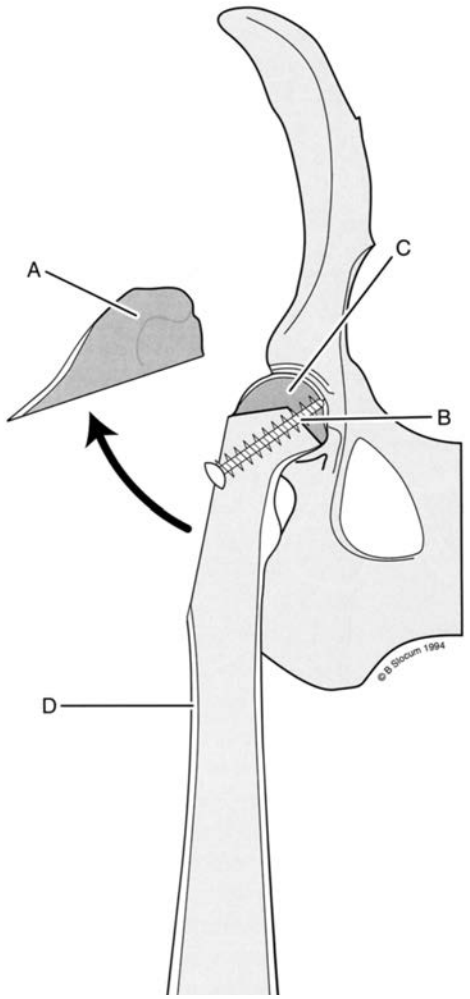


Figure 60-66. After osteotomy, the greater trochanter *(A)*, with the internal and external rotators attached, is retracted dorsally (arrow). A small opening in the cranial joint capsule gives access for assessment of the reduction and placement of the screw. Respecting the blood supply to the epiphysis, which enters dorsally, a lag screw *(B)* is used to fix the epiphysis *(C)* to the femur *(D)*.

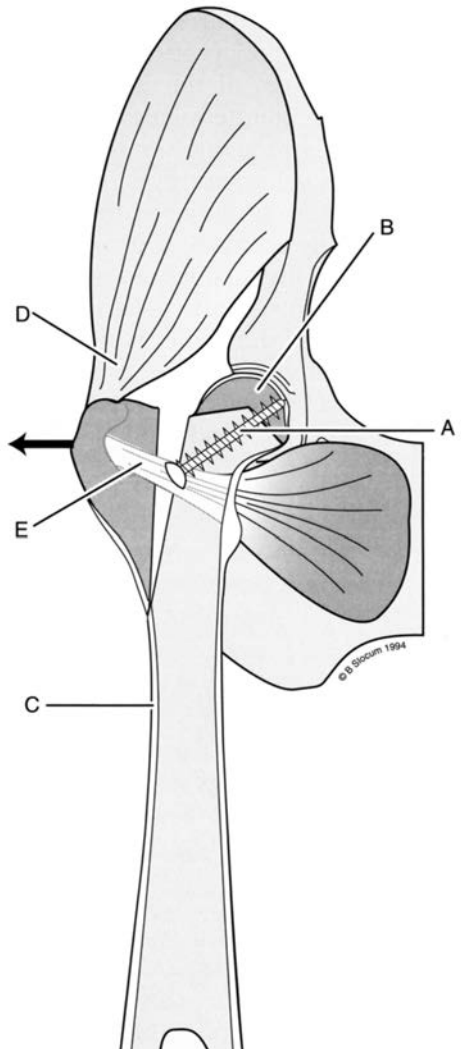


Figure 60-67. The screw *(A)* that holds the capital femoral epiphysis *(B)* to the femur *(C)* is hidden by the replacement of the greater trochanter. Femoral neck lengthening moves the trochanter laterally *(arrow)* to establish the adult femoral neck length in anticipation of the capital femoral physeal fusion because of the trauma and screw fixation. The internal *(D)* and external *(E)* rotators of the hip are placed under tension. Trochanteric fixation is not shown.

trochanter. The lag screw is tightened while taking care not to split the cortex of the trochanteric fragment. The Femoral Neck Lengthening Wedge can be fixed by a screw through the lateral cortex, wedge and medial cortex, but a pin and cerclage wire, as previously described, are more secure. Closure is similar to that described for classic femoral neck lengthening.

Modified Technique

A lateral approach to the proximal half of the femur is achieved by unwrapping the origin of the vastus lateralis muscle from the femur as previously described while leaving the femoral insertion of the deep gluteal intact. An osteotomy of the femur is made in the sagittal plane from the depression in the web between the greater trochanter and the femoral head to a point 6.5-cm (2.5-inch) distal. A small biradial or cylindric saw blade is used to complete the osteotomy between the kerf generated and the lateral cortex. The internal hip rotators (superficial, middle, and deep gluteal muscles) and the external hip rotators (gemelli, internal, and external obturator, and quadratus femoris muscles) remain attached to the greater trochanteric segment (Figure 60-68).

A 3.5-mm hole is drilled through the distal end of the trochanteric segment and also through the medial cortex. The depth of the hole is measured with a depth gauge, and a screw 2 to 4 mm longer is selected. The lateral cortex is overdrilled using a 4.5-mm drill bit and is countersunk. The medial cortex is tapped with a 3.5-mm tap. A 3.5-mm cortical lag screw is placed through the lateral cortex and loosely engaged in the medial cortex. A second hole is drilled through the lateral cortex at the level of the third trochanter, is countersunk, and is tapped. The depth of the hole is measured to the medial cortex. The screw selected is equal to the depth of the hole plus the displacement of the femoral head obtained by comparing the compression and distraction radiographic views. When the screw is placed in the second hole, the greater trochanter is lateralized the appropriate amount. Third and fourth screws are placed proximal and distal to the second

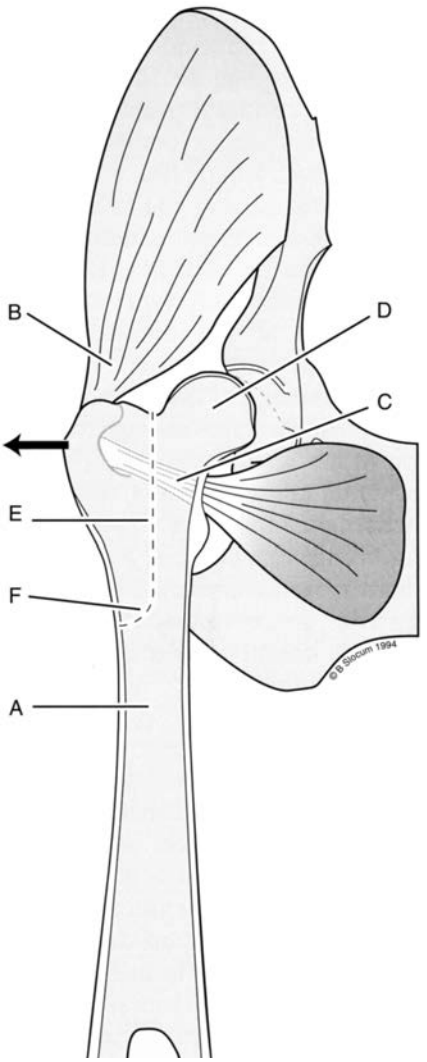


Figure 60-68. The femur *(A)* is moved laterally *(arrow)* to tension the internal hip rotator group *(B)* and external hip rotator group *(C)*. The femoral head *(D)* is in the luxated position. A linear portion *(E)* and a cylindric portion *(F)* of the modified femoral neck lengthening osteotomy are shown by the dashed line.

screw, engaging both the lateral and medial cortices (Figure 60-69). The first screw is then firmly tightened. Closure is routine.

A more stable configuration is the application of an appropriately sized wedge placed at the second screw hole. The wedge size is determined from the displacement of the femoral head obtained by comparing the compression and distraction radiographic views. This configuration prevents the femoral neck lengthening from relying on the threads of the screws alone.

Although the primary indication for femoral neck lengthening is hip dysplasia, this technique can also be used with a pelvic osteotomy in patients with an excessively stretched joint capsule. The excessive slope of the dorsal acetabular rim is corrected before the femoral neck lengthening. A dorsal acetabular rim slope greater than 7.5° is addressed by a pelvic osteotomy because that surgical procedure deals with the axial compressive forces of the femur; the femoral neck lengthening technique increases the medial directed forces created by the rotators. Bone graft has not been necessary for augmenting bone healing, because bone marrow elements promote extraordinarily rapid bone healing, usually within 5 to 6 weeks.

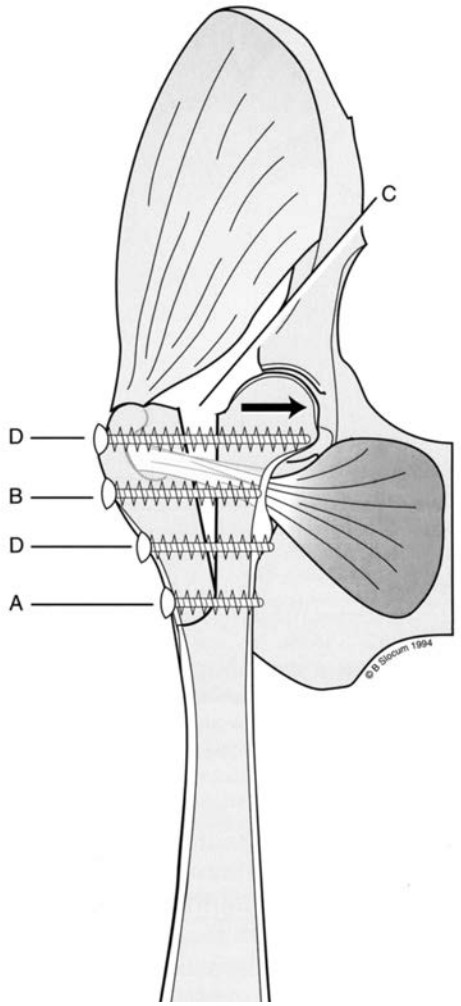


Figure 60-69. The modified femoral neck lengthening osteotomy is fixed by four screws. The distal screw *(A)* is a lag screw, which is initially loosely applied. Only the lateral cortex is drilled and tapped for femoral neck lengthening screw *(B)*, which is equal in length to the depth plus displacement measured from the compression and distraction radiographs. The first screw *(A)* is firmly tightened to complete the creation of the femoral neck lengthening gap *(C)*. Both the lateral and medial cortices are drilled and tapped for neutral screws *(D)* used to maintain fixation.

The postoperative instructions are strict for femoral neck lengthening surgery. The patient must be kept under direct control of the owner while in the house, on good footing, with no playing, and with no other dogs or other excitable activities. The patient is allowed outside only to perform bodily functions on a leash with a bellyband. The patient is kept in a traveling kennel when the owner is not present, to prevent the patient from injuring itself. Tranquilizers may be necessary to maintain this confinement until the femoral neck lengthening is healed.

Femoral neck anteversion can also be corrected using the femoral neck lengthening procedure. In addition to lateralizing the greater trochanter, the lateral cortex is moved cranially to detorse the femur and to provide the appropriate relationship between the greater trochanter and the femoral head. The Femoral Neck Lengthening Wedge and internal fixation are applied with routine closure.

The femoral neck lengthening technique is powerful when used according to the proper indications. Overlengthening the femoral neck can cause the femoral head to move ventral to the acetabulum, particularly if performed concurrently with a pelvic osteotomy technique. The advantage of the femoral neck lengthening technique is that it provides an increase in the medially resultant force holding the hip in the acetabulum. This reestablishes stable hip biomechanics without the necessity for overrotating the acetabular segment in patients with excessive joint capsule laxity. In addition, this procedure is gentle on the patient, the owner, and the surgeon.

Acknowledgments

Kenneth Sinibaldi, DVM, Steven Stoll, DVM, and Gary Brown, DVM, have made contributions to the modification of the femoral neck lengthening technique.

Suggested Readings

Slocum B, Devine T. Pelvic osteotomy in the dog as treatment for hip dysplasia. Semin Vet Med Surg 1987,2:107.

Slocum B, Devine T. Femoral neck lengthening for hip dysplasia in the dog. Vet Surg 1989; 18:81.

Slocum B, Devine T. Pelvic osteotomy. In: Whittick W, ed. Canine orthopedics. 2nd ed. Philadelphia: Lea & Febiger, 1990:471.

Slocum B, Slocum TD. Pelvic osteotomy for axial rotation of the acetabular segment. Vet Clin North Am 1992;22:645.

Slocum B, Slocum TD. Femoral neck lengthening: the cutting edge. 1988.

Stoll S. Femoral neck lengthening. San Francisco, CA: American College of Veterinary Surgeons, 1996.

Pelvic Osteotomy

Barclay Slocum and Theresa Devine Slocum

The first principle in treating acetabular hip dysplasia is to neutralize any luxating force created by a slope of the dorsal acetabular rim (DAR) or adduction of the femur. This requires an axial rotation of the acetabular segment by pelvic osteotomy. The second principle is the establishment of a greater trochanteric muscle force moment for creating dynamic stability of the femoral head by femoral neck lengthening, when the femoral neck is short or the joint capsule is excessively lax. The third principle is to reduce the redundancy of the joint capsule by capsulorrhaphy, which adds static stability to the hip when the femoral neck is normal and excessive laxity of the joint capsule is greater than 6 mm. This discussion addresses the first principle, the surgical technique of pelvic osteotomy.

Pelvic osteotomy is a triple osteotomy of the pelvis that frees the acetabular segment for axial rotation to reduce the DAR angle to 0° (Figure 60-70). The primary indication for pelvic osteotomy is excessive slope to the DAR. By far the most common circumstance for this condition is acetabular hip dysplasia, which is an excessive slope of the DAR by definition. Occasionally, pelvic torsion, secondary to a transitional vertebra of the sacrum, causes a unilateral excessive slope of the DAR that is also treated by pelvic osteotomy. Dislocation of a dysplastic hip is an immediate indication for pelvic osteotomy, as long as the articular surfaces can be replaced with congruity. Reduction of a dislocated dysplastic hip fails unless pelvic osteotomy is performed. Reduction of a dislocated hip without treating the underlying hip dysplasia is unacceptable. A short femoral neck as in an akita, chow, or Tibetan mastiff, or secondary to premature closure of the capital femoral physis, requires femoral neck lengthening if found primarily, but damage to the DAR by the head of the femur with the shortened neck reduces the coverage of the DAR and requires a pelvic osteotomy to stabilize the hip.

The degree of correction for rotation of the pelvic osteotomy is determined by looking at the abnormalities in specific structures. Joint capsule laxity can be calibrated by the angle of reduction, stress radiography, and the Bardens palpation. Damage to the articular cartilage can be assessed by palpation, with the patient under anesthesia, to distinguish joint capsule distraction from tearing. The characteristics of the articular cartilage can also be distinguished by hip palpation as normal, fibrillated, or eburnated. The DAR radiographic view and linear tomography create a visual representation of articular cartilage thickness and damage to the weightbearing portion of the acetabulum. Acetabular depth can be evaluated radiographi-cally using the frog view at 45° of abduction, the compression view in the ventrodorsal position, and the DAR view. Acetabular depth can also be assessed by the angle of subluxation and the combined interpretation of actual DAR slope and ligament of femoral head redundancy.

The slope of the DAR is measured directly from the D AR radiograph. The subchondral surface of the dorsal acetabulum is linear unless distorted by acetabular filling or chronic luxation of the femoral head. The angle of subluxation provides a good assessment of the functional slope of the DAR.

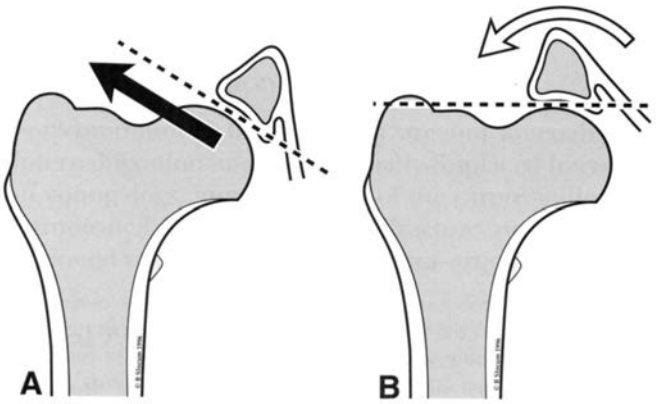


Figure 60-70. A. The excessive slope *(dotted line)* of the *Dorsal Acetabular Rim* (DAR) causes the femur under axial load to luxate *(solid arrow)*. **B.** After pelvic osteotomy *(white arrow)*, the DAR slope is 0°, and the hip is functionally stable.

Surgical Procedures

The acetabular segment of the pelvis is freed for axial rotation by osteotomies of the pubis, ischium, and ilium and is fixed with just enough rotation by a Canine Pelvic Osteotomy Plate (Slocum Enterprises, Eugene, OR) to stabilize the femoral head in the acetabulum (Figure 60-71). The patient is anesthetized, the limb is prepared for surgery with the dog in lateral recumbency, and the limb is hung by a foot wrap. The entire hindquarter is draped free to allow for access to the pubis, tuber ischiadicum, and ilium.

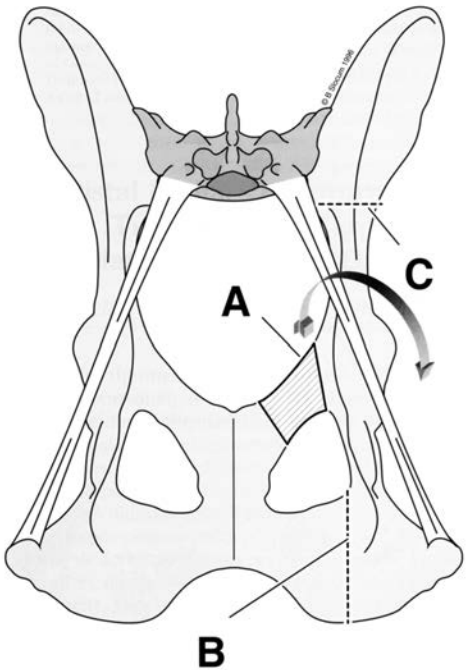


Figure 60-71. Three osteotomies of the pelvis are necessary to free the pelvis for axial rotation of the acetabular segment *(arrow)*. The pubic osteotomy *(A)* is performed first and includes removal of the pubic ramus (shaded area). The ischial osteotomy *(B)* is performed in the sagittal plane through the table of the ischium at the lateral margin of the obturator foramen. The ilial osteotomy *(C)* is performed perpendicular to a line in the sagittal plane that is tangent to the portion of the acetabulum to be rotated.

Pubic Osteotomy

The skin is incised over the proximal one-fourth of the pectineus muscle and inguinal crease. The gracilis and adductor muscles are elevated from the ventral pubis. The prepubic tendon and pectineus are elevated from the cranial pubis (Figure 60-72). The obturator nerve is retracted caudomedially. An osteotomy is made in the sagittal plane at both the medial and lateral limits of the pubis. The entire pubis along the cranial margin of the obturator foramen is removed and is saved for an ilial osteotomy bone graft. The gracilis muscle is closed to the prepubic tendon to prevent an inguinal hernia. Subdermal sutures are used to preclude difficult suture removal.

Ischial Osteotomy

A sagittal incision is made over the midtuber ischiadicum and is carried to bone of the dorsal ischial plateau. The internal obturator muscle is elevated from the dorsal table of the tuber ischiadicum. The sacrotuberous ligament is elevated from the lateral prominence of the tuber ischiadicum medially to laterally. An osteotomy of the tuber ischiadicum at the lateral limit of the obturator foramen (Figure 60-73) is performed in the sagittal plane. A 20-gauge fixation wire is preplaced through two holes on either side of the osteotomy site. Closure is delayed until after the ilial osteotomy and plate application is completed. Once the ilial osteotomy is plated, then the ischial wire is tightened. The perineal fascia is closed using a cruciate suture pattern. The skin of the ischial incision is closed with a simple interrupted pattern.

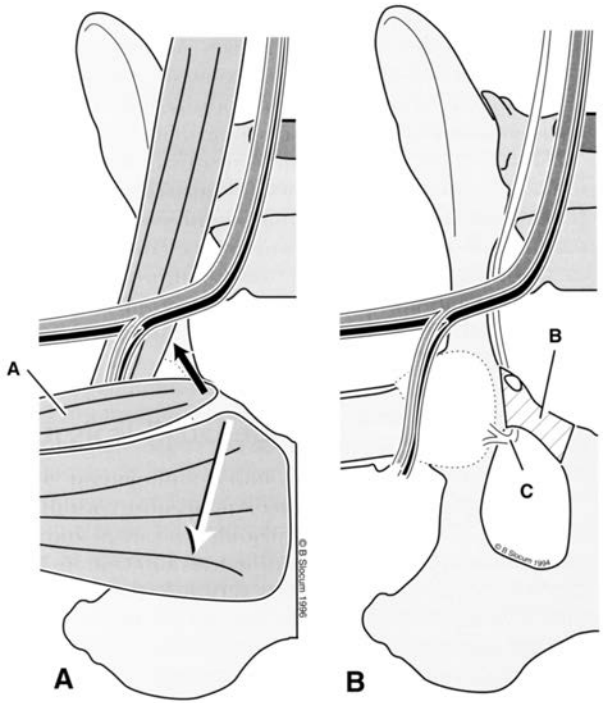


Figure 60-72. A. The pubic osteotomy is performed through a 3-cm incision centered on the inguinal crease and just caudal to the pectineus muscle *(A)*. The gracilis and adductor magnus are elevated and retracted caudally *(white arrow)*. The pectineus is elevated from the pubis and retracted cranially *(black arrow)*. **B.** With the elevation of the musculature, the pubis is exposed completely *(B)*. The obturator nerve *(C)* is retracted from the pubis. The pubic ramus *(striped area)* is cut medially and laterally and removed. It is reduced to 3-mm fragments and used as bone graft for the ilial osteotomy.

Ilial Osteotomy

A skin incision is made from the midcranial wing of the ilium to the base of the cranial aspect of the greater trochanter (Figure 60-74). The gluteal fascia is incised parallel to the skin incision. The separation between the middle gluteal muscle and the tensor fasciae latae is made. En masse, the deep and middle gluteal muscles are elevated from the body and wing of the ilium cranially, but they are left intact dorsally on the tuber sacrale (Figure 60-75). The cranial circumflex iliac artery is cauterized, but the cranial gluteal nerve to the tensor fasciae latae is preserved. A Langenbeck periosteal elevator is placed dorsal to the body of the ilium in the greater ischiatic notch and is moved cranially until contact is made between both the ilium and the sacrum. A relaxing incision in the tensor fasciae latae tendon provides the extra exposure to the greater ischiatic notch. A guide pin is placed dorsal to the lateral prominence of the tuber ischiadicum, beneath the internal obturator muscle. The pin is pushed cranially to the junction between the ventral and middle third of the cranial margin of the wing of the ilium (Figure 60-76). The ilial osteotomy is made perpendicular to the axis of the guide pin, just cranial to the Langenbeck elevator. The free acetabular segment is moved cranially into the operative field.

The caudal half of the Canine Pelvic Osteotomy Plate is applied to the body of the ilium (Figure 60-77) 3 mm dorsal to the ventral margin of the ilium using a spheric drill guide and 4.0-mm fixation screws. A 1.25-mm hemicerclage wire is placed through the wire hole in the caudal half of the plate, encircling the ilial body ventrally. The spike of ilial bone dorsal to the plate is removed.

The ilial osteotomy is reduced, and a 4.0-mm screw is placed in the ventral compression hole of the cranial portion of the Canine Pelvic Osteotomy Plate using a 1.0-mm compressive drill guide. The hip is tested for stability by axial compression of the femur in the sagittal plane (Figure 60-78). If the hip is unstable (the femoral head luxates), then the next larger angle of plate needs to be used. The screw holes of all Canine Pelvic Osteotomy Plates are in the same relative position. When applying the remaining two screws, care should be taken to place the screws perpendicular to the plate.

On small patients, these screws may have to be directed caudally to drill into the body of the sacrum. A bone graft of the pubis, fragmented to 3 mm or less, is placed caudal to the wing portion of the ilium between the sacrum and the acetabular segment. Closure of ilial approach is routine.

The objective of the pelvic osteotomy technique is to provide acetabular support and stability for the femoral head by increasing the acetabular coverage. Reducing the acetabular slope to 0° is optimal. The preoperative examination of the patient determines the angle for the Canine Pelvic Osteotomy Plate to be used. Although the angle of subluxation is theoretically the ideal angle for pelvic osteotomy, it is usually insufficient to provide hip stability unless the DAR is undamaged. The angle of reduction, which indicates joint capsule stretching, is the absolute maximum angle for pelvic osteotomy and is excessive, especially if a great difference exists between the angles of reduction and subluxation. The slope of the rim as determined

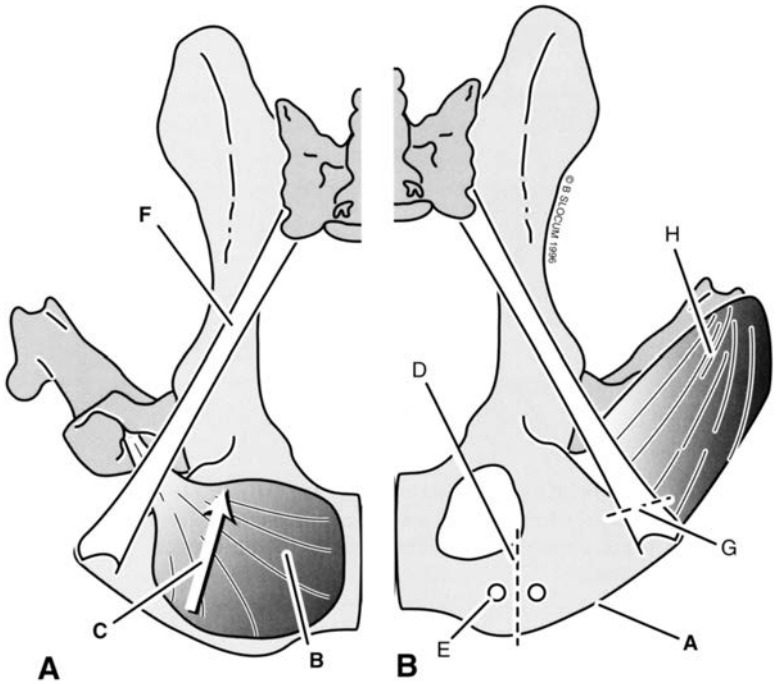


Figure 60-73. A. The ischial osteotomy is made through a 3-cm incision in the sagittal plane over the midtuber ischiadicum. The internal obturator muscle *(B)* is elevated from the ischial table, parallel and medial to the body of the ischium *(C)*. The sacrotuberous ligament *(F)* extends between the sacrum and the lateral prominence of the tuber ischiadicum. **B.** With the table of the ischium freed from muscle *(A)*, a reciprocating saw is used to make a sagittal plane osteotomy in the tuber ischiadicum, as far laterally in the obturator foramen as possible *(D)*. A wire hole is placed on either side of the osteotomy *(E)*. The sacrotuberous ligament is incised just proximal to the lateral prominence *(G)*. The ligament is held loosely in relative position by the biceps femoris muscle *(H)*.

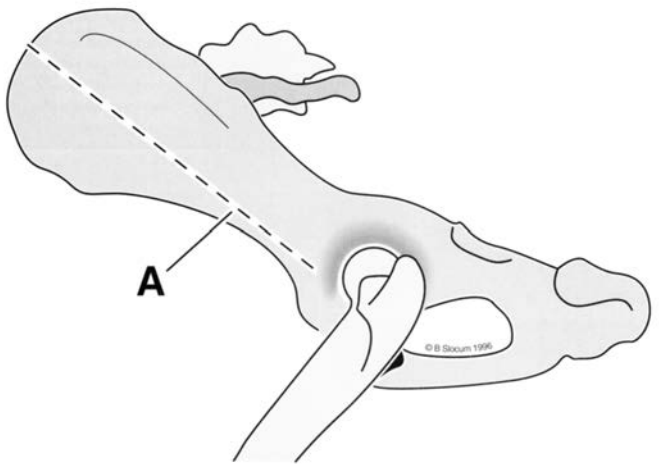


Figure 60-74. For the ilial osteotomy, a linear skin incision *(A)* is made from the cranial border of the wing of the ilium, halfway between the tuber sacrale and the tuber coxae, to the cervical tubercle of the femur.

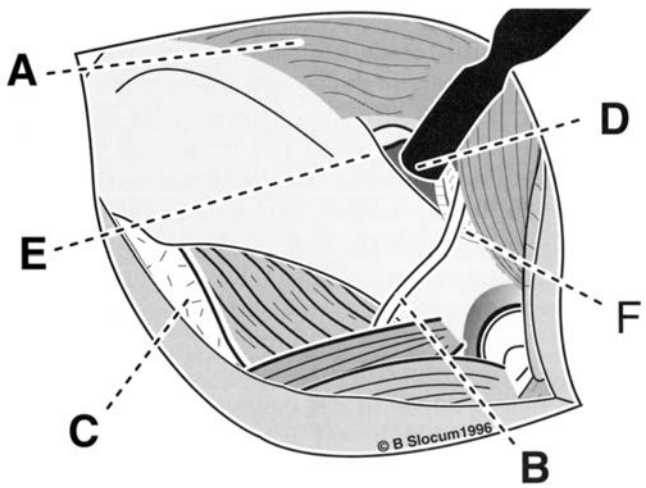


Figure 60-75. The ilial approach is made by rolling up the middle and deep gluteal muscles *(A)*. The cranial gluteal nerve to the tensor fasciae latae muscle *(B)* can be preserved by a relaxing incision in the tensor fascia origin *(C)*. A Langenbeck retractor *(D)* is placed dorsal to the body of the ilium and is moved cranially to contact the sacrum *(E)*. This protects the cranial gluteal neurovascular bundle to the gluteals *(F)*, and the cranial margin of the retractor is a guide for the osteotomy.

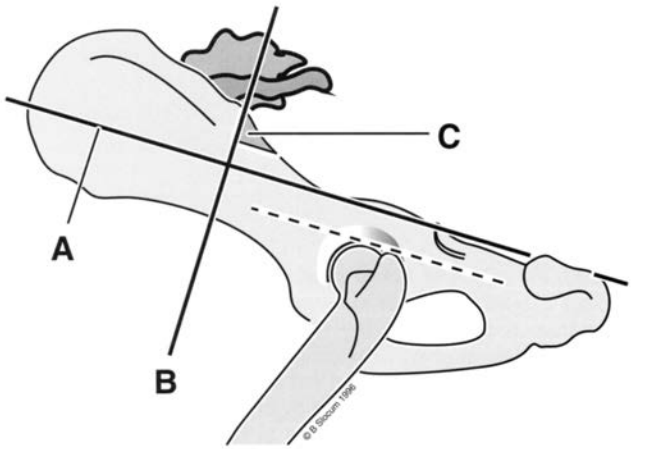


Figure 60-76. The tangent to the acetabulum *(broken line)* contacts the acetabulum at the singular point at which the femoral head leaves during subluxation. The guide pin *(A)* is placed parallel to the tangent to the acetabulum. The ilial osteotomy *(B)* is made perpendicular to the guide pin at the junction of the sacrum and the pelvis. The pointed piece of bone *(C)* is removed.

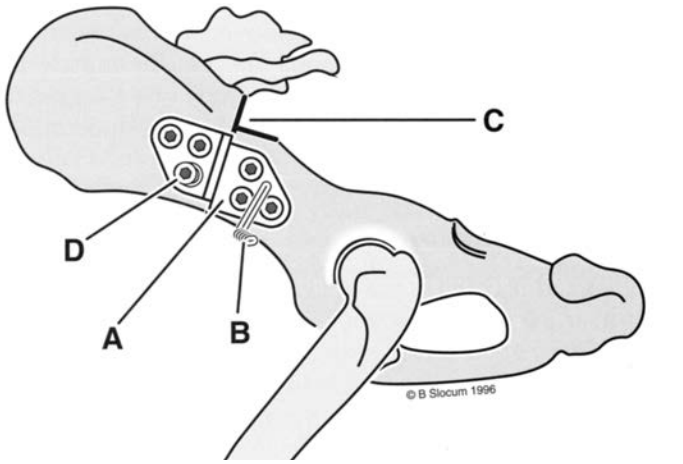


Figure 60-77. The Canine Pelvic Osteotomy Plate *(A)* is applied to the acetabular segment, and a hemicerclage wire *(B)* is added. The point *(C)* is removed. The compression screw *(D)* is applied, and the hip is checked for stability by the femoral axial compression test. If the hip is unstable, a capsulorrhaphy, femoral neck lengthening or the next larger angle of osteotomy plate should be considered.

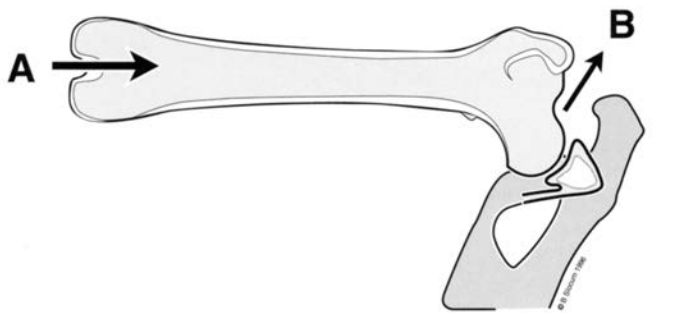


Figure 60-78. The axial compression test of the femur is performed by applying a force *(A)* to the distal femur in the sagittal plane and witnessing the response of the femoral head *(B)*. A positive test is when the femoral head leaves the acetabulum and represents hip instability. A negative test is when the hip remains within the acetabulum.

from the DAR radiograph is an accurate reference for the amount of axial rotation for the acetabular segment.

If joint capsule laxity is excessive, femoral neck lengthening or capsulorrhaphy should be used to achieve hip stability while maintaining an optimum range of motion rather than overrotation of the acetabular segment. Overrotation causes impingement of the femoral neck, the advancement of degenerative joint disease, and pain.

Several aspects of the pelvic osteotomy need to be observed to ensure consistently good results from the procedure. Most important, only enough axial rotation of the acetabular segment to provide hip stability should be performed. The slope of the DAR should be brought to 0° and not beyond, for the benefit of the function of the patient. When the ilial osteotomy is placed as described, the ilial osteotomy overlies the sacrum about 3 mm cranial to its caudal margin. This prevents the saw from penetrating the ilium, to damage the pelvic plexus and cause dysuria, as may occur when the osteotomy is made caudal to the sacrum. Using the guide pin properly orients the osteotomy and prevents excessive angulation of the caudal portion of the acetabular segment, as occurs when the osteotomy is made perpendicular to the long axis of the ilium, rather than the long axis of the pelvis. Rotation of the acetabular segment and internal fixation are much more difficult when the cut is incorrect. A Hohmann retractor should not be used dorsal to the body of the ilium. The sciatic nerve, which lies medial to the body of the ilium, is easily crushed between the tip of the retractor and the bone during retraction. The well-intentioned assistant often replaces a displaced Hohmann retractor into a position of danger.

If the SI nerve root is encountered when drilling the dorsal holes in the cranial portion of the plate, then the screw applied to that hole should be short enough to avoid contact with the nerve or the hole should be redirected to avoid the nerve root.

The Canine Pelvic Osteotomy Plate has two characteristics which makes it superior to twisted linear plates. The width of this plate and the placement of screws more efficiently resist the torsional moments of the acetabular segment than the linear plates, which tend to pry the screws from the bone (Figure 60-79).

The sacrotuberous ligament release prevents elevation of the caudal acetabular segment during axial rotation that would otherwise malalign the ilial osteotomy and place static tension on the sacrotuberous ligament, leading to a gradual release of tension in the elongating ligament and subsequent loss of compression at the ilial osteotomy as the sacrotuberous ligament lengthens (Figure 60-80). The loss of compression by yielding of the sacrotuberous ligament causes cyclic forces on the screws with premature loss of fixation. This same effect is noted when the angle of the osteotomy is not perpendicular to the axis of the pelvis. The greater the angle of the osteotomy from the perpendicular to the guide pin, the greater is the ventralization of the tuber ischiadicum (Figure 60-81). With the release of the sacrotuberous ligament at surgery, the fixation relies on compression of the bone that statically loads the screws only in one direction and prevents cycling.

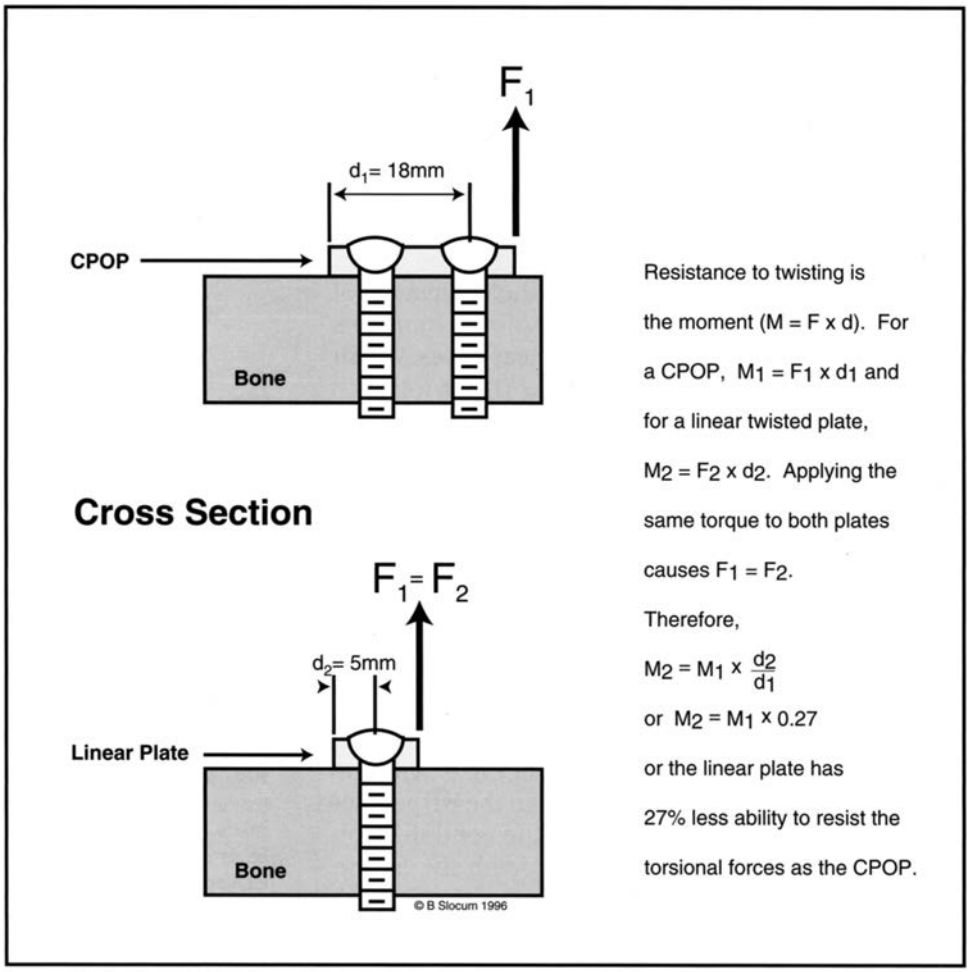


Figure 60-79. Diagram comparing the resistance of a torsional load of a Canine Pelvic Osteotomy Plate (CPOP) with that of a standard 10-mm wide linear plate.

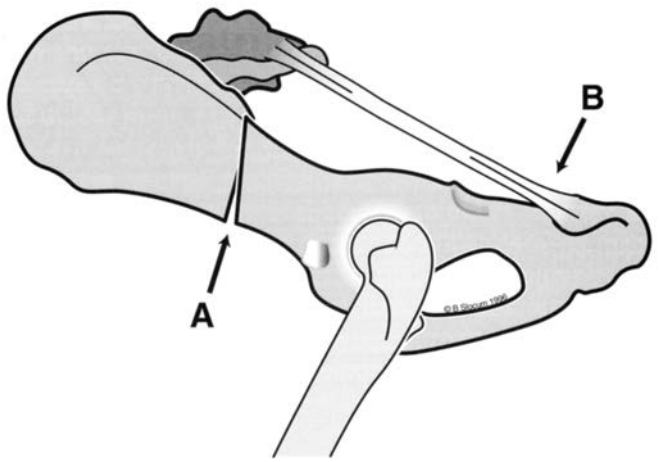


Figure 60-80. The sacrotuberous ligament maintains a fixed length between the sacrum and the lateral prominence of the tuber ischiadicum. Unrestricted rotation of the acetabular segment around the guide pin axis lengthens the distance between the sacrum and the tuber ischiadicum. As a result, a gap will occur *(A)* unless the ligament is released *(B)*.

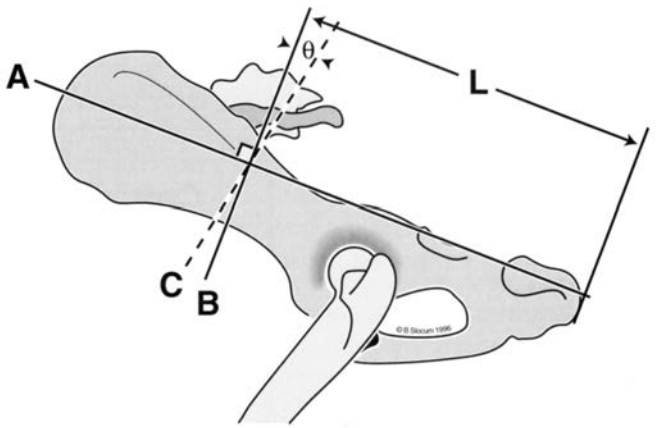


Figure 60-81. The direction of the ilial osteotomy *(B)* is ideally made perpendicular to the guide pin *(A)*. If the osteotomy were made parallel to the guide pin, then the tuber ischiadicum would be lateralized by the distance from the osteotomy to the tuber ischiadicum, *L*, times the sine of the angle, θ, of the plate used. If the osteotomy *(C)* is made at angle θ to the perpendicular to the guide pin, then lateralization of the tuber ischiadicum, *T*, can be expressed as: $T = L \times \sin Ø \times \sin \theta$.

The results of pelvic osteotomy are predictably good if meticulous attention is paid to case selection, surgical technique, and aftercare. The technique provides for the return of normal function and activity for dogs with hip dysplasia and prevents the progression of degenerative osteoarthritis. The ideal candidate for this procedure has minimal filling of the acetabulum, an intact DAR, and an increased slope of the DAR of 10 to 20° on the dysplastic hip. The amount of joint capsule laxity (angle of reduction or distraction index) is smaller after healing of the pelvic osteotomy because the joint capsule tightens when the capsule-stretching forces created by the increased slope of the DAR are treated by the pelvic osteotomy. The most advanced stage of acetabular hip dysplasia that has a good functional result for the patient depends on the amount of acetabular filling and trauma to the DAR.

Suggested Readings

Slocum B. AVORE. Pelvic osteotomy: the results ol 285 pelvic osteotomies (abstract). Vet Surg 1986;15:134.

Slocum B, Devine T. Pelvic osteotomy in the dog as treatment for hip dysplasia. Semin Vet Med Surg 1987,2:107.

Slocum B, Devine T. Femoral neck lengthening for hip dysplasia in the dog. Vet Surg 1989; 18:81.

Slocum B, Devine T. Dorsal acetabular rim radiographic view for evaluation of the canine hip. J Am Anim Hosp Assoc 1990,26:289.

Slocum B, Devine T. Pelvic osteotomy. In: Whittock W, ed. Canine orthopedics. 2nd ed. Philadelphia: Lea & Febiger, 1990:471.

Slocum B, Slocum TD. Slope of the dorsal acetabular rim for hip evaluation in the dog. In: 17th annual conference of Veterinary Orthopedic Society. Jackson Hole, WY: Veterinary Orthopedic Society, 1990:12.

Three Plane Intertrochanteric Osteotomy

Terry D. Braden and W. Dieter Prieur

Introduction

Early stage canine hip dysplasia is manifested by coxofemoral joint laxity, lameness, pain and characteristic radiographic changes.[1] The first radiographic change is femoral head subluxation (Figure 60-82).[2] Subluxation results from the following causes, singly or in combination: increased femoral neck inclination angle; increased femoral neck anteversion; or loose supporting structures (muscles, joint capsule, ligaments).[3] Subluxation decreases the contact area between the acetabulum and femoral head. Because the contact area is decreased in dysplastic dogs, the load per area of articular cartilage is increased. This continued biomechanical overloading of the joint surface results in cartilage necrosis, which leads to progressive worsening of the radiographic and clinical signs of Canine Hip Dysplasia (CHD).[4]

The first report[5] of successful use of the intertrochanteric osteotomy treatment of coxofemoral osteoarthritis in human beings appeared over 60 years ago, although the procedure itself was first described by Kirmission in 1894.[6] The purpose of the intertrochanteric osteotomy is to reestablish or improve the contact area of the acetabular and femoral head surfaces and thus improved the biomechanical function of the hip joint.[7,8] This is accomplished using the intertrochanteric osteotomy by changing the femur's position relative to the acetabulum in three planes. The first plane, the inclination of the femoral neck, is changed from a valgus to a varus position.[9] The second plane, the anteversion of the femoral neck, is rotated toward normoversion.[10,11] The third plane is medialization of the femoral head, neck and trochanteric region in relation to the shaft of the femur (See Figures 60-82 and 60-83).



Figure 60-82. Ventrodorsal radiograph of the pelvis and femurs of a 9-month-old St. Bernard with early-stage hip dysplasia. Note the subluxation of the coxofemoral joints but relatively normal acetabulum and femoral head and neck, bilaterally.



Figure 60-83. Ventrodorsal radiograph of the pelvis and femurs of the same dog as in Figure 60-82 immediately after a three-plane intertrochanteric osteotomy of the left hip. Note the improvement in the contact area between the femoral head and acetabulum.

Indications for Intertrochanteric Osteotomy

Intertrochanteric osteotomy is indicated when both the radiographic and clinical signs of early stage CHD are present. The typical clinical signs are stiffness on rising, rising using the front legs only, bunny hopping, pain, and lameness. Any or all of these signs may be present. The radiographic signs of early stage CHD are subluxation of the head of the femur from the acetabulum, with minimal or no deformity of the acetabulum or femoral head, and minimal or no arthritis of the joint (See Figure 60-82). In the early manifestation of this disease, the most common radiographic sign is subluxation of the hip. Subluxation of the coxofemoral joint also may be present in dogs without CHD.[12] Therefore, subluxation of the coxofemoral joint alone is not diagnostic of early stage CHD. Subluxation of the femoral head with the appropriate clinical signs is necessary for the initial diagnosis of early-stage CHD. If the subluxation advances to luxation, or if the deformity to the femoral head or acetabulum (shallowness) is significant, or if there is moderate to severe arthritis, this procedure is not indicated. In those situations, a total hip replacement would be indicated.

Greater than 95% of dogs that have CHD are affected bilaterally. The radiographic pathology is not generally symmetric; that is, one side usually is worse than the other, but most of the time both sides have some pathology (See Figure 60-82). The indications for surgical intervention on the first side, as mentioned previously, are radiographic subluxation of the coxofemoral joint and clinical signs of CHD. The indication for surgery for the second side (4 to 6 weeks later) are radiographic subluxation with or without the clinical signs. Surgery on the second side generally is prophylactic, whereas the first side is therapeutic. Because of the dog's ability to shift weight, if the surgery is performed on the second side only after clinical signs are noticed, there are too many secondary changes to the acetabulum and femur, and an intertrochanteric osteotomy is no longer indicated. Subluxation of the second hip must be seen at least once (either on the initial examination radiograph, the postoperative radiograph of the first hip, or the 4 to 6 week postoperative follow-up radiograph). Greater than 95% of the time, subluxation can be seen at one or all of these times on the second hip, and the second surgery is indicated (Figures 60-84 and 60-85). If all three of these radiographic examinations are negative for subluxation, the surgery is not recommended on the second side.



Figure 60-84. Ventrodorsal radiograph of the pelvis and femurs of the same dog as in Figure 60-82, shown 6 weeks postoperatively. Note the healing and remodeling at the osteotomy site.



Figure 60-85. Ventrodorsal radiograph of the pelvis and femurs of the same dog as in Figure 60-82. The left hip is shown 6 weeks postoperatively, and the right hip is shown immediately postoperatively. Note the biomechanical improvement of the coxofemoral joints bilaterally.

Preoperative Planning

The first step in the preoperative planning for an intertrochanteric osteotomy is determination of the angle of inclination of the femoral neck. This is the angle between the axis of the femoral shaft and the axis of the femoral neck. Properly positioned ventrodorsal hip (pelvis and femurs) radiographs are absolutely essential in establishing these axes. The femurs must not be rotated; therefore, the patellas must be centered on the intercondylar sulci and the outline of the intertrochanteric fossa must be well-visualized. The pelvis must not be rotated; therefore, the obturator foramen must be equal in size on both sides of the pelvis (See Figure 60-82).

A transparent paper is placed over the ventrodorsal (V-D) radiograph, and the femur is traced. The axis of the shaft of the femur is established by drawing two lines perpendicular to the long axis from the medial to the lateral cortices (Figure 60-86). One is drawn at the junction of the proximal and middle third of the shaft (line A), and the second is drawn at the junction of the middle and distal third of the shaft (line B). These two lines are then bisected (points A and B), and these points are connected by a straight line extended to the top of the femur (See Figure 60-86). This is the axis of the femur.

To determine the axis of the femoral neck, a line is drawn perpendicular to the femoral axis line, connecting the most distal point of the intertrochanteric fossa to the medial cortex of the femoral neck (line C). The bisect of this line is point D (See Figure 60-86).

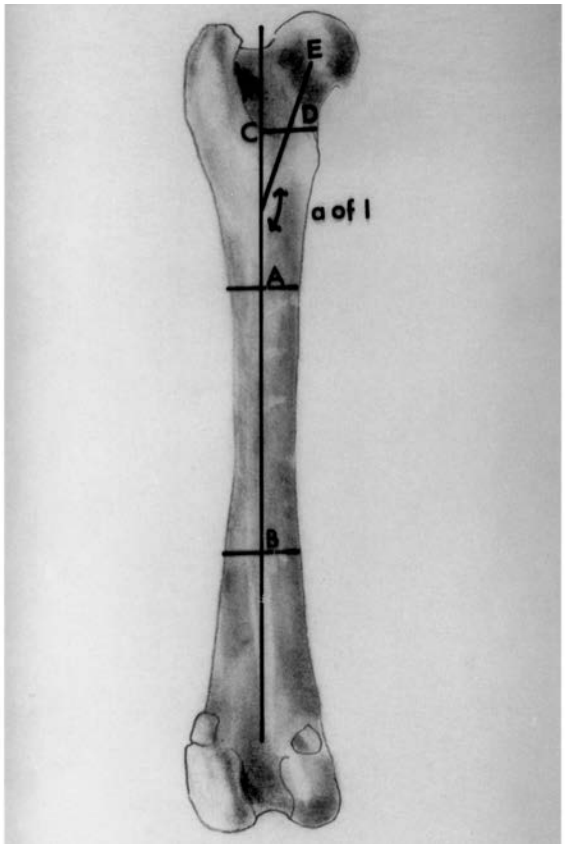


Figure 60-86. Drawing of posterior view of the femur illustrating a method of determining the angle of inclination (a of I) of the femoral neck. Line A-B is the axis of the femoral shaft, and line E-D is the axis of the femoral neck.

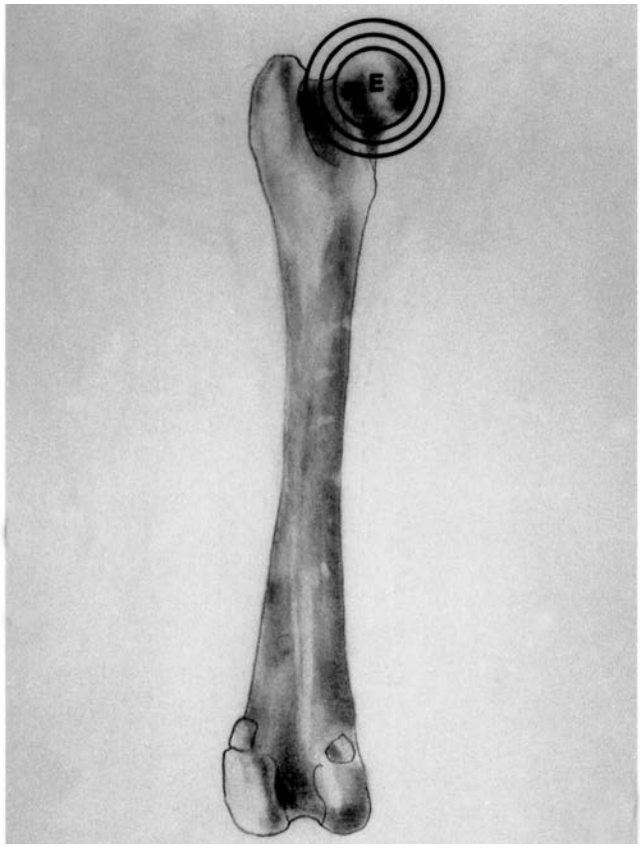


Figure 60-87. Posterior view of the femur illustrating the determination of the center (point E) of the femoral head using concentric rings of a standard goniometer.

The center of rotation of the femoral head (point E) is determined, using the concentric circles of a standard goniometer (Roentgen Ischiometer MEM, Protek AG, Berne, Switzerland), which has a number of concentric rings with a known central point. By matching the identically sized ring with the femoral head, the center of the head is easily determined (Figure 60-87).[13] Points E and D are connected, and this line is continued until it crosses line AB. The obtuse angle formed by these two lines is the angle of inclination (a of I) of the femoral neck (See Figure 60-86).

The average angle of inclination of the femoral head in the dog is 149 degrees with a range of 141 to 157 degrees. The desired angle of inclination resulting from an intertrochanteric osteotomy is 135 degrees. The degree of overcorrection is thought to decrease stress on the joint cartilage by increasing the loaded surface area of both the femoral head and acetabulum. The difference between 135 degrees and the measured angle in the dog with early stage CHD is the size of the wedge removed in the intertrochanteric osteotomy. The typical wedge removed is approximately 25 degrees. On severe cases of valgus inclination of the femoral neck, a 35 degree wedge is removed.

On a second transparent paper overlying the V-D radiograph of the hip, a line perpendicular to the line of axis of the femoral shaft is drawn connecting the lateral cortex (point F) and the point of the lesser trochanteric (point G). This represents the first osteotomy site (Figure 60-88). Using a goniometer or a protractor to measure the degrees of the wedge to be removed, a mark (point H) is made on the medial cortex of the femoral neck, above the lesser trochanter. Points F and H are connected. This line is the second osteotomy (See Figure 60-88). The triangular wedge of bone, HFG, is removed.

Care must be taken that the line F-H, the second osteotomy, does not enter the ventral medial aspect of the femoral head. In dogs with a short area between the femoral head and the lesser trochanter, the calculated edge may be too large to remove without taking part of the ventral femoral head. In those cases, the second osteotomy is directed to the junction of the femoral neck and femoral head.

The transparency paper is cut in half from point F to point G. Then, the wedge (point F to Point H) is cut out of the paper. The paper femur is reduced, and the plate (Double Hook Plate, Synthes, Paoli, PA) is contoured to the lateral aspect of the paper femur. The center of the solid portion of the plate, between the first and second proximal holes (Figure 60-89), should be aligned over point F. Additional bending of the plate may be necessary during surgery.

The second step in the preoperative planning for an intertrochanteric osteotomy is measuring the anteversion. The anteversion of the femoral neck and head can be measured from an axial radiograph of the femur. With the dog on its back on the radiographic table, the long axis of the femur is positioned at a right angle to the table and the x-ray beam is aimed down the shaft of the femur

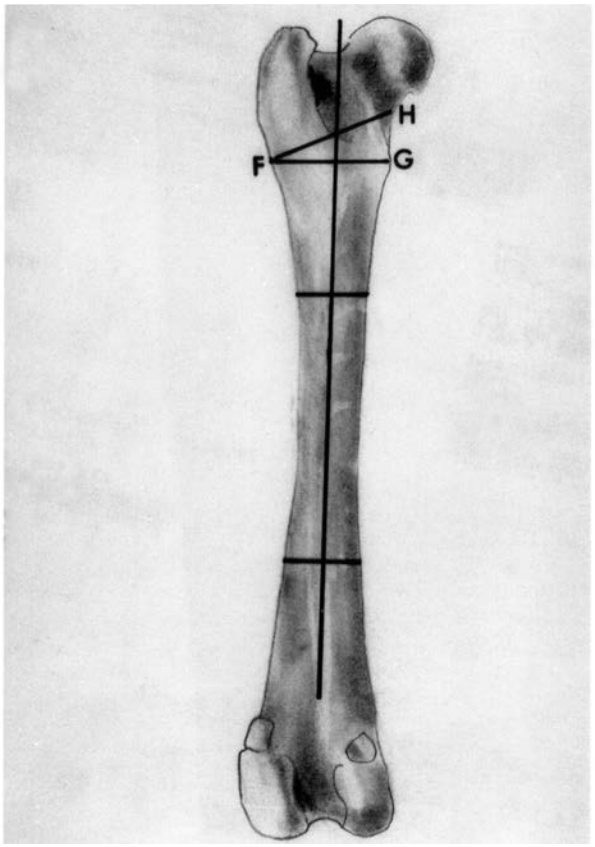


Figure 60-88. Posterior view of the femur illustrating the determination of the first osteotomy (line F-G) and the second osteotomy (line F-H) of the intertrochanteric osteotomy surgery.

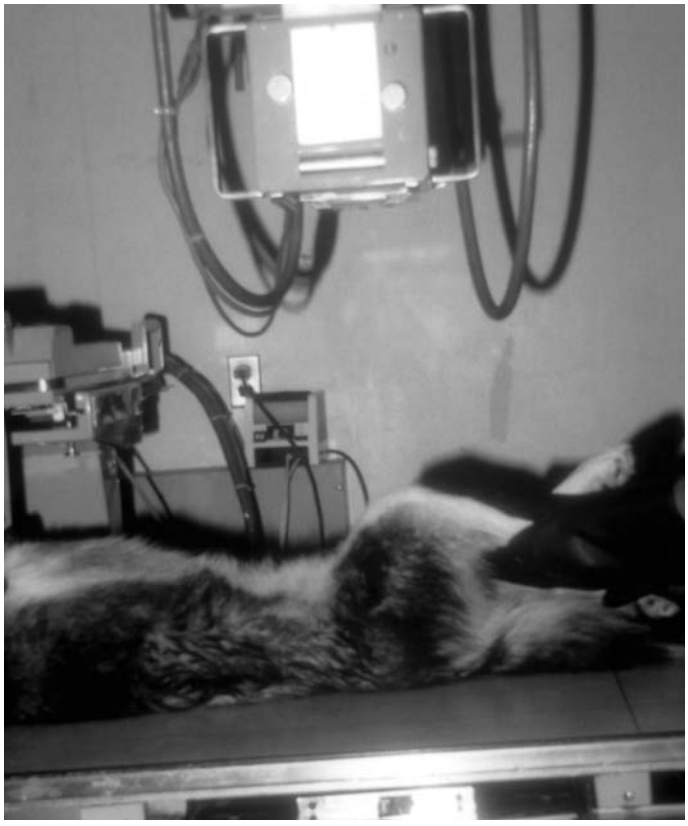


Figure 60-90. Dog in dorsal recumbency on the radiographic table with the femur positioned at the right angle to the table. The x-ray beam is directed down the long axis of the femoral shaft to obtain an axial radiograph of the femur.



Figure 60-89. Five-hole double hook plate used for fixation after three-plane intertrochanteric osteotomy of the femur.

from the stifle to the coxofemoral joint (Figure 60-90). Femoral head and neck anteversion is defined as the angle formed by the plane containing the axis of the shaft and the plane containing the axis of the femoral neck.[13] In other words, with the medial condyle being medial, the lateral condyle being lateral, and the patella being anterior, the shaft of the femur is in anatomic position. With the femur in anatomic position, the direction the femoral neck takes as it leaves the shaft of the femur is either normoverted (straight medial), anteverted (anterior towards the ilium), or retroverted (posterior towards the ischium). An excellent radiographic sign of anteversion is the outline of the lesser trochanter. With the femur in a normal anteversion (10 to 20 degrees), only the tip of the lesser trochanter will be seen on the standard ventrodorsal (V-D) radiograph of the pelvis and femurs. With increased anteversion, more or the entire lesser trochanter will be seen on the standard (V-D) radiograph (See Figure 60-82).

To measure the angle of anteversion, a piece of transparent paper is placed over the axial radiograph of the femur (Figures 60-91 and 60-92). A straight line is drawn from the most posterior point of the medial condyle (point M) to the most posterior point of the lateral (point L) condyle (Figure 60-93). Next, a straight line is drawn from the point where the femoral head meets the femoral neck dorsally (point J) to the ventral femoral head-neck junction (point I). Also, a straight line is drawn between the points where the femoral neck meets the femoral shaft dorsally (point K) and ventrally (point N). A line is drawn connecting the bisect of these two lines. This line is the axis of the femoral neck. This axis line is extended to the condylar line (Figure 60-93). The angle between the two lines is the angle of anteversion of the femoral neck.

Preoperative Planning – Shortcut

The above radiographic measuring and preoperative planning should be carried out on each surgeon's first half a dozen cases, or until the surgeon has a really good feel for the three dimensional geometry of the coxofemoral joint. During those first surgeries you will notice that the size of the wedge you surgically remove is almost always the same even though your measurements were different. The reason for this is twofold. One, there

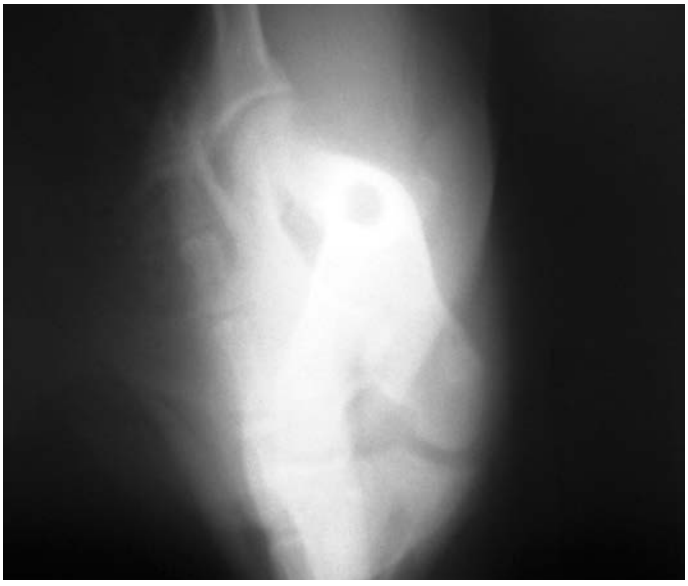


Figure 60-91. Axial radiograph of the femur. Note the angle of the femoral neck in relation to the shaft of the femur. This angle is the anteversion of the femur.

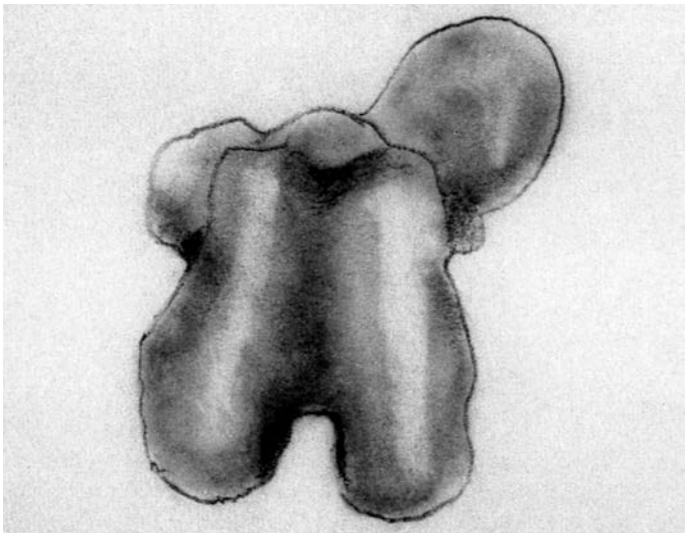


Figure 60-92. Axial view of the femur. Compare this drawing to the axial radiograph of the femur in Figure 60-91.

is 5 to 10% error in everyone's measuring, i.e., if you come back a day later and remeasured your angles, you would vary 5 to 10%. The second reason is there is a 2 to 5 degree variation in the surgery itself, even with the instrumentation available. This all adds up to a 2 to 10 degree variation between what you measured and what you accomplished surgically.

Therefore, the philosophy that can be practiced (after you have a firm three dimensional mental vision of the geometry of the coxofemoral joint) is to improve the relationship of the femoral head to the acetabulum, you should not think you are returning the angles of the femoral neck to normal. Mainly because most people do not agree what normal is, it varies with different breeds, your measurements are not exact and your surgery is not exact (within 1 or 2 degrees).

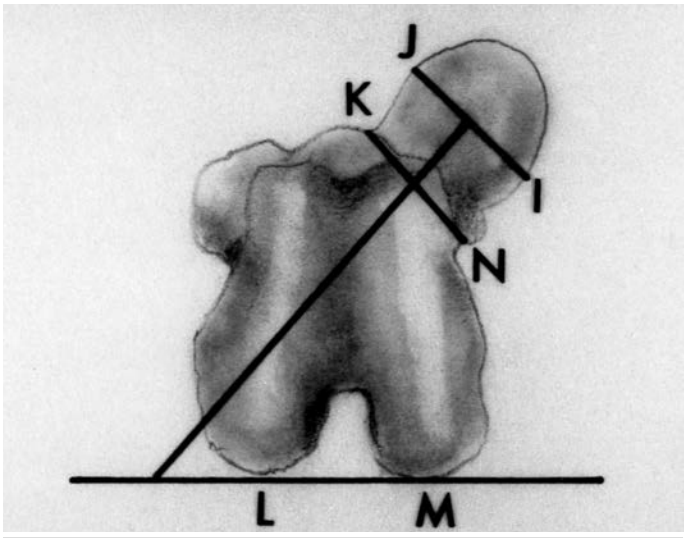


Figure 60-93. Axial view of the femur illustrating one method of determining the angle of anteversion of the femoral neck. *M* = posterior point of medial condyle; *L* = posterior point of lateral condyle; *J* = dorsal junction of femoral head and neck; *I* = ventral junction of femoral head and neck; *K* = dorsal junction of femoral neck and shaft; *N* = ventral junction of femoral neck and shaft.

Therefore with the philosophy of improving the subluxated coxofemoral joint, you can skip the measuring and proceed directly to removing a wedge from the intertrochanteric region that has a base 1/4" (6 mm). The base of the wedge is H-G (See Figure 60-88). This is accomplished by making a mark on the lateral surface of the femur directly opposite the lesser trochanter. This mark and the point of the lesser trochanter is the line of your first osteotomy (point F on Figure 60-88). After the first osteotomy, the proximal part of the femur is steadied with a bone clamp on the greater trochanter and the muscles elevated off the medial femoral neck with a periosteal elevator. The second osteotomy is started at the same point the first osteotomy was started and directed so the wedge of bone has a base of 1/4 inch (6 mm). You can stop as often as necessary and check to see that your saw blade is directed correctly. Please realize that this generalization or shortcut is only possible because most of the dogs are large breed young dogs, very similar in size. If you decide to do this procedure on a medium size dog or a giant breed dog, you can adjust the base of your wedge +/- 1 or 2 mm.

After removing the wedge of bone, the proximal metaphysis of the femur is reduced to the diaphysis of the femur. This reduction (making sure you have bone on bone and no gap) will improve the angle of inclination 15 to 25 degrees.

The other two planes of correction (antiversion and medialization) of the proximal femur are accomplished as directed in the surgical procedure, and without the need of presurgical measurements.

In conclusion, this shortcut was presented not to save time or because of laziness. It was presented to inspire in each surgeon the surgical goal of improving the biomechanical potential of the coxofemoral joint, not returning the joint to normal (or so-called normal) angles.

Surgical Procedure

The dog is prepared for aseptic surgery of the intended rear leg from the dorsal midline to the hock and placed in lateral recumbency. The proximal half of the femur is exposed by routine incision of the skin, subcutaneous tissues, and fascia lata. The biceps femoris muscle is retracted posteriorly. The superficial gluteal muscle is elevated from its insertion and retracted dorsally.

The posterior half of the origin of the vastus lateralis muscle (on the lateral aspect of the femur) is incised and retracted cranially (Figure 60-94). The lesser trochanter is palpated with the forefinger on the posterior-medial aspect of the femur, and a mark is made in the bone with a bone saw on the lateral aspect of the femur exactly opposite the lesser trochanter (See Figure 60-94). The special drill guide (No. 380.01, Synthes, Paoli, PA) is laid on the lateral aspect of the femur so that the line on the drill guide is exactly above the mark scored on the bone (Figure 60-95). Using the leveling screw, the long axis of the drill guide is set parallel to the shaft of the femur (Figure 60-95). If the long axis of the drill guide is not parallel, there will be the possibility that the first osteotomy may not be perpendicular to the long axis of the femur. The proximal-caudal hole is drilled with a 3.2 mm drill bit (Drill bit with stop, No. 380.03, Synthes, Paoli, PA) into the greater trochanter to the stop on the drill bit. The 3.2-mm locking pin from the drill guide is placed through the guide into the hole in the greater trochanter. The most distal hole of the three proximal holes in the guide is drilled with a 2.0 mm drill bit into the greater trochanter. The 2.0 mm locking pin is placed through the drill guide into the bone. The remaining hole (proximal-cranial) is now drilled in the greater trochanter with the 3.2 mm drill bit down to the stop. Using this specially designed drill guide ensures that holes in the greater trochanter are exactly placed to accept the hooks on the plate (See Figure 60-89). Next, a 2mm hole is drilled through the center of the distal hole in the tail of the drill guide through one cortex only (Figure 60-95). This hole will be used later for anteversion correction.

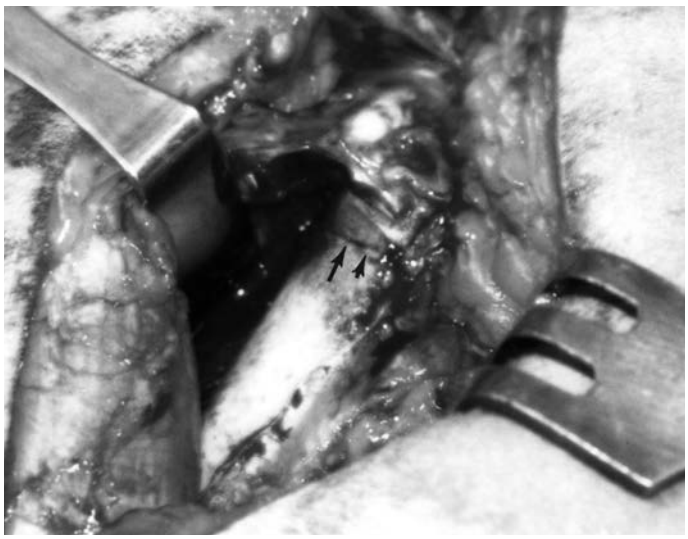


Figure 60-94. Lateral aspect of the femur with the vastus lateralis retracted cranial and the biceps femoris muscle retracted caudal. A mark is made on the bone of the lateral cortex *(arrows)* exactly apposite the lesser trochanter.

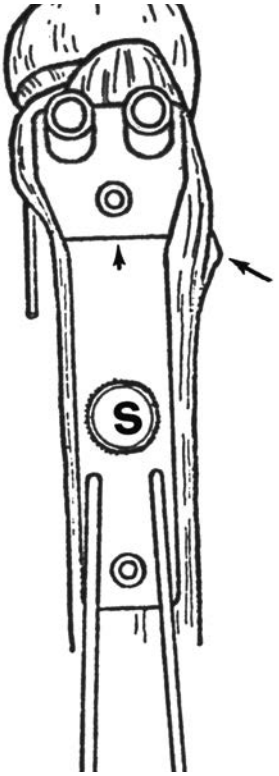


Figure 60-95. Drawing of the lateral aspect of the femur with the special intertrochanteric drill guide in place on the lateral femur. The line on the drill guide *(small arrow)* is placed exactly on top of the mark made on the lateral cortex of the femur, which indicates the level of the lesser trochanter *(large arrow)*. The leveling screw *(S)* is used to set the long axis of the drill guide parallel to the shaft of the femur.

The first osteotomy is now performed, cutting the femur from the mark scored on the lateral aspect of the shaft to the point of the lesser trochanter. There is a saw guide (No. 380.07, Synthes, Paoli, PA) available that hooks into the two 3.2 mm holes in the greater trochanter (Figure 60-96). After the hooks of the saw guide are in place, the blade of the saw guide is adjusted and directed so it is lined up on the score in the bone on the lateral aspect of the femur and the tip of the lesser trochanter on the medial side of the femur. After the first osteotomy is performed, the goniometer (No. 380.05, Synthes, Paoli, PA) is placed in the osteotomy and the femur reduced with two bone clamps. The goniometer is held stable by the pressure of the reduced femur. The blade of the saw guide is now changed to the degree as calculated from the radiograph during the planning stage or to give you a 1/4 inch (6 mm) base to your wedge (Figure 60-97). The saw guide blade is tightened. Using the saw guide, the second osteotomy is made and the wedge of bone removed (Figure 60-98). The femur is now reduced taking extreme care that there is 100% bone contact at the osteotomy site. To have the varus correction of the angle of inclination of the femoral neck, there must be bone-to-bone contact with no gap where the wedge was removed. While maintaining this reduction at the osteotomy site, an aluminum template is laid on the lateral aspect of the femur and contoured to match the femur. The template slides into the saw guide allowing coordinated bending of the proximal plate and the three predrilled holes in the proximal femur. The final bending of the plate is performed to match the template. The hooks are then inserted into the greater trochanter.

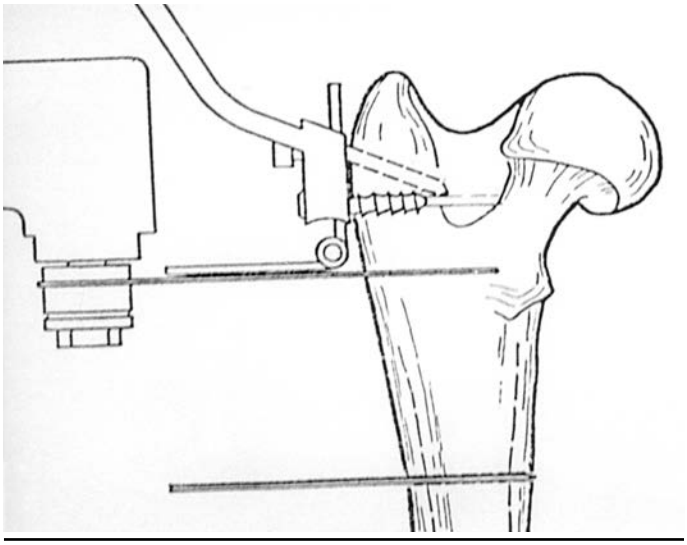


Figure 60-96. Posterior view of the proximal femur with the intertrochanteric saw guide in place. The two hooks of the saw guide fit into the proximal two holes that were drilled in the greater trochanter for the hooks of the intertrochanteric plate.

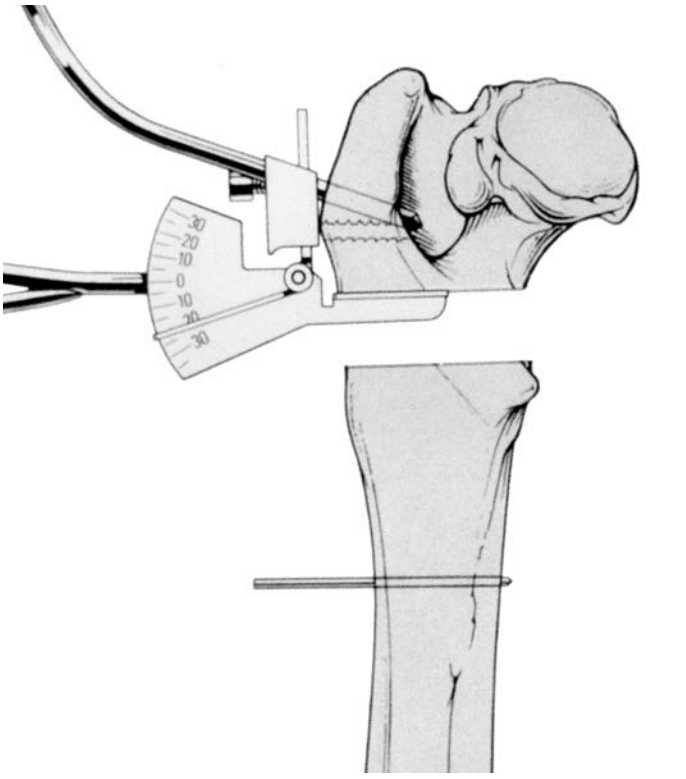


Figure 60-97. Posterior view of the proximal femur with the first osteotomy made (See Figure 60-88) and the saw guide in the greater trochanter and the goniometer in the first osteotomy.

The femur is now reduced again, making sure there is no gap at the osteotomy site. The hole just distal to the two hooks in the proximal segment is now redrilled with a 2.5 mm drill bit. This hole is tapped with a 3.5 mm cortical tap. The plate is loosened approximately 4 mm and two washers (No. 219.99, Synthes, Paoli, PA) are placed between the hook plate and the bone, in line with the hole in the plate and bone (Figure 60-99). The screw is then placed and tightened. The washers placed under the plate will medialize the proximal femur 3 mm compared to the shaft of the femur, and this pushes the head of the femur deeper into the acetabulum. If the placement of these washers interferes with reduction at the osteotomy site, the screw and the plate should be removed. The plate is recontoured as needed to conform to the perfectly reduced femur. The plate is then reapplied. This step is repeated as necessary until the reduction at the osteotomy site is perfect, with no gap between the proximal and distal femur.

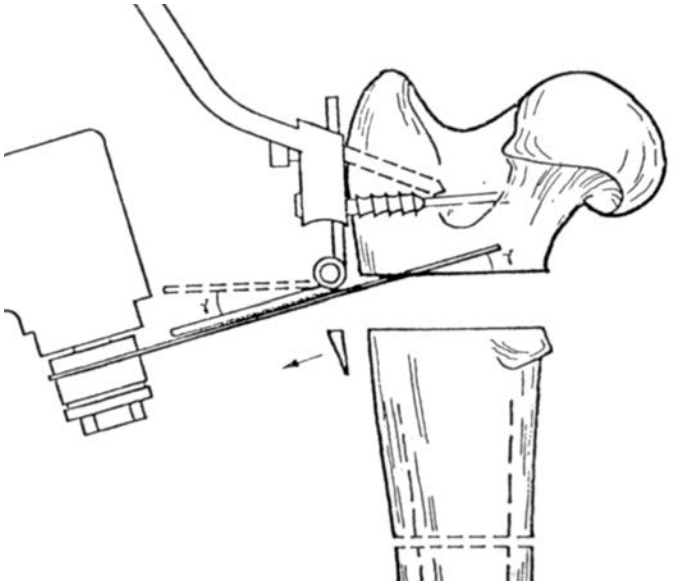


Figure 60-98. Posterior view of the proximal femur with the saw guide in the greater trochanter. The second osteotomy is performed with the help of the blade of the saw guide in the new position (compared to Figure 60-96) to remove the calculated wedge of bone.



Figure 60-99. Ventrodorsal radiograph of the pelvis and femurs of a 7-month-old Golden Retriever immediately following a three-plane intertrochanteric osteotomy of the right hip. Note that the femoral head, neck, and trochanteric region are medialized compared to the shaft. This is accomplished by placing two washers between the plate and the bone at the most proximal screw.

With the femur reduced at the osteotomy site, the shaft of the femur is rotated outwardly so that the stifle rotates outward until the 2 mm hole that was drilled in the distal lateral cortex is just visible at the caudal edge of the plate. This degree of rotation will cause a 15 degree reduction in anteversion of the femoral head toward normoversion (Figures 60-100 and 60-101). The hole just distal to the osteotomy site is now drilled with a 2.5 mm drill bit through a compression (loaded) drill guide, tapped, and a 3.5 mm cortical bone screw is placed. After each screw placement, the reduction must be checked at the osteotomy site and at the rotation guide hole. The remainder of the holes in the plate are now filled with 3.5 mm screws placed in a neutral position.

The vastus lateralis muscle is pulled over the plate and sutured to its incised origin. The superficial gluteal muscle is pulled over the greater trochanter and proximal plate and sutured to the lateral fascia of the vastus lateralis muscle. The biceps femoris muscle is sutured to the fascial lata. The subcutaneous tissue and skin are sutured closed.

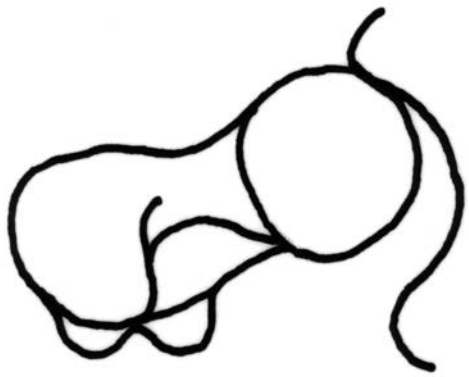


Figure 60-100. Axial view of the femur and acetabulum. This femur has 50 degrees of anteversion.

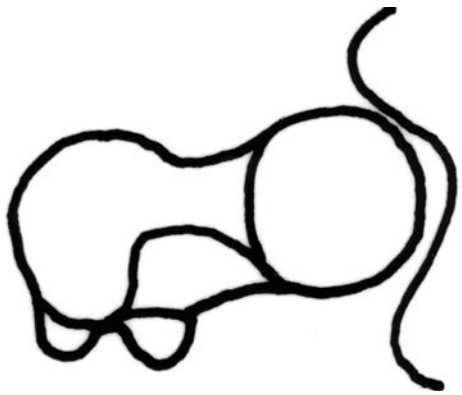


Figure 60-101. Axial view of the femur and acetabulum. This femur has been derotated (retroversion correction) to 15 degrees of anteversion.

Postoperative Care

After surgery, a wound bandage is applied and left in place until suture removal 12 to 14 days later. If the dog removes the bandage, it usually is not replaced. Candidates for an intertrochanteric osteotomy are usually young, healthy animals with no preoperative traumatized tissue; therefore, prophylactic antibiotics are not needed. The dogs are allowed to use the leg immediately. When the procedure is properly performed, there is little concern about fixation loosening before clinical union. Dogs usually are dismissed from the hospital 1 or 2 days after surgery to be confined to the house or kennel and walked restrained by a leash. Running and jumping are not permitted for 4 weeks, and no yard freedom is allowed.

The second side is reconstructed 4 to 6 weeks later, if necessary. Postoperative care for the second side is the same as the first. Owners are requested to give a progress report 6 weeks later. The plates are not removed unless a problem, such as loose screw(s), cause clinical signs of pain or lameness.

Results

There have been two retrospective studies on this procedure.[11,14] The first study[11] was performed on 210 dogs that underwent intertrochanteric osteotomies. Clinical evaluation from 1 to 7 years after surgery on 183 of the dogs revealed an 89.6% excellent or good return to motor activity. The results relating to motor activity at a minimum of 1 year were rated as follows: excellent, walking and running normally without pain for long distances; good, was defined as walking or running normally without pain but with a slight limp appearing after exercise. Postoperative physical examinations on 90 dogs from 6 months to 1 year after surgery demonstrated an increase in circumferential thigh muscle mass over the operated leg in the dogs that showed good to excellent results.[11]

Dogs operated on before the appearance of radiographic signs of degenerative joint disease had better results than those operated on after degenerative joint disease was established.

Only 12.1% of the dogs with severe osteoarthritis had excellent results, whereas a 51.4% of the dogs without preoperative osteoarthritis changes and 45.8% of those rated as having moderate osteoarthritis were considered to have excellent results.

The second study involved a clinical evaluation after 7 years of using this surgery on dogs with early stage CHD.[14] The retrospective study was performed on 37 dogs that had 43 hips reconstructed. The clinical evaluation consisted of a questionnaire, and/or an orthopedic examination; and/or a report from the owner(s) via telephone. At least one form of evaluation was conducted for 42 of 43 hips (98%). Before surgery, on 11 of 37 hips (30%) had been evaluated as functionally good or excellent. In this study, excellent function was defined as normal function. Good function was defined as normal weight bearing with joint stiffness after strenuous exercise or long rest. On the basis of the owner's telephone report, 19 of 28 hips (68%) were functionally good or excellent at postoperative month 11 (on average). On the basis of the questionnaire data, 17 of 24 hips (70%) were functionally good or excellent at postoperative year 1. On the basis of the orthopedic examination findings, 27 of 33 hips (84%) were functionally good or excellent at postoperative month 15 (on average). Of 36 owners, 33 (91.6%) reported they would have the procedure performed again if the circumstances were the same.

Results of statistical analysis indicated that the procedure was helpful for up to 3 years after surgery.[14] This observation was true regardless of who examined the dog after surgery, surgeon

or owner. Because there were not enough data after postoperative year 3, no statement could be made concerning whether the benefit of surgery would still be detected after that point.

After performing the intertrochanteric osteotomy for the treatment of early-stage hip dysplasia for twenty-five years, we have found a 92% success rate for the surgery, if performed on dogs without moderate or severe degenerative joint disease, i.e., with no or only mild degenerative joint disease and subluxation. The remaining 8% of the dogs have advanced their osteoarthritis from mild to severe, and have been treated with a total hip replacement or with pain medication if the owner did not wish the replacement.

Discussion

Because the potential for remodeling is greatest early in life, corrective orthopedic procedures such as the three-plane intertrochanteric osteotomy ideally should be performed while the bones and joints have the greatest remodeling potential.[1,14,15,16] Therefore, as soon as clinical signs of CHD and subluxation of the coxofemoral joint are detected, surgery should be recommended.

In early stage CHD, the femoral head is movable in and out of the acetabulum; therefore, subluxation may not always be demonstrable on each radiographic exam. This may be due in part to the inward rotation that the holder puts on the limbs; this will torque the joint capsule and may move the head into the acetabulum. Others feel this same torque is developed by overextending the hind limbs to obtain the standard V-D view of the pelvis. It also may be influenced by muscle tension; therefore, some have recommended all radiographic exams of the canine pelvis be performed under anesthesia or at least heavy tranquilization.

Because there is a direct correlation between increasing age and severity of osteoarthrosis[11] and because there is an inverse relationship between severity of osteoarthrosis and improvement after surgery, intertrochanteric osteotomy is best performed in young dogs prior to the development of osteoarthrosis. Once degenerative changes occur, the prognosis for return to normal function diminishes.

In early stage CHD, relief of pain owing to the three-plane intertrochanteric osteotomy may be explained by biomechanical principles involving 1) improved congruity of the head and acetabulum with wider surfaces of contact, 2) a medial shifting of the line of weight bearing, and 3) relief of pressure by release of muscle contracture.[17]

The results of the two studies are remarkably similar. In the first study, 89.6% of the dogs were evaluated as excellent or good in return to motor activity. In the second study, 91.6% of the owners indicated they were pleased with the results and would have the procedure performed again if the circumstances were the same.

The intertrochanteric osteotomy is a conservative procedure because the option of a conversion to a total hip replacement in unsuccessful situations remains.[17] In fact, when this procedure was adopted 25 years ago, it was performed with the goal eliminating pain and improving function in young dogs until they were old enough for total hip replacement. Of the first 240 hips in which an intertrochanteric osteotomy was performed, 9 have subsequently required a total hip replacement to relieve the pain of osteoarthritis secondary to CHD.

Intertrochanteric osteotomy provides relief of pain in humans for an average 5 to 6 years.[18] Although each dog varied as to duration of benefit, most remained comfortable and had normal function for their entire lives.

In conclusion, the goal of the three-plane intertrochanteric osteotomy is to decrease stress in the coxofemoral joint, thereby relieving pain associated with early stage CHD. Although radiographically detectable degenerative changes within the coxofemoral joint continue, the degenerative changes proceed at a slower pace than if the surgery was not performed and the clinical signs of hip pain do not manifest for the greater majority of the dogs having this procedure (Figure 60-102).



Figure 60-102. Axial view of the femur and acetabulum. This femur has been derotated (retroversion correction) to 15 degrees of anteversion.

References

1. Brinker WO: Corrective osteotomy procedures for treatment of canine hip dysplasia. Vet Clin North Am 1:467, 1971.

2. Archibold J, Ballatyne JH: A practical prosthesis for the canine and feline femoral head. North Am Vet 34:496, 1953.

3. Prieur WD: Coxarthrosis in the dog. Part 1: Normal and abnormal biomechanics of the hip joint. Vet Surg 9:145, 1980.

4. Pauwels F: Uber eine Kausale Behandlung der coxa valgu luxans. Z Orthop 79:305-315, 1950.

5. Hey Groves EW: Surgical treatment of osteoarthritis of the hip. Br Med J 1:3, 1933.

6. Kirmission E: De l'osteotomie sous trochanterienne applique a certains cas de luxation congenitale de la hauche: Rev Orthop 5:137, 1984.

7. Knodt H: Pressure-reducing effects of hip osteotomies. Clin Orthop 77:105, 1971.

8. Prieur WD: Intertrochanteric osteotomy in the dog: theoretical consideration and operative technique. J Small Anim Pract 28:3, 1987.

9. Prieur WD, Scartazzini R: Die Grundlagen und Ergebrisse der intertrochanteren variationsosteotome bei huftdysplasia. Kleintur-Prax 25:393, 1980.

10. Dueland DJ: Femoral torsion and its possible relationship to canine hip dysplasia. Vet Surg 9:48, 1980.

11. Walker T, Prieur WD: Intertrochanteric femoral osteotomy: Semin Vet Med Surg (Small Animal) 2:117, 1987.

12. Belkoff SM, Padgett G, Soutas-Little RW: Development of a device to measure canine coxofemoral laxity. Vet Comp Orthop Trauma 1:31-36, 1989.

13. Montavon PM, Hohn RB, Olmstead ML, et al: Inclination and anteversion angles of the femoral head and neck in the dog. Vet Surg 14:277, 1985.

14. Braden TD, Prieur WD, Kaneene JB: Clinical evaluation of intertrochanteric osteotomy for treatment of dogs with early-stage hip dysplasia: 37 cases (1980-1987). J Am Vet Med Assoc 196:337, 1990.

15. Salter RB: Innominate osteotomy in the treatment of a congenital dislocation and subluxation of the hip. J Bone Joint Surg (Br) 43:518, 1961.

16. Salter RB: Role of innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip in the older child. J Bone Joint Surg (Am) 48:1413, 1966.

17. Goldie MD, Dumbleton JH: Intertrochanteric osteotomy of the femur. Clinical Biomechanics: A case history approach. New York, Churchill Livingstone, 1981, p 72.

18. Reigstad A, Gronmark T: Osteoarthritis of the hip treated by intertrochanteric osteotomy. J Bone Joint Surg (Am) 66: 1, 1984.

DARthroplasty: Another Treatment for Hip Dysplasia

Dean R. Gahring and Theresa Devine Slocum

Introduction

In hip dysplasia, laxity and incongruity of the hip joint lead to progressive degenerative changes, inflammatory responses, and pain. The consequences of these responses are gait abnormality, lameness, and limb weakness.

Treatment for hip dysplasia has historically included four options: 1) long-term medications, 2) femoral head and neck excision arthroplasty (FHE), 3) triple pelvic osteotomy (TPO), and 4) total hip replacement (THR). Each of these approaches has its benefits and drawbacks. The ultimate objective is to return the patient to the most comfortable and functional status possible. FHE will often leave the patient with gait abnormalities and limb weakness (especially larger patients weighing over 25 pounds). Results with TPO are best when done in young patients with minimal degenerative changes, reasonably good joint congruity, and minimal to no acetabular filling. Cases with more advanced degenerative changes, acetabular filling, and laxity usually continue to show progressive degenerative changes. Consequently, we choose to perform TPO's on patients with the restricted criteria of minimal degenerative changes and incongruity of the hip joints, no appreciable acetabular filling, and the presenting complaint is essentially pain and lameness with joint laxity. THR is not recommended in young patients less than a year old. It is primarily recommended as a salvage procedure for hips with extensive loss of cartilage. Consequently, a "gap" in surgical treatment options has developed between the candidate for TPO and the candidate for THR.

A fifth option is DARthroplasty.[1] This procedure was designed to create additional dorsal bone support of the femoral head and prevent the pain associated with joint capsule tears from the dorsal acetabular rim by creating a bony extension of the dorsal acetabular rim (DAR) of the acetabulum. The new DAR shelf should dramatically reduce dorsal subluxation and often significantly reduces the tendency for lateral translation. The additional dorsal bone support should provide the patient more joint stability and thus allow the patient to gain more strength in the limb.

The Surgical Procedure

The DARthroplasty technique is a two-part process which involves harvesting cortical and cancellous bone graft from the wing of the ilium and applying that bone graft to the dorsal acetabulum. One, two, or even three corticocancellous strips can be used, which are tied together and then anchored to the dorsal hip joint capsule with strong absorbable sutures that are passed through drill holes in the bone strips, and the strips are placed next to or overlapping the original dorsal acetabular rim. Holes are drilled into the original DAR and the new shelf is overlaid with cancellous bone graft.

The dog is placed in lateral recumbency to prepare for surgery. The hair is shaved over the affected hip dorsally to the midline of the spine, to 5 cm cranial to the wing of the ilium, ventrally 10cm distal to the greater trochanter, and caudally to the level of the tuber ischium. Appropriate sterile surgical preparation and draping of the surgical site is done. A 5 cm incision is made half way between the tuber sacrale and the tuber coxae from the cranial limit of the ilium toward the greater trochanter. A standard gluteal muscle roll-up approach is used. A Gelpi retractor is placed just under the gluteal fascia.

A Langenbach elevator is used to elevate the middle and deep gluteal muscles by placing it on the wing of the ilium at the sartorius muscle and sliding along the ilium toward the greater trochanter. Elevate only to the level of the deep gluteal nerve. Three to five corticocancellous bone strips are harvested from the lateral aspect of the wing of the ilium using a bone gouge to obtain appropriate sized graft curls. Cut parallel to the long axis of the ilium with the bone gouge, being careful not to perforate the medial cortex of the ilium. Note the order of the corticocancellous strips for easy assembly later. Cancellous bone graft is then harvested with a curette from the same site. Closure of this incision is routine.

A dorsal approach is made to the acetabular rim, either via a second incision or an extension of the first one. The skin incision is made parallel to the cranial margin of the biceps femoris muscle, from the level of the third trochanter to the level of the sacrotuberous ligament. The fascia along the cranial margin of the biceps femoris is incised and the biceps femoris is retracted caudally. The sacrotuberous ligament is isolated from the sciatic nerve and caudal gluteal vessels. In cases where two or three

strips are used, the sacrotuberous ligament may need to be transected to minimize the risk of sciatic nerve impingement. The superficial and middle gluteal muscles are retracted cranially. The joint capsule can be palpated between the deep gluteal muscle and the cranial margin of the gemellis muscles. A small vessel can usually be identified at this landmark between these muscles. Handheld retractors are used to gently retract the gemellis caudally and the deep gluteal muscle cranially and these muscles are freed from the joint capsule cranially, caudally and dorsally to the bone of the acetabulum with a periosteal elevator. *Always be aware of the sciatic nerve and be very careful not to be too aggressive in retracting the gemellis.* Pushing the femoral head distally, withdraw any excessive joint fluid. We also inject bupivacaine into the joint to provide postoperative pain relief.

A protected 1/8 inch (3.2 mm) Steinman pin or a drill bit is used to drill 6-10 holes in the lateral cortex around the acetabulum (Figure 60-103), being careful to avoid perforation of the acetabulum. The dorsal apex of the femoral head is palpated through the joint capsule. The leg can be manipulated to help identify the point of maximal subluxation of the femoral head. The number of corticocancellous strips anchored to the joint capsule depends upon how many are needed to cover the joint capsule from the high point of femoral head luxation to the edge of or to slightly overlap the acetabular rim. If 2 or 3 strips are needed, they are sutured together with absorbable sutures at the ends and in the middle to create an appropriate bone "cap" over the femoral head. The corticocancellous bone strips are contoured to create an appropriate bone cap using Kelly forceps to put a curve in the strips. The corticocancellous bone cap is laid over the joint capsule, *cortical side to the joint capsule and cancellous side toward the dorsal rim drill holes,* placed beneath the external rotators and the deep gluteal muscles, then anchored to the joint capsule with 1 or 2 heavy absorbable sutures, passed through the joint capsule from medial to lateral, then through drill holes in the middle of the most lateral bone strip and tied snugly in place. Place a strip of graft on its edge dorsally to prevent medial migration of graft. Cancellous bone graft is placed over the drill holes and between the strips. The cancellous bone graft should be in contact with the drill holes so blood supply and the conditions for healing directly between the graft and acetabulum are established. Any additional corticocancellous strips are packed over the new graft to provide a cortical shell.

The deep gluteal muscle is pulled over the new graft and sutured to the internal obturator tendon and muscle. This helps stabilize the graft and minimizes its tendency for movement and/or migration. The superficial gluteal muscle is reattached to its incised fascia, the biceps femoris muscle is reapposed to the gluteal fascia, and the remainder of the closure is routine. Post-operatively, 3 radiographic views are taken: hip-extended, lateral, and DAR views.

Results

We have been performing this procedure for several years. Our criteria for performing a DARthroplasty are simple. As long as there is joint cartilage present in cases of hip dysplasia, then a DARthroplasty can be done (Figures 60-104 and 60-105). If joint cartilage is completely worn away and the joint palpates with notable crepitus, then that hip is *not* a candidate for DARthroplasty. We have performed DARthroplasties on cases where one hip had a TPO done and the other hip was a DARthroplasty. Thigh circumference is usually slightly greater on the TPO side, which would be anticipated since TPO requires a hip with no acetabular filling, whereas the indications for DARthroplasty include both acetabular filling and distortion of the DAR. What was surprising was that, in most cases, the DARthroplasty hip was deemed as strong and as functional as the TPO hip by the owners, even

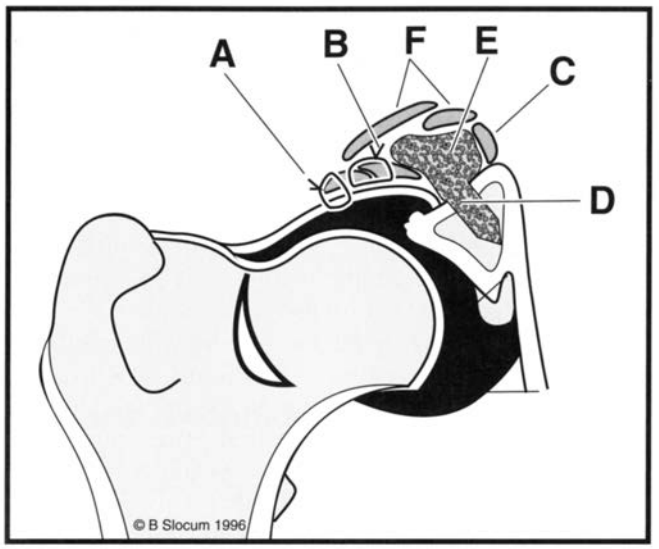


Figure 60-103. The DARthroplasty is formed from a bone graft. A corticocancellous strip is contoured to the joint capsule at the dorsal apex of the femoral head, and it is held in place by one or two capsular sutures *(A)*. A second strip may be contoured to the joint capsule and sutured to the first *(B)*. Barrier strips are placed dorsally, cranially, and caudally *(C)*. The lateral cortex of the pelvis is perforated with multiple holes *(D)*, which are packed with cancellous bone *(E)* and are covered with additional corticocancellous strips *(F)*.

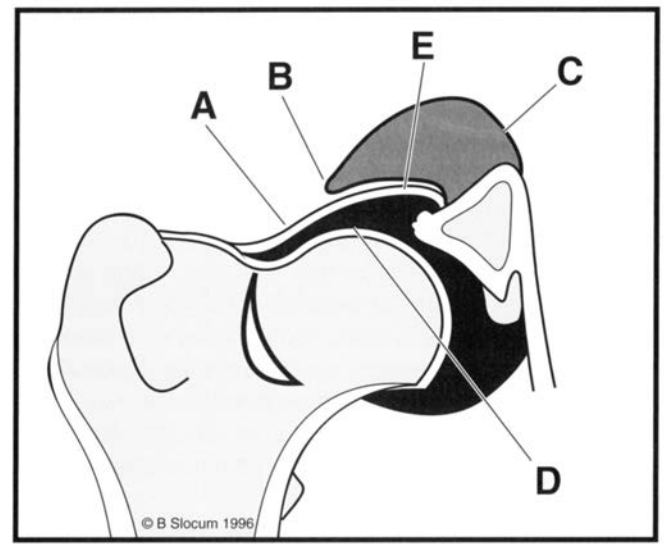


Figure 60-104. Four months after bone grafting, the joint capsule *(A)* is covered by the new dorsal acetabular rim (DAR) *(B)*. The DARthroplasty *(C)* is maturing into a solid bone continuous with the pelvis. The dorsal apex of the femoral head *(D)* lies beneath the new DAR *(B)*. Usually, one sees a concavity for the joint capsule *(E)*, and the femoral head does not subluxate.

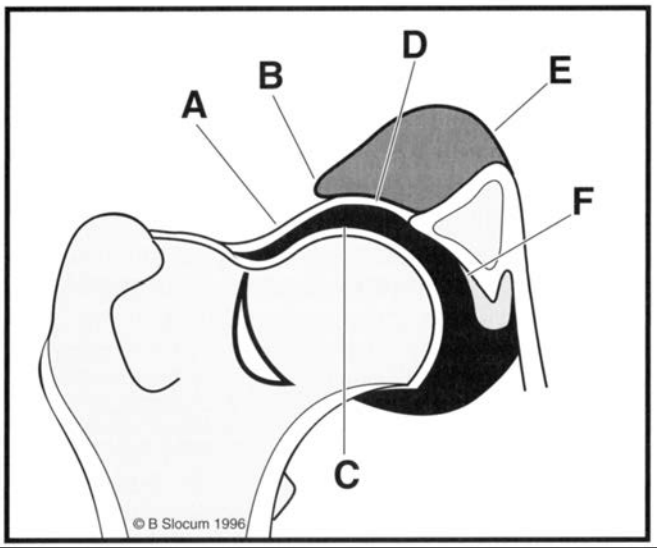


Figure 60-105. One year after bone grafting, the joint capsule *(A)* is covered by the new dorsal acetabular rim (DAR) *(B)*. The dorsal apex of the femoral head *(C)* lies beneath the new DAR *(B)*. The concavity for the head beneath the DARthroplasty *(D)* is often continuous with the old DAR. The DARthroplasty *(E)* is mature bone that is continuous with the pelvis. Acetabular osteophytes *(F)* continue slow and progressive filling of the acetabulum until the femoral head is stable in the "new acetabulum".

though the DARthroplasty was performed on the "poorer" hip. We have also performed DARthroplasties on hips that were *markedly* arthritic, but had intact cartilage, that also did very well clinically.

Weight bearing is surprisingly rapid after surgery and most patients are sent home with their owners the day after surgery. Exercise and activity are restricted to leash walking for the first month after surgery, and then allowed to increase once the graft is radiographically fused to the pelvis (usually 8 to 16 weeks after surgery). Pain free, normal activity can be noted as early as 2 weeks after surgery and the hip joint palpates stable, with no evidence of subluxation noted. All patients experience a decrease in abduction due to the extended DAR. By 4 months post-operatively, most patients are running, jumping, and playing normally, without pain. Radiographs 2 to 4 months after surgery may show that the femoral head has migrated medially, back into the acetabulum.

Long-term follow-ups have also been rewarding. We have found that patients continue to be active, athletic, and pain free and a very high percentage do not require any anti-inflammatory medications. As the shelf arthroplasty matures, it provides a stable bony support for the femoral head and the joint capsule becomes an extension of the joint cartilage weightbearing surface. The joint capsule loses its collagenous appearance, which is presumed to undergo metaplasia to a fibrocartilage. Because pain free activity results, limb strength and muscle mass increase. As noted, abduction remains minimally to moderately limited, but all other ranges of motion usually remain at or near normal.

Complications with the procedure primarily involve temporary sciatic dysfunction. The sciatic nerve may be injured during retraction or drilling and may, in cases requiring very large grafts, become trapped between the bone graft and the sacrotuberous ligament. This can be prevented by severing the sacrotuberous ligament at the time of surgery. These complications should be minimized as the surgeon and assistants gain experience. Infections are almost nonexistent. Although the criteria are very broad for performing DARthroplasties, one limitation, besides lack of cartilage, may be patients with completely luxated hips.

Conclusion

DARthroplasty has been a very effective procedure that fills the gap between the cases with narrow indication criteria for TPO and the end-stage salvage criteria for total hip replacement. DARthroplasty was originally developed by Dr. Barclay Slocum with the idea that additional bone could be produced that would enhance future THR. Although previous DARthroplasty does not preclude THR, none of our patients that have undergone DARthroplasty have developed signs that would even suggest *considering* total hip replacement. As stated before, we have been pleasantly surprised at how small a percentage of cases that have undergone DARthroplasty even require anti-inflammatory medications to remain comfortable.

Suggested Readings

Slocum, B. & Slocum, T.D. "DARthroplasty". In: Bojrab, M.J., ed. *Current Techniques in Small Animal Surgery,* 4th Ed. Baltimore: Williams & Wilkins 1998: 1168-1170.

Total Hip Arthroplasty

Marvin L. Olmstead

Surgical Description: Total Hip Arthroplasty

Total hip arthroplasty is also known as total hip replacement. It is the most effective way to provide a canine patient with a mechanically sound, pain free, ball and socket hip joint, once osteoarthritis is present. Both cemented and cementless prosthesis have been successfully used to treat non-infectious, non-neoplastic disabling conditions of the canine coxo-femoral joint. The cementless hip is commercially available. Most dogs can be successfully treated with either a cemented or a cementless total hip arthroplasty. However, some small boned dogs can have a cemented prosthesis implanted but not a cementless one. Also large boned dogs with a straight or "stove pipe" femur are not good candidates for implantation of a cementless stem, as the risk of subsidence is high. In the event of a failure of a cementless prosthesis, a cemented prosthesis is often used to successfully preserve the total hip arthroplasty. The cementless hip prosthesis is also less forgiving during implantation than the cemented prosthesis. For these reasons, a surgeon should be very comfortable with the technique for cemented hip arthroplasty before learning the technique for implanting a cementless prosthesis. Thus, this chapter will concentrate primarily on cemented techniques.

The most commonly implanted prosthesis is a cemented modular prosthesis made by BioMedtrix Inc. (Boonton, NJ), which also manufacture cementless implants that use the same head as

the cemented prosthesis. This allows the surgeon to implant a cemented component in one portion of the hip (either the acetabulum or the femur) and a cementless component in the hip's other portion. This creates a hybrid total hip arthroplasty.

Dogs with clinical signs related to hip dysplasia or other disabling hip conditions are candidates for surgery once their physis have closed at 9 to 10 months of age and they have a skeletal size that will accommodate the available prosthesis, which generally starts at 14 kg. They are candidates if they are not responsive to medical management or if medical management is no longer relieving clinical signs. When the dog's function is used as an indicator of the need for total hip arthroplasty and not just radiographic evaluation, 80% of dogs will only need one total hip arthroplasty.

Special care must be taken to insure that the surgery is done under strict aseptic conditions. The dog's hind limb is clipped the day prior to surgery. The skin is evaluated for bacterial dermatitis, which, if present, will delay the procedure until the condition is resolved. If the skin is dirty, the dog is bathed. Intravenous antibiotics are administered immediately prior to surgery. Draping of the patient with sterile paper and self-adhering plastic drapes provides a barrier at the surgical site that is impermeable to bacteria. Special instrumentation has been developed to facilitate the implantation of the modular prosthesis (BioMedtrix Inc., Boonton, NJ). Radiographic templates are used prior to surgery to estimate the size of acetabular cup and femoral stem that will be implanted.

The coxo-femoral joint is exposed via a cranial lateral approach. The skin incision starts dorsal and caudal to the greater trochanter and curves along the front edge of the femur. The tensor fascia lata is reflected cranially. Retracting the middle and superficial muscles dorsally with an Army-Navy retractor exposes the deep gluteal muscle. The deep gluteal muscle is incised at its origin and split into 2 segments. The joint capsule is incised along with the vastus medialis and lateralis muscles (Figure 60-106).

At various points in the surgical procedure the femur will be rotated in position. All references in the following text to the lateral, medial, cranial or caudal surface of the femur refer to that surface when the femur is in normal position. To properly perform the femoral osteotomy, the femur is externally rotated so the patella is oriented 90% lateral to its normal position. The medial edge of the greater trochanter is identified. The femoral osteotomy originates at this point. A template of the femoral prosthesis is aligned parallel to the long axis of the femur and the axis of the femoral neck (Figure 60-107). The template acts as a guide for performing the osteotomy. The diseased femoral head is removed. Instrumentation developed specifically for the modular prosthesis allows power reaming of the femur and acetabulum. Although the reaming can be done by hand it is easier and more accurately done with power.

The acetabular bed is prepared first using the acetabular reamer (Figure 60-108). No flush is used during the acetabular reaming so that the cancellous bone shavings can be collected and saved for possible use later. The shavings can be packed into areas of

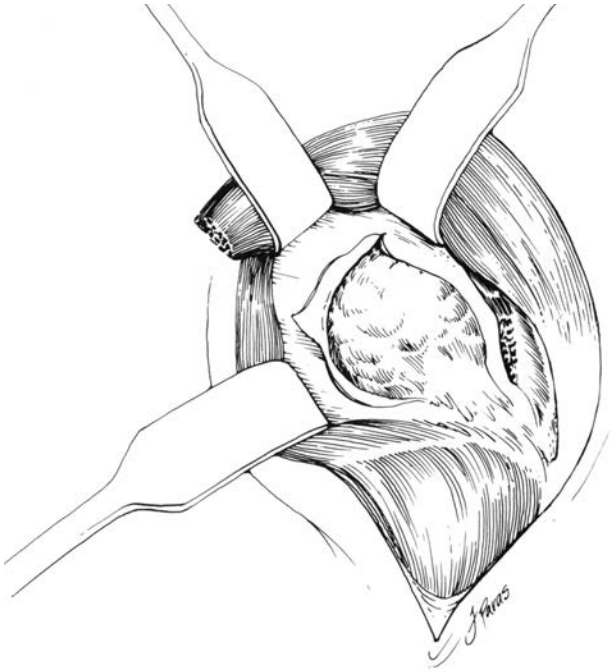


Figure 60-106. The hip joint is exposed through a cranial lateral approach. The deep gluteal muscle is partially incised at its origin, divided longitudinally and retracted cranially. The joint capsule is incised parallel with the axis of the femoral neck and along its insertion on the femur. (Used with permission from BioMedtrix Inc.)

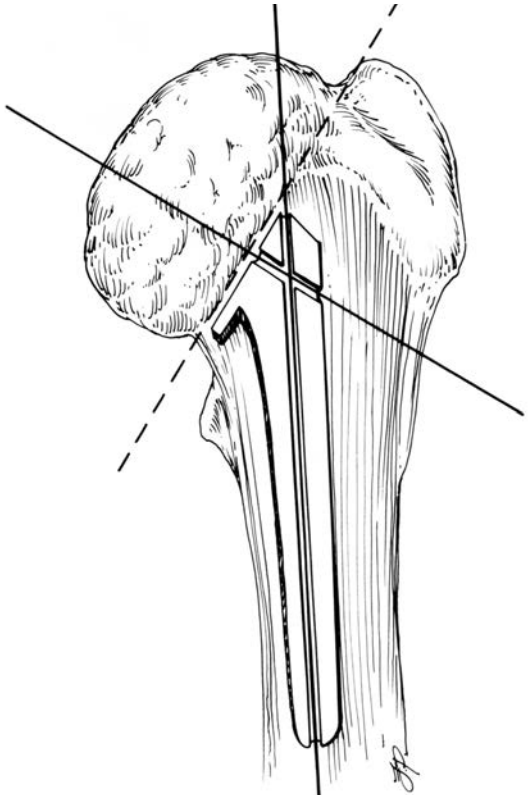


Figure 60-107. A template is used to insure that the osteotomy of the femur is properly positioned. The line running the long axis of the template should parallel the long axis of the femur and the short line on the template is aligned parallel with the axis of the femoral neck. The medial edge of the trochanter is the landmark for the origin of osteotomy. The cut should parallel the collar of the prosthesis. (Used with permission from BioMedtrix Inc.)

deficit in the acetabulum or along fissures in the femoral neck, should either of these be present. The acetabulum is reamed until the medial cortical wall is exposed. Remnants of ligament of the head of the femur may need to be removed to fully expose the medial wall. Three or more holes are drilled around the rim of the acetabulum using a drill bit from the modular system and the tissue guard, which protects soft tissues (Figure 60-109). The holes are connected with a curette. This undercut provides anchor sites for the bone cement or polymethyl methacrylate (PMMA).

The femoral shaft is rotated laterally 90%. A wide tipped Hohmann retractor is used to elevate its proximal end lateral to the tissues that lie dorsal to it. The femoral shaft is first drilled with a drill bit that matches the size of the femoral stem that has been selected for insertion (Figure 60-110). It may be necessary to start drilling with the bit oriented perpendicular to the osteotomy line. As soon as the proximal cancellous bone is penetrated the drill bit should be reoriented so it is parallel with the long axis of the femur. The fluted reamer, that is the same number as the drill bit used, widens the hole in the femoral shaft (Figure 60-111). The final preparation of the femoral shaft is done by hand with a finishing file and sometimes a broach (Figure 60-112). It is important to ream the femoral shaft along the medial edge of the trochanter to insure complete access to the femoral canal. In some cases the wall of the trochanteric fossa must be removed with a rongeur after the drill bit has created an opening to insure that the femoral canal is adequately opened. Reaming along the endosteal surface of the femoral neck accommodates for the curved portion of the femoral prosthesis. A trial prosthesis the same size as the one to be implanted is inserted to ensure the prosthesis will fit properly and that there will be an adequate cement mantel around the prosthesis. The trial prosthesis should move freely in all directions after it is inserted. This motion indicates that there is adequate room for cement around the stem.

Thoroughly cleaning the acetabular bed and the femoral shaft is necessary before the cement is injected. The PMMA should be mixed according to the manufacture's specifications. Only PMMA with a liquid phase of 3 to 7 minutes can be injected. PMMA is injected through a catheter tip syringe into the acetabular bed first. Specific landmarks and the acetabular cup positioner are used to achieve proper position of the acetabular cup (Figure 60-113). All excess PMMA is removed. A second batch of PMMA is mixed for the femoral shaft injection. The shaft is cleared of blood and debris and PMMA is injected into the femoral canal

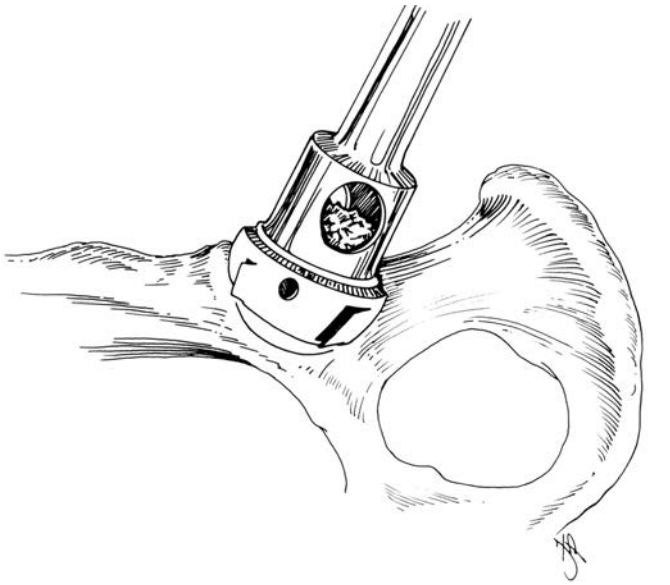


Figure 60-108. An acetabular reamer is used to remove degenerative bone and cartilage to the level of the medial cortical wall of the acetabulum. (Used with permission from BioMedtrix Inc.)

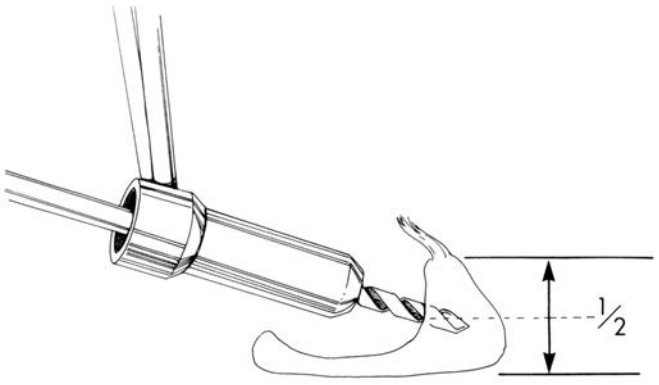


Figure 60-109. Multiple holes in the acetabular bed are made into a trough by connecting the holes. The trough provides anchor points for the polymethyl methacrylate (PMMA) or "bone cement". A tissue guard is used with the drill bit. The holes should be located in the cancellous bone 1/2 between the medial cortical wall and the lateral most edge of the acetabular rim. (Used with permission from BioMedtrix Inc.)

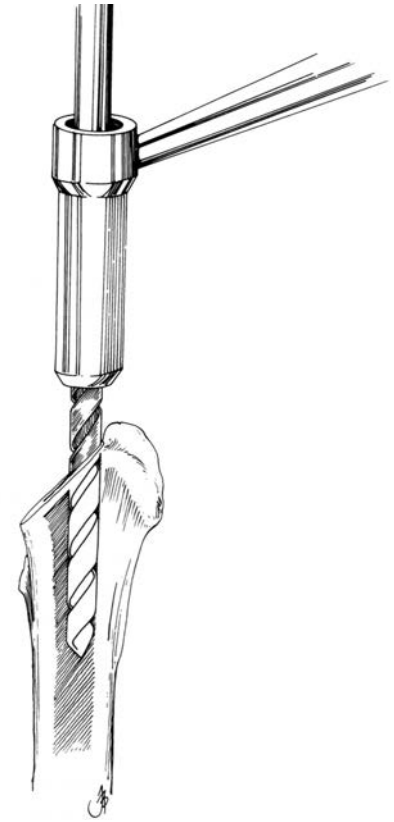


Figure 60-110. The opening into the femoral canal is started with a drill bit the same size as the femoral stem selected for implantation. (Used with permission from BioMedtrix Inc.)

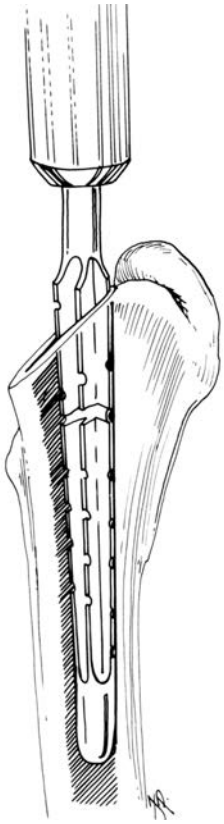


Figure 60-111. The femoral canal is opened further with a power driven fluted reamer. (Used with permission from BioMedtrix Inc.)

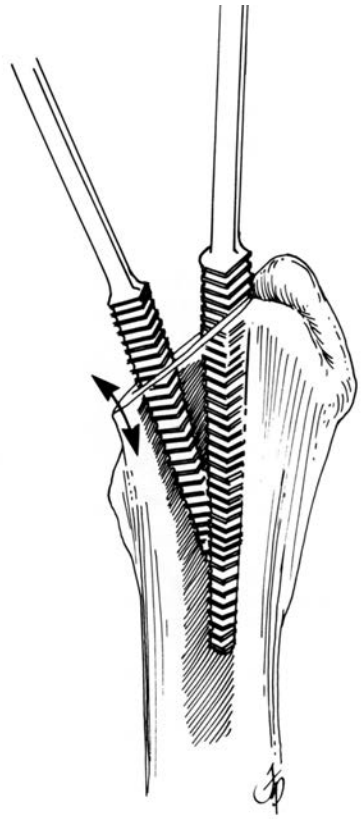


Figure 60-112. After power reamers are used to make holes in the femoral shaft, a finishing file and sometimes a broach (not shown) are used to make the hole in the shaft of an adequate size to accept the femoral stem. (Used with permission from BioMedtrix Inc.)

using a 60 cc catheter tip syringe. The cobalt chrome femoral stem is aligned with the long axis of the femur and inserted down the shaft until the prosthesis collar rest is flush with the osteotomy line. The stem is held solidly in place with the stem impactor. Excess PMMA is removed while the cement in the femoral canal hardens.

A trial plastic head is placed on the femoral stem so that neck length can be assessed (Figure 60-114). The prosthesis with the trial head is reduced and the tightness of fit tested. Once the proper neck length has been determined the cobalt chrome head is placed on the stem and tapped securely into position. The head is reduced into the acetabular cup. Cultures are taken and the joint capsule is tightly closed. The surgical site is closed in layers.

Lateral and ventro-dorsal pelvic radiographs are taken immediately post operatively so the position of the acetabular and femoral components and the fill of the PMMA can be assessed. Antibiotic therapy is continued until the culture results are known. If the results are negative, which is almost always the case, antibiotics are discontinued. On the rare occasion when results are positive, antibiotics based on sensitivity patterns should be continued for at least 4 weeks. The dogs are maintained on limited activity for 2 months following the surgery. No activity more strenuous than a walk is allowed and the dog

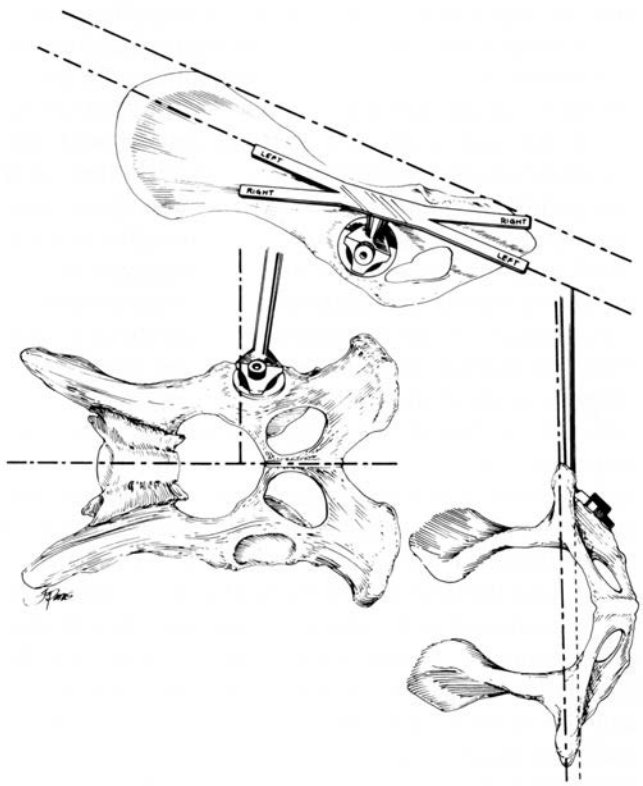


Figure 60-113. To position the acetabular cup correctly the positioner must be aligned in 3 planes relative to specific anatomic landmarks. In the top drawing the bar of the positioner is aligned parallel with the top of the ilium and the ischium. In middle left drawing the bar of the positioner is tilted caudally, positioning the cup in retroversion. In the bottom right drawing the shaft of the positioner is aligned parallel with the tuber ischia. (Used with permission from BioMedtrix Inc.)

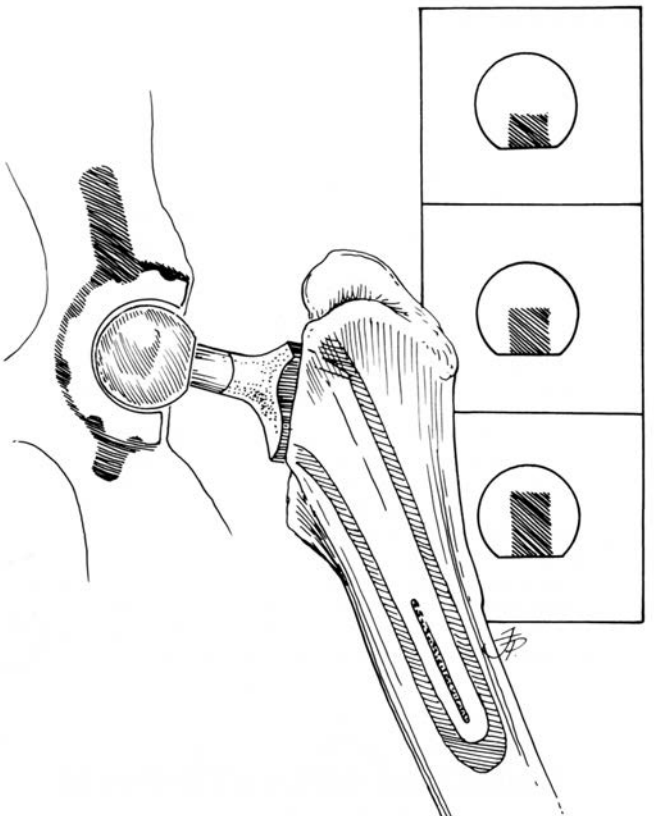


Figure 60-114. Cross-sectional cuts of the femoral head show the 3 different depths of holes that are found in the femoral head. Placing a head with the shallow hole on the stem will result in long femoral neck, while placing a head with the deep hole on the stem will give a short femoral neck. Neck length is determined with trial heads after the femoral stem and acetabular cup are cemented. (Used with permission from BioMedtrix Inc.)

is to be outside only on a leash. After that period the dog can gradually return to normal activity.

Discussion

The modular system has improved the technique of total hip arthroplasty in the dog over the previously used fixed head prosthesis. It gives the surgeon state of the art instrumentation, a wider choice of neck lengths and increased implant sizes. Thus it is possible for the veterinary surgeon to offer better care for the dog with disabling hip conditions. Smaller dogs can be treated because a wider range of prosthesis sizes is available. The size of the femoral canal and acetabulum are limiting factors in prosthesis implantation. The modular system allows the proper size of prosthesis to be chosen for each dog's femoral canal and acetabular cup. The clinical results achieved with the modular system are better than those of the fixed head system. Experience obtained with the fixed head system has shortened the learning curve for the modular system.

Dogs with THAs have achieved normal or near normal hind limb function 95% or more of the time. Pain free function, a full range hip motion, increased exercise tolerance, increased muscle mass and an improved quality of life are standard findings. Working dogs returned to field or police work and pets were exercised more without pain. It has been found that 80% of the dogs will not need the other un-operated hip replaced. They get enough relief from 1 THR that operating on the other side is not necessary. Often on reevaluation it was found that neither hip was painful when both had been hurt before surgery. The thigh circumference of the side with the THR is routinely 1 to 4 cm larger than the un-operated side. Because the prosthesis provides the normal ball and socket arrangement of the hip joint, the femur maintains its normal position relative to the pelvis and the hind limb is able to generate maximal propulsion forces during locomotion. This is not the case if the ball and socket joint configuration is not present.

Total hip arthroplasty in the dog is a very effective way of treating disabling conditions of the dog's hip joint. To be proficient at this procedure a surgeon must be well trained in the technique and do it routinely. Not every veterinarian should be doing THAs. However, every veterinarian should know enough about the procedure to be able to discuss it as a treatment option when indicated.

Total hip arthroplasty is well known by the general public as a treatment for people with hip problems. Because of this more owners are demanding it for their pets and more referral centers are offering it as part of their service. The future of THAs in veterinary medicine is bright and will continue to be so as long as the latest information and technical developments are incorporated into the total hip arthroplasty protocol.

Suggested Readings

DeYoung, DJ, DeYoung BA, Aberman Ha, et al: Implantation of an uncemented total hip prosthesis: Technique and initial results of 100 arthroplasties. *Vet Surg* 21: 168, 1992.

Hoefle, WD: a surgical procedure for prosthetic total hip replacement in the dog. *J Am Animal Hosp Assoc* 10:269, 1974.

Leighton, RL: The Richard's II canine hip prosthesis. *J Am Anim Hosp Assoc* 15:73, 1979.

Lewis RG, Jones JP: A clinical study of canine total hip replacement. *Vet Surg* 9:20, 1980.

Olmstead, ML, Hohn RB: Ergbisse mt der hufltoltal-prostheses bei 103 klinischen fallen an der Ohio State University. *Klin Prox* 25; 407, 1980.

Olmstead, ML, Hohn, RB, Turner, TM: A five year study of 221 total hip replacements in the dog. *J Am Vet Med Assoc* 183:191, 1983.

Olmstead, ML: Total hip replacement. *Vet Clin N Am* 17:943, 1987.

Olmstead, ML: The canine cemented modular total hip prosthesis: surgical technique and preliminary clinical results. *J Am Anim Hosp Assoc* 31:109, 1995.

Parker, RB, Bloomberg, MS, Bitetto, W et al: Canine total hip replacement: a clinical review of 20 cases. *J Am Anim Hosp Assoc* 20:97, 1984.

Paul HA, Bargar WL: A modified Technique for canine total hip replacement. *J Am Anim Hosp Assoc* 23:13, 1987.

Excision Arthroplasty of the Femoral Head and Neck

Joseph M. Prostredny

Introduction

Numerous pathologic conditions exist that interfere with the normal function of the canine coxofemoral joint. Regardless of the inciting cause, dogs with coxofemoral joint pathology usually experience pain during motion of the joint. Surgery of the coxofemoral joint is usually performed to improve comfort and function.

Femoral head and neck excision is one of the most common surgeries performed on the coxofemoral joint. A more common name for the procedure is femoral head ostectomy (FHO). However, the term FHO is misleading because it is necessary to remove both the femoral head and neck to consistently achieve satisfactory results.

Removal of the femoral head and neck allows formation of a pseudoarthrosis (false joint) between the femur and the acetabulum. This procedure is considered a salvage operation to improve the quality of life in patients with severe coxofemoral joint disease. Pain is relieved and function is improved by eliminating the articulation of the femur and the acetabulum.

Indications

Femoral head and neck excision is suitable for most conditions that compromise the integrity of the coxofemoral joint. Common indications in dogs and cats include aseptic necrosis of the femoral head (Legg- Perthes disease), severe fractures of the coxofemoral joint, chronic or recurrent coxofemoral luxations, coxofemoral joint instability, or severe osteoarthritis. Femoral head and neck excision is most commonly used as a lower cost alternative to total hip replacement, or in animals that are too small for hip replacement. There is a tendency for some veterinarians to overuse femoral head and neck excision for conditions that can be managed by primary repair.

Results of femoral head and neck excision depend on a number of factors, including body size, body condition, animal temperament, surgical technique and postoperative physical therapy. There is a general consensus that success varies with the size of the patient. Cats and small breed dogs can, in general, be expected to do well. With adequate postoperative care, satisfactory results can be consistently achieved in non-overweight dogs up to 50 kg or more. However, dogs over 25 kg will usually perform better with primary repair or total hip replacement if appropriate or affordable to the owners. Results in giant breed dogs are, at best, inconsistent, and a femoral head and neck excision should only be considered as a last resort in these breeds.

Surgical Technique

Several approaches to the coxofemoral joint have been described. The currently accepted standard technique for femoral head and neck excision is the craniolateral approach. Some surgeons prefer the ventral approach because it is more cosmetic and allows for bilateral excision without repositioning the patient. However, the exposure with the ventral approach is more limited and should only be used in small patients.

Craniolateral Approach

The patient is positioned in lateral recumbency. A straight or slightly curved incision is centered at the level of the greater trochanter along the cranial border of the femur. The incision should extend distally approximately one-fourth to one-third of the length of the femur and proximally two-thirds the distance to the dorsal midline. After dissecting through the subcutaneous tissue, the incision is continued through both layers of the fascia lata along the cranial border of the biceps femoris muscle, extending proximally along the cranial border of the superficial gluteal muscle. The incision through this layer should include the insertion of the tensor fascia lata muscle in the deep layer of the fascia lata. The fascia lata and tensor fascia lata muscle are retracted cranially and the biceps femoris and superficial gluteal muscles are retracted caudally to expose the underlying vastus lateralis, middle gluteal and deep gluteal muscles. The middle gluteal muscle is then retracted caudodorsally to expose the insertion of the deep gluteal muscle on the greater trochanter (Fig. 62-115). To improve exposure of the hip joint, a partial tenotomy of the ventral two-thirds of the deep gluteal insertion can be performed prior to dorsal retraction to expose the underlying joint capsule of the coxofemoral joint.

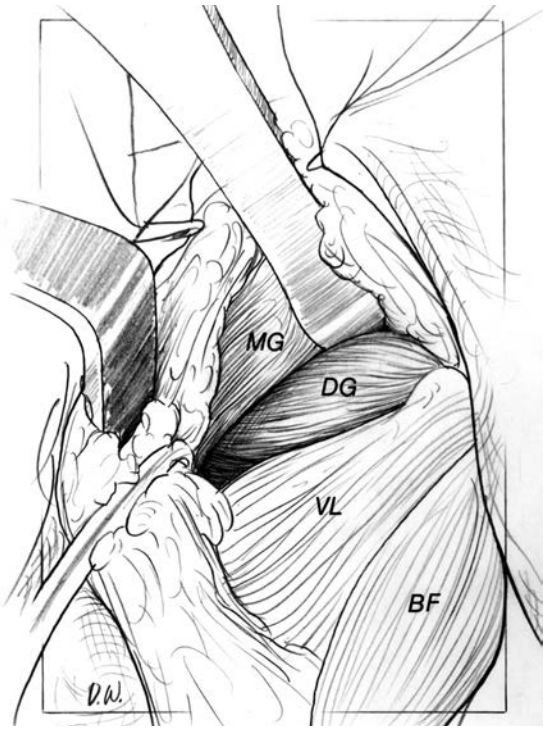


Figure 60-115. Craniolateral approach to the coxofemoral joint. The middle gluteal muscle *(MG)* has been retracted craniodorsally to expose the deep gluteal muscle *(DG)*. The vastus lateralis muscle *(VL)* and biceps femoris muscle *(BF)* are also shown. (From Prostredny, J.M., Toombs, J.P., Van Sickle, D.C. Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. Vet Surg Blackwell Publishing 1991; 20:298-305.)

A transverse incision is made in the joint capsule to expose the femoral head. A second longitudinal incision should be made through the joint capsule, along the femoral neck through the origin of the vastus lateralis muscle for adequate exposure of the femoral neck. The femoral head should be luxated prior to the osteotomy. It is necessary to cut the ligament of the head of the femur if it is still intact. The femur should then be externally rotated ninety degrees so the cranial aspect of the femoral head and neck are facing up. The osteotomy to excise the femoral neck can be made with an oscillating saw or an osteotome. An oscillating saw will provide the smoothest and most accurate cut. An osteotome also works well as long as it is sharp. Use of a dull osteotome can result in a subtrochanteric fracture of the femur. A proper osteotomy should remove all of the femoral head and neck without damaging the greater or lesser trochanter. With the femur held in ninety degrees of external rotation, the oscillating saw or osteotome should be placed on the upward facing cranial surface of the femoral neck at an angle demonstrated in Fig. 62-116. The cut should be directed caudally and medially. If the cut is directed perpendicular to the surgery table, a portion of the caudal femoral neck will remain because of anteversion of the femoral neck. The cut should extend from the base of the greater trochanter across the neck, in a line that will completely remove the neck without removing the lesser trochanter. The osteotomy must be smooth, without bony projections or irregularities. If present, they may be removed with a bone rasp or rongeurs. Incomplete removal of the femoral neck may result in increased contact between the femur and acetabulum, resulting in long-term discomfort.

After completing the osteotomy, the femoral head is grasped and any remaining attachments of the joint capsule are divided to allow removal of the femoral head and neck. Closure is achieved by placing one or two mattress sutures in the deep gluteal tendon. The incised edge of the vastus lateralis muscle is sutured to the cranioventral edge of the deep gluteal muscle. The fascia lata and tensor fascia lata muscle are sutured to the cranial edge of the biceps muscle. The remainder of the closure is routine.

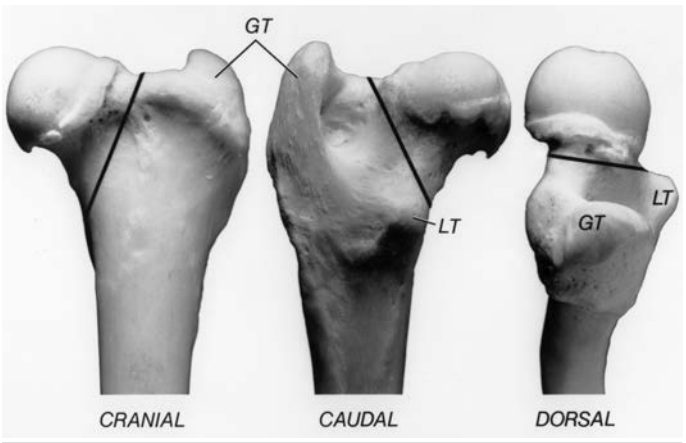


Figure 60-116. Correct angles for femoral head and neck excision. *GT:* greater trochanter, *LT:* lesser trochanter.

Ventral Approach

This approach provides a much more limited exposure than the previously described craniolateral approach. The patient is placed in dorsal recumbency with the hind legs abducted. The skin incision is made over the pectineus muscle, which is easily palpable. The underlying fascia is divided and the pectineus muscle is isolated, taking care to avoid the femoral artery, vein, and saphenous nerve cranial to the muscle belly. The pectineus muscle is transected at its origin on the pubis. The pectineus is then reflected distally. The iliopsoas muscle is retracted cranially and the adductor muscle is retracted caudally to expose the ventral joint capsule. Care must be taken to avoid the deep femoral artery and vein, as well as the obturator nerve, which lie ventral and medial to the joint. The joint capsule is then incised to reveal the ventral femoral head and neck. The osteotome or oscillating saw is then positioned on the ventral-most aspect of the femoral neck and directed to the trochanteric fossa to the allow complete removal of the femoral head and neck as described previously. The pectineus muscle can be re-attached to its origin or the prepubic tendon with mattress sutures. The remainder of the closure is routine.

Muscle Transposition

Early postoperative lameness following femoral had and neck excision is thought to be at least partly due to bone on bone contact between the femur and the pelvis. This contact may be more pronounced in larger dogs because their greater body mass tends to drive the bones together. Pain in the early postoperative period can significantly slow the return to function and result in a more restrictive pseudoarthrosis. Techniques that interpose a muscular pad between the osteotomy site and the acetabulum have been developed in an effort to decrease early postoperative pain and lameness. These flaps can be used at the surgeon's discretion.

There are two commonly used muscle pad techniques; the deep gluteal flap and the biceps sling. Biceps slings provide more coverage of the femoral osteotomy site then deep gluteal flaps. The biceps sling can be either a full or partial thickness flap. In a controlled experimental setting, the use of full thickness bicep slings was associated with high postoperative morbidity. This morbidity was not seen in a similar study using partial thickness slings.

Both deep gluteal flaps and biceps slings are performed through the previously described craniolateral approach. To create a deep gluteal flap, a tenotomy of the ventral two-thirds of the deep gluteal tendon is performed at its insertion on the greater trochanter. The muscle is then incised longitudinally from the tenotomy to its origin on the ilium. This creates a muscular flap that can be rotated distally (Fig. 62-117). After the femoral head and neck excison is performed, the femur is rotated externally to expose the insertion of the iliopsoas muscle on the lesser trochanter. The distal end of the deep gluteal flap is then sutured to the insertion of the iliopsoas muscle (Fig. 62-118). When the femur is returned to its normal position, the deep gluteal flap is drawn across the osteotomy site to form a pad between the osteotomy site and the acetabular rim (Fig. 62-119).

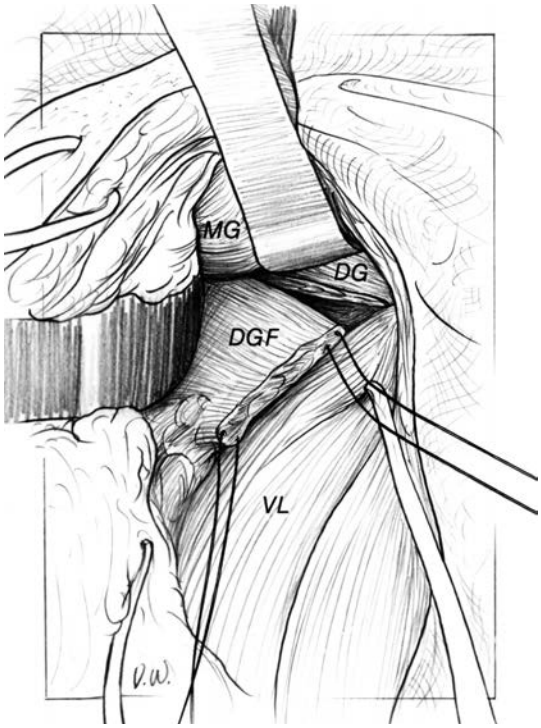


Figure 60-117. A partial tenotomy is made in the tendon of insertion of the deep gluteal flap *(DG)*. The muscle is split longitudinally from the tenotomy proximally to mobilize a deep gluteal flap *(DGF)*. The middle gluteal muscle *(MG)* and vastus lateralis muscle *(VL)* are also shown. (From Prostredny, J.M., Toombs, J.P., Van Sickle, D.C. Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. Vet Surg Blackwell Publishing 1991; 20:298-305.)



Figure 60-118. With the femur *(F)* held in external rotation so the osteotomy site is positioned cranially, sutures are placed between the distal portion of the deep gluteal flap *(DGF)* and the underlying iliopsoas muscle *(I)*. The acetabulum *(A)* is medial to the femur. *VL:* vastus lateralis muscle. (From Prostredny, J.M., Toombs, J.P., Van Sickle, D.C. Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. Vet Surg Blackwell Publishing 1991; 20:298-305.)

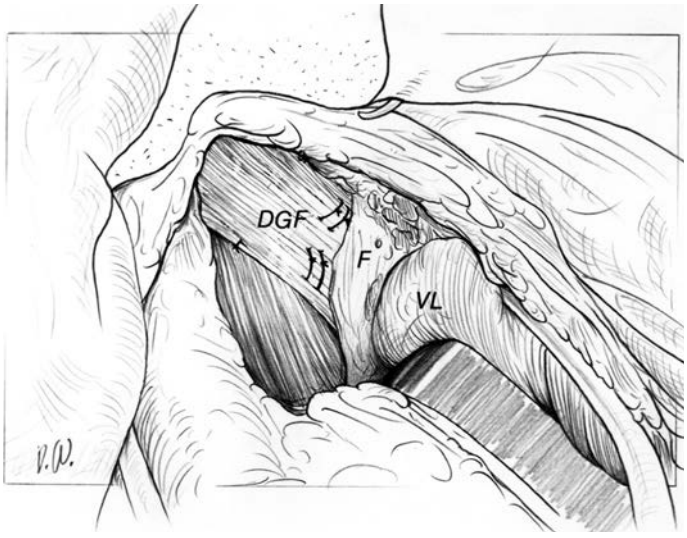


Figure 60-119. Final placement of the deep gluteal flap *(DGF). F:* femur, *VL:* vastus lateralis muscle. (From Prostredny, J.M., Toombs, J.P., Van Sickle, D.C. Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. Vet Surg Blackwell Publishing 1991; 20:298-305.)

To create a biceps sling, the previously described skin and fascial incision for the craniolateral approach must be extended to the stifle. Creation of a partial thickness sling is recommended to avoid excessive postoperative morbidity. The muscle flap is created from the craniolateral portion of the biceps femoris muscle. The free end of the flap should be widest at the base (approximately 1.5 times the width of the osteotomy site) and should taper distally (Fig. 62-120). The sling is elevated by sharp dissection with the cut angled to produce a flap 0.5 to 1 cm thick, depending on the size of the patient. A wide fenestration is made in the caudal aspect of the coxofemoral joint capsule to allow easy passage of the sling through the joint in a caudal to cranial direction. Use of a suture snare to pull the muscle flap through the joint, minimizes muscular trauma (Fig. 62-121). The sling is then positioned to cover the osteotomy site and the distal portion of the sling is sutured to the vastus lateralis muscle (Fig. 62-122). To prevent movement of the sling across the osteotomy site, the sling can also be sutured to the deep gluteal muscle dorsally and the iliopsoas muscle ventrally. The fascia lata is then sutured to the remaining biceps muscle.

Postoperative Management

An early return to function is necessary for the development of a functional pseudoarthrosis. Motion of the coxofemoral joint in the early postoperative period will aid in the formation of a fibrous joint with a good range of motion. If postoperative motion is restricted, the pseudoarthrosis that forms will have a limited range of motion and the long-term function will be less desirable.

Appropriate doses of analgesics for at least one to two weeks (longer if necessary) are essential to encourage early use. The owners should perform passive range of motion exercises at least two to three times a day. Exercise should be encouraged in the form of walking or swimming. Swimming is one of the best forms of postoperative physical therapy, and owners should be encouraged to pursue this option if it is available.

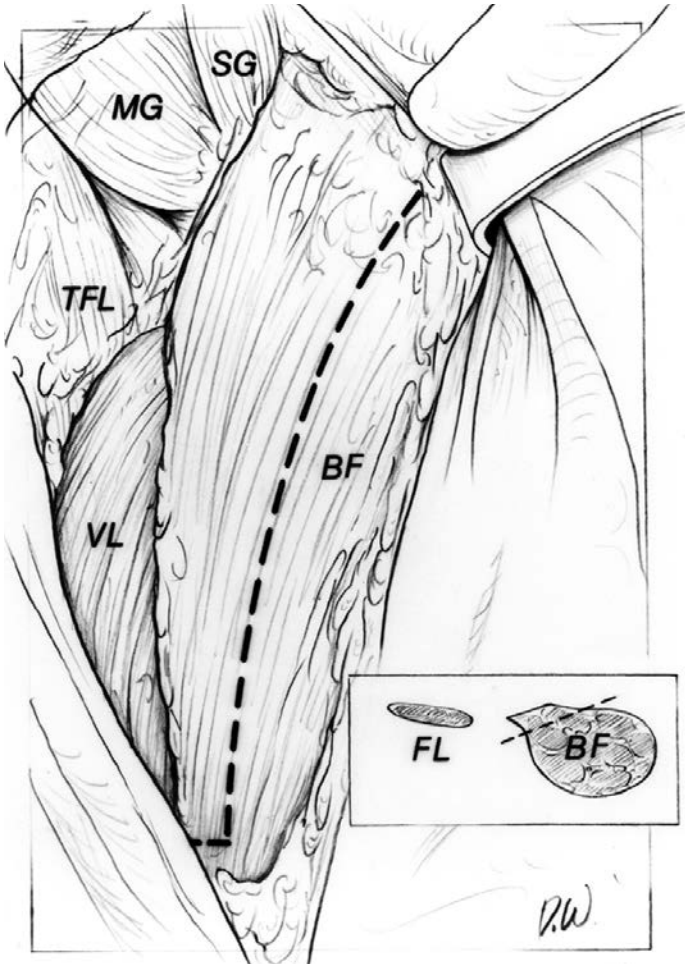


Figure 60-120. Dimensions of the partial thickness biceps sling are indicated by the broken line on the lateral surface of the biceps femoris muscle *(BF)*. The superficial gluteal muscle *(SG)*, middle gluteal muscle *(MG)*, tensor fascia lata muscle *(TFL)*, and vastus lateralis muscle *(VL)* are shown. The cut is angled as shown by the broken line in the inset drawing; a cross-sectioned view of the biceps femoris muscle and fascia lata *(FL)*. (From Prostredny, J.M., Toombs, J.P., Van Sickle, D.C. Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. Vet Surg Blackwell Publishing 1991; 20:298-305.)

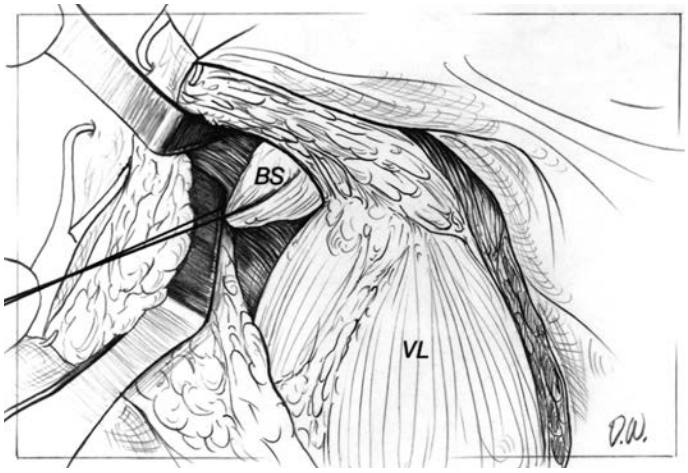


Figure 60-121. After a large fenestration is made in the caudal aspect of the joint capsule, a loop of suture is passed through the joint from cranial to caudal. The loop is placed around the distal portion of the sling ("Suture Snare") and the biceps sling *(BS)* is pulled across the osteotomy site from the caudal to cranial. *VL:* vastus lateralis muscle. (From Prostredny, J.M., Toombs, J.P., Van Sickle, D.C. Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. Vet Surg Blackwell Publishing 1991; 20:298-305.)

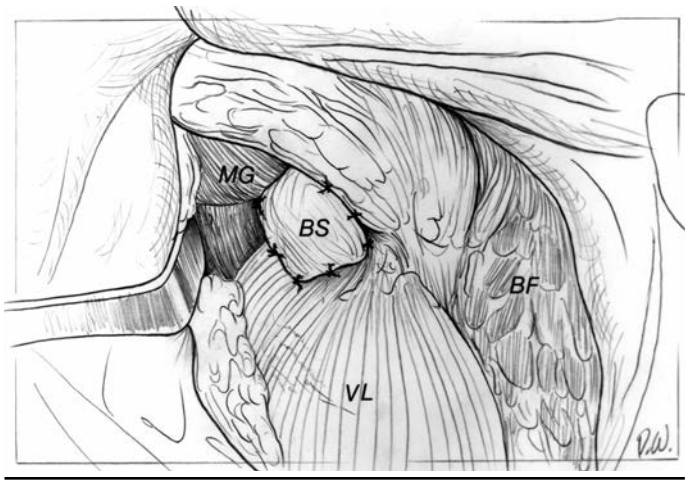


Figure 60-122. The sling *(BS)* is positioned to cover the osteotomy site and sutured to the vastus lateralis muscle *(VL)* and the underlying deep gluteal and iliopsoas muscles. *MG:* middle gluteal muscle. (From Prostredny, J.M., Toombs, J.P., Van Sickle, D.C. Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. Vet Surg Blackwell Publishing 1991; 20:298-305.)

Proper surgical technique and proper postoperative physical therapy can produce consistent satisfactory results in non-overweight dogs of most breeds. Results may still be inconsistent in overweight dogs and giant breeds.

Suggested Readings

Lippincott CL: Excision arthroplasty of the femoral head and neck. *Vet Clin North Am [Small Anim Pract]* 17:857, 1987.

Berzon JL, Howard PE, Covell SJ, et al.: A retrospective study of the efficacy of femoral head and neck excisions in 94 dogs and cats. Vet Surg 9:88, 1980.

Tarvin G, Lippincott CL: Excision arthroplasty for treatment of canine hip dysplasia using the biceps femoris muscle sling: An evaluation of 92 cases. *Semin Vet Med Surg [Small Anim]* 2:158, 1987.

Mann FA, Tanger CH, Wagner-Mann C, et al.: A comparison of standard femoral head and neck excision and femoral head and neck excision using a biceps femoris muscle flap in the dog. *Vet Surg* 16:223, 1987.

Lippincott CL: Improvement of excision arthroplasty of the femoral head and neck utilizing a biceps femoris muscle sling. *J Am Anim Hosp Assoc* 17:668, 1981.

Lippincott CL: Excision arthroplasty of the femoral head and neck utilizing a biceps femoris muscle sling. Part two: The caudal pass. *J Am Anim Hosp Assoc* 20:377, 1984

Gendreau C, Cawley AJ: Excision of the femoral head and neck: the long-term results of 35 operations. *J Am Anim Hosp Assoc* 13:605, 1977.

Lewis DD, Bellah JR, McGavin MD, Gaskin JM: Postoperative examination of the biceps femoris muscle sling used in excision of the femoral head and neck in dogs. *Vet Surg* 17:269, 1988.

Prostredny, JM, Toombs, JP, Van Sickle, DC: Effect of two muscle techniques on early morbidity after femoral head and neck excision in dogs. *Vet Surg* 20:298, 1991.

Bjorling DE, Chambers JN: The biceps femoris flap and femoral head and neck excision in dogs. *Compend Contin Educ Pract Vet* 8:359, 1986

Piermattei DL, Johnson KA: *An Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat.* 4th ed. Philadelphia: Saunders 2004, 290.

Hosgood G, Toombs JP: The suture snare technique for passage of tissue strips or flaps. *J Am Anim Hosp Assoc* 26:322, 1990.

Millis DL. Levine D, Taylor RA: *Canine Rehabilitation and Physical Therapy* 1st ed. Saint Louis: Saunders 2004.

Chapter 61

Femur and Stifle Joint

Internal Fixation of Femoral Fractures

Dougald R. Gilmore

Editor's Note – The reader is encouraged to review other sections of this text regarding more recent options for the repair of femoral fractures: Chapter 50 – Interlocking Nailing; Chapter 51 – SOP Locking Plates; Chapter 52 – Plate-Rod Fixation; and Chapter 53 – Hybrid External Skeletal Fixation.

Fractures of the Femoral Head and Neck

Pelvic limb lameness with vehicular trauma often is caused by a fracture of the acetabulum or proximal femur. In the immature animal, fracture through the physis of the femoral head is encountered most commonly. This fracture is due to the weak area at the zone of hypertrophy at the growth plate. Other, less common fractures involve the base of the neck or the trochanteric region (Figure 61-1).

When examination of a dog less than 12 months of age reveals pain on manipulation of the hip joint, one should suspect either a fracture of the proximal femur or acetabulum or a coxofemoral luxation. The exact diagnosis requires radiographic evaluation including ventrodorsal (normal hip dysplasia position) and lateral views. Occasionally, a "frog leg" view assists in the diagnosis. This view requires the animal to be in dorsal recumbency with the pelvic limbs held in a flexed and slightly abducted position. An awake animal is more likely to cooperate for this view than for the normal ventrodorsal view.

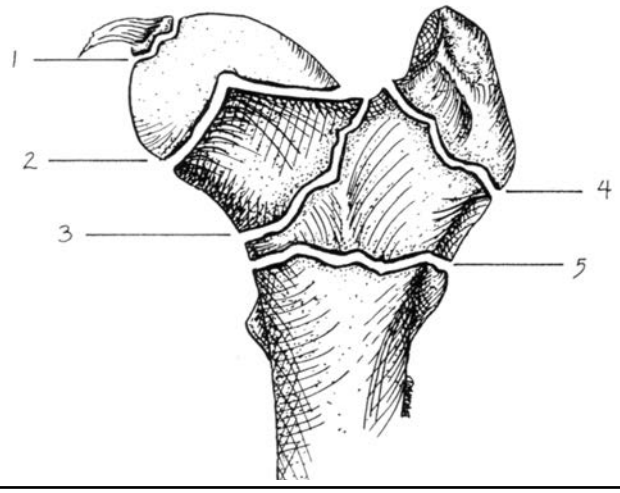


Figure 61-1. Sites of common fractures of the femoral head and neck and of the proximal femur: 1, capital epiphysis (avulsion fractures); 2, capital (proximal) physis; 3, femoral neck; 4, greater trochanteric physis; and 5, intertrochanteric region.

Anatomic Considerations

In the extremely young animal, the proximal growth plate extends from the greater trochanter to the femoral head. As the animal matures, separation into a capital femoral growth plate and a greater trochanteric growth plate occurs. Investigators have estimated that the capital physeal growth plate contributes up to 25% of the femoral length, whereas the greater trochanteric physis contributes little to the length. The ligament of the femoral head, which extends from the femoral fovea to the acetabular fossa, provides significant support to the hip joint.

The vascular supply to the femoral head continues to be of concern to most veterinary surgeons. If precise, delicate surgical intervention with appropriate stabilization is practiced, few complications should be encountered. Important aspects of the vascular supply include the lateral and medial circumflex femoral arteries, which are branches of the femoral and deep femoral arteries. The lateral branch provides most of the supply to the femoral head and the dorsal aspect of the femoral neck. The medial branch supplies the ventral aspect of the joint capsule, and a branch of the caudal gluteal artery supplies a small portion of the dorsal aspect. Dorsal and ventral ascending branches from the lateral and medial circumflex femoral arteries anastomose and form a rich interosseous arch within the epiphysis. Metaphyseal branches of the lateral and medial circumflex vessels do not communicate with the epiphyseal branches in the immature animal. No evidence suggests that a blood supply enters the epiphysis from the ligament of the femoral head.

Presurgical Considerations

Avascular necrosis of the femoral head secondary to a fracture is not a significant problem if appropriate surgical treatment is followed. Most reports of repair list few cases of avascular necrosis. Although the femoral head completely loses its vascular supply at the time of the initial trauma, revascularization is rapid after stabilization. The time interval to surgery is important because more damage is sustained if the repair is delayed. Attempts by the animal to walk on the affected limb may damage the soft metaphyseal bone of the neck as it rubs on the acetabular rim. Loss of bone results in the inability to reduce and stabilize the fracture components correctly. The degree of damage is most often ascertained at the time of surgery. Occasionally, radiographic evaluation reveals the damage.

Surgical Approach

The craniolateral approach is most often recommended for femoral head and neck fractures because of the preservation of vascular supply. The dorsal approach, including greater trochanteric osteotomy, may be used if increased exposure is required, but it damages the branches of the lateral circumflex femoral artery. In addition, damage to the physis of the greater trochanter may lead to a valgus deformity in a young animal. Successful use of the dorsal approach has been reported, but research also shows that the vascular damage may not be significant.

In the craniolateral approach, the skin incision is curved in a cranial direction starting 3 to 4 cm proximal to the greater trochanter and extending distally to include the proximal one-quarter of the femoral shaft. An incision is made into the fascia lata just cranial to the greater trochanter and is extended to allow retraction of the biceps femoris muscle caudally and the fascia cranially. The muscular tensor fasciae latae is then dissected from the fascia of the vastus lateralis and the middle gluteal muscles. The gluteal muscles are retracted dorsally and the tensor fasciae latae cranially to allow visualization of the cranial aspect of the joint capsule. The joint capsule is incised perpendicular to the acetabular rim, extending to the origin of the vastus intermedius and lateralis. The exposure can be increased by performing a partial tenotomy of the deep gluteal muscle. If difficulty is encountered in visualization and reduction of the fracture, trochanteric osteotomy may be performed. With either approach, the location of the sciatic nerve should be noted.

Fixation Techniques

Capital Physeal Fractures

Reduction of a capital physeal fracture may be difficult. Handling of the femoral head with a retractor or bone-holding forceps should be minimized to lessen damage to the articular cartilage. One or several Kirschner wires are placed to stabilize the fracture after reduction. These pins are placed in retrograde fashion from the fracture site laterally or in a normograde manner from the lateral surface of the proximal femur (Figure 61-2A). After fracture reduction, the pins are seated in the femoral head.

If a lag screw is to be used, the gliding hole through the proximal femur may be drilled before reduction to ensure placement into the center of the neck. A small threaded hole is drilled into the femoral head before measuring and tapping the hole (Figure 61-2B). As the head is encountered, tapping becomes more difficult. Care is taken to ensure that the articular surface is not penetrated. A screw that is 2 to 4 mm shorter than the measured length should be used because of the shortening obtained during lag screw fixation (Figure 61-2C).

Use of measurements taken from the radiographs can help to ensure that implants of appropriate size are used. The articular surface should be inspected after implant placement to check for implant penetration. Areas not visualized may be inspected using a curved instrument to check for any irregularities. Any articular damage fills with fibrocartilage, which permits satisfactory recovery of most animals.

Interfragmentary compression alone should be adequate for most animals. Kirschner wires may be left in place to increase rotational stability if necessary. After the joint is flushed, the joint capsule is closed with a nonreactive suture material before anatomic closure of the other layers.

Other Articular Fractures

Occasionally, an avulsion fracture of the ligament of the femoral head occurs in association with a coxofem-oral luxation. Removal of this fragment and the ligament is recommended if surgical intervention is necessary for stabilization of the hip joint. Closed reduction of this type of coxofemoral luxation may result in degenerative joint disease because the interposed avulsed fragment produces cartilaginous damage.

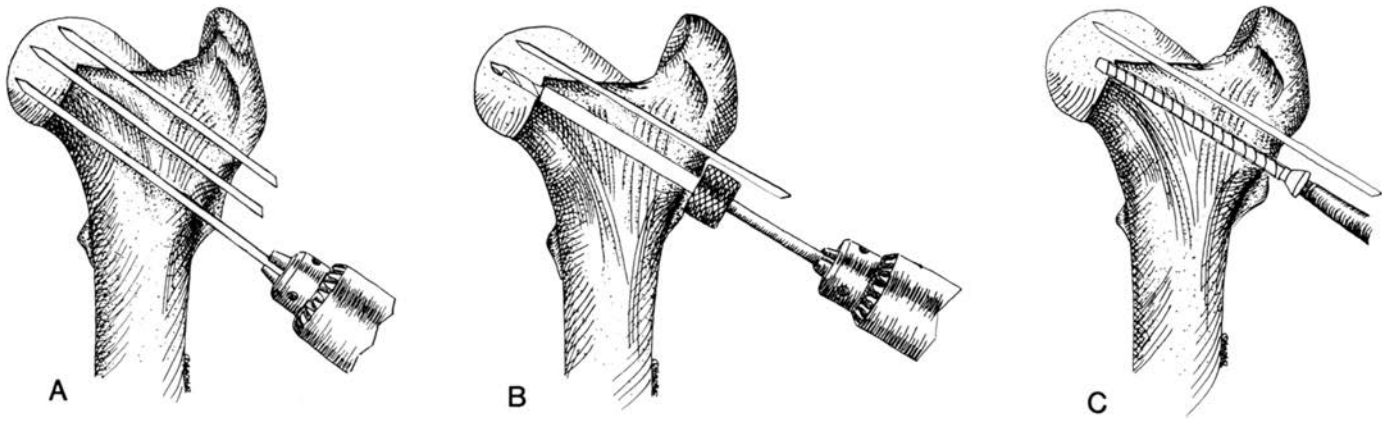


Figure 61-2. A capital physeal fracture can be stabilized by multiple Kirschner wires placed from the lateral surface into the subchondral bone **A.**, or by lag screw fixation. In the latter method, after normograde or retrograde drilling of the glide hole, a drill guide is inserted and a thread hole drilled **B.**; a screw is then inserted to compress the fracture **C.** The Kirschner wire can be left in place to provide further stabilization.

Fractures involving the dorsal articular surface require stabilization to lessen degenerative joint disease. Femoral head and neck excision is an alternative if the articular cartilage is severely damaged or if reduction is too difficult. Fracture fragments involving the non-articular surfaces may be removed.

Extracapsular Fractures

Fractures through the base of the femoral neck are most often encountered in mature animals. Repair is performed as described previously for femoral head fractures (See Figure 61-2). Osteonecrosis is not a problem because of the extracapsular nature of the fracture. Fractures through the apophysis of the greater trochanter sometimes occur in association with a capital physis fracture. Careful evaluation of the radiographs may be necessary because of the superimposition of the greater trochanter on the femoral shaft. Stabilization is performed through a craniolateral approach with retraction of the greater trochanter. After stabilization of the femoral head with a Kirschner wire and lag screw, the greater trochanter is reattached by tension band fixation (Figure 61-3). Care is necessary to ensure complete reduction and realignment before stabilization.

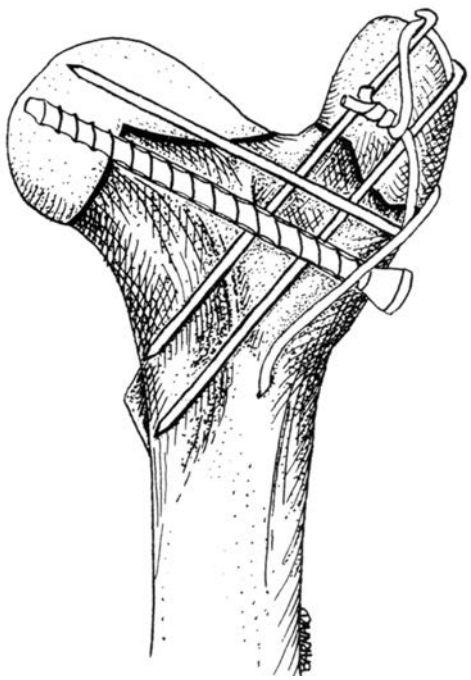


Figure 61-3. Fractures involving both the greater trochanteric and capital physis are stabilized by a lag screw, Kirschner wire, and tension band fixation. This type of fixation also is used when a trochanteric osteotomy is performed to approach the coxofemoral joint.

Proximal Femoral Fractures

Greater Trochanteric Fractures

Fractures of the greater trochanter are commonly associated with fractures involving the femoral head in young animals and with comminuted proximal femoral fractures in mature animals. The traction physis associated with the greater trochanter is believed to provide no significant contribution to longitudinal bone growth.

Repair of a greater trochanteric fracture is necessary because the distraction forces applied by the gluteal muscles do not allow for normal union. Approach is made just cranial to the greater trochanter, allowing separation of the fascia lata from the biceps femoris muscle. Incision into the origin of the vastus lateralis may be necessary to allow visualization of the fracture.

Of the repair methods available, tension band fixation is probably the easiest and most satisfactory. This method converts distracting forces into compressive forces at the fracture site. Two Kirschner wires are inserted at right angles to the fracture line (See Figure 61-3). Care is taken to gain maximum purchase prox-imally in the greater trochanter and to ensure purchase into the medial cortex at or below the lesser trochanter. Orthopedic wire (18 to 20 gauge) is placed through a hole drilled in a craniocaudal direction 3 to 4 cm distal to the fracture line. This wire is placed around the proximal ends of the Kirschner wires in a figure-of-eight configuration and then is tightened to counteract the distracting forces of the gluteal muscles.

Intertrochanteric and Subtrochanteric Fractures

Either stack-pinning or plate fixation can be used to neutralize both bending and rotational forces acting on the intertrochanteric and subtrochanteric fractures. Approach to the area requires transection of the origins of both the vastus lateralis

and intermedius muscles. Pin placement should originate from the proximal point of the greater trochanter and should extend distally, gaining maximal purchase in the femur. A common mistake is to exit the pins within 3 to 4 cm of the fracture line. This technique provides less than satisfactory stabilization. A figure-of-eight wire may be placed in association with the pins to provide increased rotational stability for subtrochanteric fractures (Figure 61-4).

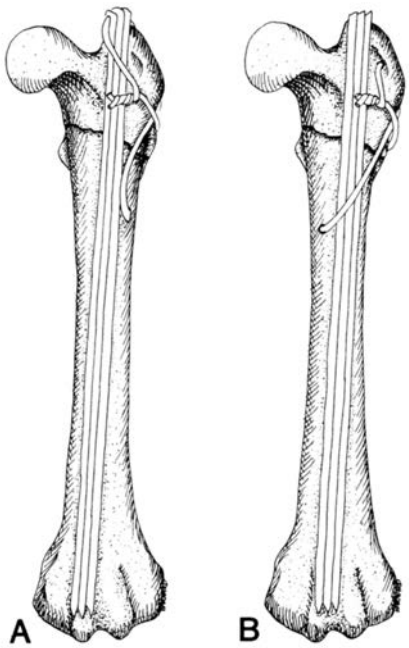


Figure 61-4. A. and **B.** An intertrochanteric fracture of the femur is repaired with multiple intramedullary pins and a figure-of-eight tension band wire. Two different methods of attaching the wire are shown.

Application of a bone plate to the lateral surface is indicated in large dog breeds for repair of these fractures. Careful contouring of the bone plate allows for the placement of at least two screws in the short proximal segment in most cases. One screw (usually cancellous) should extend into the femoral neck for increased purchase, and at least four screws should be placed in the distal segment (Figure 61-5).

Comminuted Fractures

Highly comminuted fractures of the proximal femur require aggressive fixation, usually with a bone plate and lag screws. Care must be taken to ensure adequate stabilization of the calcar region (lesser trochanter) because it is an important medial buttress. Early fixation failure can be expected if stabilization is inadequate. The fracture segments are reduced and stabilized with both lag screws and Kirschner wires. The plate is then contoured and is attached to the proximal segment with one screw placed through the second hole into the femoral neck and head. The proximal screw is placed into the greater trochanter. Use of a dynamic compression plate permits angling of the screws up to 30° from center. The plate acts as a neutralization or buttress plate for this type of fracture. The plate should be attached to the distal segment with at least three screws penetrating six cortices (Figure 61-6A). A cancellous bone graft should be placed into any areas that lack cortical bone.

Intramedullary fixation of comminuted proximal fractures is more applicable to small and medium-sized dogs than to large ones, especially if the fracture has only three or four segments. By use of hemicerclage wire and transcortical pins, a comminuted fracture can be reduced to a two-piece fracture, which then is fixed by normograde or retrograde stack-pinning (Figure 61-6B). Care must be taken to ensure that the transcortical pins do not enter to the medullary canal to allow for the introduction of a

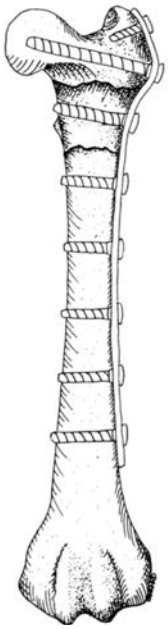


Figure 61-5. Intertrochanteric and subtrochanteric fractures can be stabilized with a bone plate applied to the lateral surface of the femur. A cortical or cancellous screw is placed through the femoral neck for increased purchase.

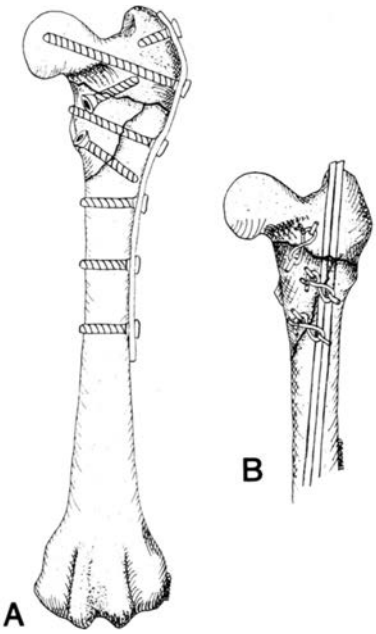


Figure 61-6. A comminuted proximal femoral fracture can be stabilized by a bone plate applied to the lateral surface and lag screw fixation of the butterfly fragment **A.** or by intramedullary pins with the butterfly fragment attached by transcortical pins and figure-of-eight wires **B.**

maximum number of stack pins. Lag screws are more difficult to incorporate into fractures stabilized with intramedullary pins.

Diaphyseal Fractures of the Femur

Transverse Fractures

Transverse diaphyseal fractures are most commonly repaired with one intramedullary pin. Although success is often reported with this method, so too is failure, mainly because of the lack of rotational stability provided by one pin. This method is most likely to succeed with immature animals in which healing is rapid and with small to medium-sized adult animals in which the single pin tends to fill a significant part of the medullary canal. Failure occurs most often in large dogs, when a small pin that does not fill a significant portion of the canal is used. Use of a Kirschner-Ehmer external fixation device (two-pin half-pin splint) in association with the intramedullary pin increases rotational stability.

Stack-pinning of transverse fracture is an easy procedure that results in few complications in most cases. The curved skin incision should be just cranial to the femoral shaft. The biceps femoris muscle belly is encountered if the incision is directly over the shaft; incision through this muscle belly is not the approach of choice. After approaching the fracture by incising the fascia lata cranial to the biceps muscle, the vastus lateralis muscle is retracted cranially, and the biceps femoris muscle is retracted caudally to allow visualization of the fracture site. Minimal stripping of the periosteum is done to check for any fissure lines

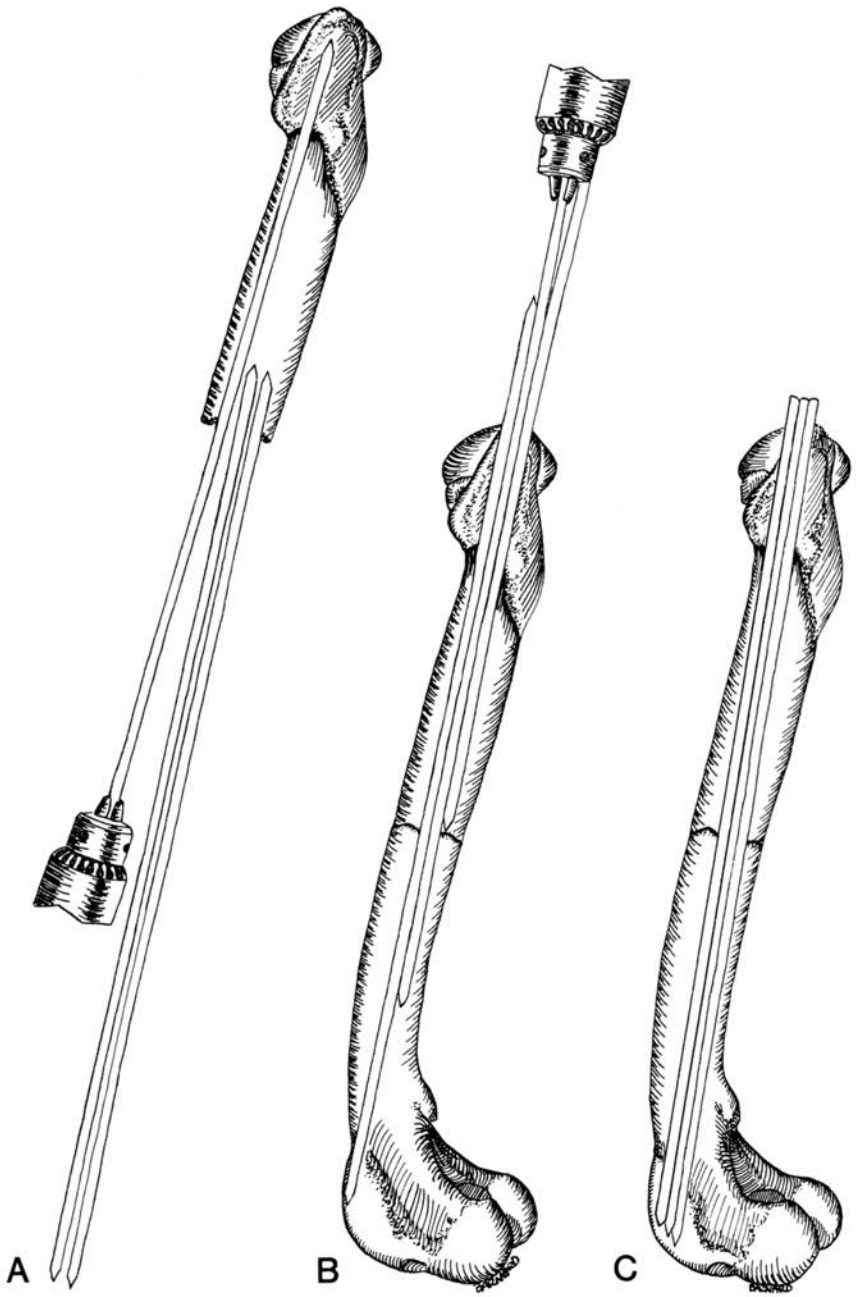


Figure 61-7. Retrograde stack-pinning of a transverse midshaft femoral fracture. **A.** The hip is extended and the femur is adducted before retrograde placement of all pins through the trochanteric fossa. **B.** The pins are driven distally to engage cortical bone. **C.** The pins are placed into but not through the distal cortex beneath the trochlear groove.

in the fracture segments. The pins are placed in retrograde fashion, exiting proximally through the trochanteric fossa (Figure 61-7A). The surgeon must extend the animal's hip joint and adduct the femur when passing the pin proximally to avoid the sciatic nerve as it passes over the greater trochanteric notch. All pins are placed proximally before reduction of the fracture segment. Enough pins are used to fill the medullary canal at its narrowest point. The pins are then driven distally into cortical bone. Because of the cranial curvature of the femoral shaft, the pins usually seat distally in the cranial metaphyseal area near the proximal end of the trochlea (Figure 61-7B). Overreduction of the distal segment allows seating of the pins further distally, but usually this leads to malalignment and instability. Because the feline femur has less curvature, the pins can be seated farther distally in the intercondylar region in cats (Figure 61-7C).

Several methods are available to add rotational support to pin fixation of transverse diaphyseal fractures. A two-pin half-pin Kirschner-Ehmer splint in association with a single intramedullary pin is one method. Use of hemicerclage or figure-of-eight orthopedic wire also can increase rotational stability. The figure-of-eight wire can be passed through holes drilled proximal and distal to the fracture line, or two can be placed around transverse Kirschner wires and tightened to form a cruciate pattern (Figure 61-8). The distance from the holes or Kirschner wires to the fracture should be at least equal to the width of the femur at the fracture site.

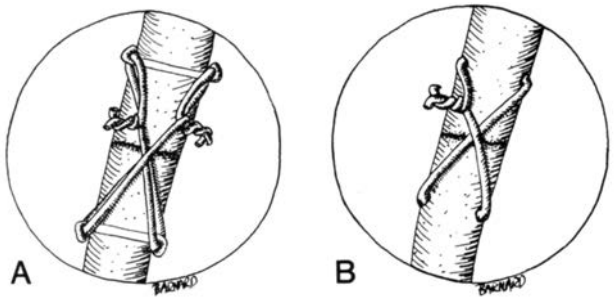


Figure 61-8. Increased rotational stability of transverse femoral fractures is achieved by use of two figure-of-eight wires placed around transversely placed Kirschner wires **A.**, or by orthopedic wire placed in a figure-of-eight fashion through two holes drilled proximal and distal to the fracture line **B**.

Application of a bone plate to the lateral or cranial surface is indicated for stabilization of transverse fractures in large breeds or in any animal requiring rigid internal fixation. Compression of the fracture line allows for rapid primary bone healing. Screw fixation in at least six cortices above and below the fracture should be obtained.

Oblique and Spiral Fractures

Oblique and spiral fractures are most successfully repaired with intramedullary pins, with additional stability provided by transcortical pins and hemicerclage wire or by full-cerclage orthopedic wire. The fracture is first stabilized with intramedullary pins, as discussed in the section on transverse fractures. Wire can be placed around transcortical pins in a figure-of-eight pattern to provide increased rotational stability (Figure 61-9A). Alternatively, full-cerclage wires can be used (Figure 61-9B).

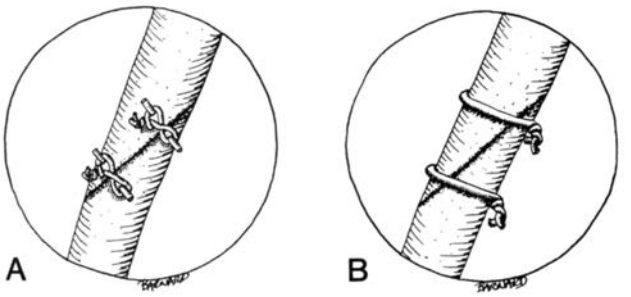


Figure 61-9. Long oblique fractures of the femur can be stabilized by transcortical pins with figure-of-eight wires **A**. or by full-cer-clage wires **B**. The transcortical pins should not enter into the medullary canal, to avoid interference with intramedullary pin placement.

Although investigators initially thought that full-cerclage wires interfered with the new periosteal blood supply needed for fracture healing, more recent studies have shown that this may not occur. Problems only arise when the wire is improperly applied. Common mistakes include inappropriate wire diameter (18 to 20 gauge is appropriate for most animals), placement too close to the fracture ends (a minimum of 5 mm is appropriate), and use of insufficient number of wires (a minimum of two wires placed 1 cm apart is appropriate). As with any technique, failure is more likely to occur when wires are applied in less than ideal fashion. Most complications occur when the wire slips into the fracture site, producing a nonunion.

Comminuted Fractures

Reduction of the fracture segments into two main segments before primary fixation with intramedullary pins provides successful stabilization of most comminuted fractures. Pin fixation is less effective with highly comminuted fractures because of the inability to neutralize compressive forces. Collapse of the fracture is more likely in these cases. Midshaft fractures with one or two butterfly fragments can be stabilized with techniques similar to those discussed in the section on oblique fractures.

Application of a bone plate to the lateral or cranial surface as a neutralization plate (no compression at the fracture site) or a buttress plate (a cortical gap is present) can stabilize most comminuted diaphyseal fractures. The large fragments are attached with Kirschner wires, orthopedic wire, or lag screws before plate attachment. Care must be taken to ensure that these implants do not interfere with placement of the plate. If possible, the plate is positioned to allow for placement of screws in all holes. Occasionally, the number of fissure lines necessitates leaving one or more holes vacant. This situation is to be avoided, especially with a buttress plate, because fatigue failure is more likely to occur at this site. Use of a leg-lengthening plate that lacks holes in the central one-third of the plate may be indicated in these cases (Figure 61-10). Contouring of the plate is made easier if a radiograph of the contralateral femur is available for comparison. By using the greater trochanter, stifle, and linea aspera (the caudal rough surface where the adductor magnus muscle attaches) as reference points, normal anatomic alignment can be obtained in these comminuted fractures.

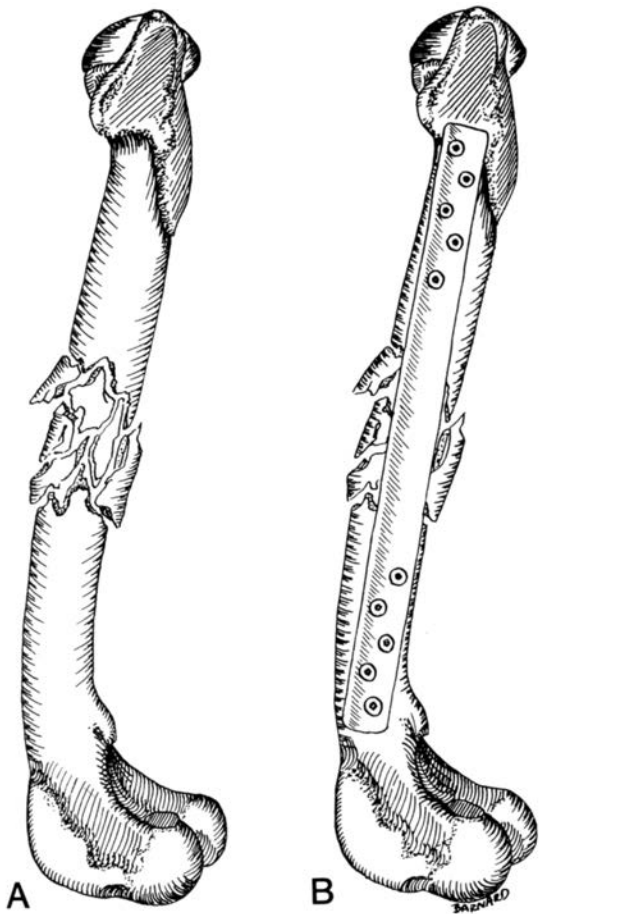


Figure 61-10. A comminuted midshaft femoral fracture **A.** can be stabilized by a buttress plate applied to the lateral surface **B**. A leg-lengthening place is used so no vacant holes are positioned over the comminuted segments.

Occasionally, highly comminuted diaphyseal fractures cannot be pieced together with pins or lag screws. Both removing these fragments and leaving them in place while spanning the gap with a bone plate have been reported. The gap is filled with autogenous cancellous bone to stimulate healing. Leg-lengthening plates are ideally suited, because they allow the closer placement of screws in the proximal and distal fragments without leaving several vacant holes over the gap. Success has been reported with the use of dynamic or standard plates with vacant holes. The plate used must be as large as possible in such cases.

Distal Femoral Fractures

Metaphyseal (Supracondylar) Fractures

Although encountered infrequently, distal metaphyseal fractures provide a challenge for repair. Fortunately, the rich blood supply to this trabecular bone promotes rapid bone healing in most cases. This type of fracture occurs most often in mature animals and is often associated with comminution.

The approach to this region is an extension of the approach used for stifle arthrotomy. The incision in the fascia lata cranial to the biceps femoris muscle is extended distally to include the lateral fascia of the stifle. Incision into the joint capsule is extended proximally, lateral to the vastus lateralis muscle to allow medial retraction of the quadriceps group and the patella. A large muscular branch of the popliteal artery must be ligated as this incision is made. Flexion of the stifle with medial retraction of the muscles allows visualization of the medial surface of the distal femur.

Bone plating of the lateral surface is recommended for stabilization of metaphyseal fractures in larger dogs, especially if comminution is present. Use of cancellous screws in the distal segment increases holding power, which is often needed because of the short length of the distal segment. Intramedullary pinning is more appropriate for stabilization in small and medium-sized animals (Figure 61-11). The techniques discussed in the following sections on physeal and epiphyseal fractures are used.

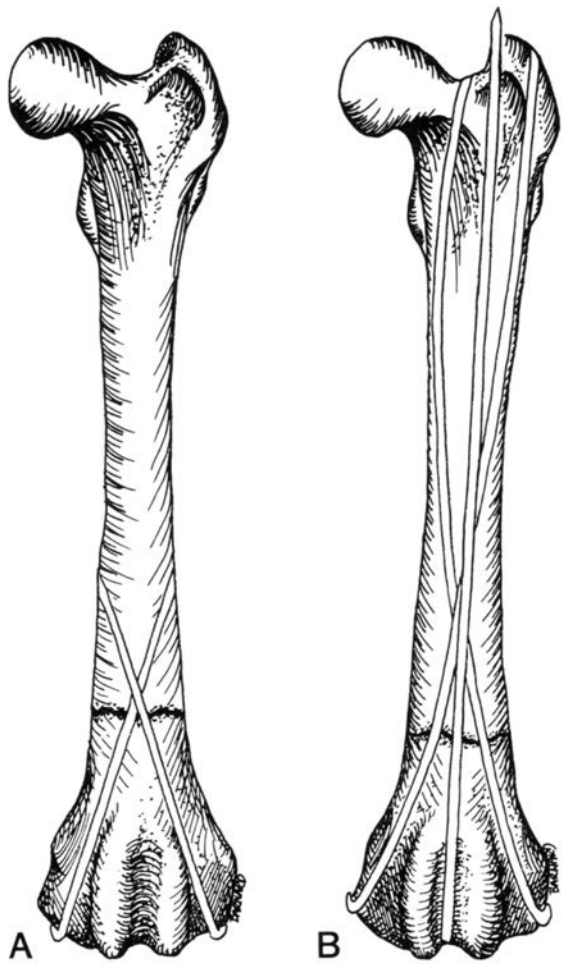


Figure 61-11. A transverse distal metaphyseal femoral fracture can be stabilized by cross-pins driven from the condyles **A.** or by double intramedullary pins driven in a Rush pin technique from the condyles and one intramedullary pin driven from the trochlea **B**.

Physeal Fractures

Most distal physeal fractures occur in immature animals (4 to 12 months old) because the zone of hypertrophy is structurally much weaker than the surrounding bone, tendons, and ligaments. The most common fractures are Salter I (involvement of the growth plate only) and Salter II (involvement of the growth plate and metaphysis), which fortunately do not involve the germinative or growth layer of the physis. Few complications associated with

premature closure of the physis have been noted. Rapid healing can be expected because of the adjacent rich blood supply.

External support alone infrequently allows for normal reduction and bone union and subsequent normal functional use. As with any joint, immobilization of the stifle may lead to adhesion formation and loss of joint motion. Most distal physeal fractures, however, require internal fixation by some type of pinning procedure.

Antegrade introduction of a single Steinmann pin from the trochlea just cranial to the origin of the cruciate ligaments provides maximum purchase in the small distal segment. Reduction of the fracture before pin placement is ideal. Careful handling of the distal segment is important because of the softness of the bone and the presence of articular cartilage. Over-zealous use of bone forceps may result in significant damage. Placement of the pin in the distal segment before reduction, using the pin as a lever, is possible if done carefully (Figure 61-12A). The pin may pull out of the bone, resulting in enlargement of the hole, if the veterinary surgeon is not careful. The pin is driven proximally, exiting through the trochanteric fossa (Figure 61-12B). After the distal end is cut, the pin is retracted proximally until the blunt end is seated just below the cartilaginous surface of the trochlea (Figure 61-12C). Stabilization of these fractures is aided by the interlocking of metaphyseal protuberances in epiphyseal fossae, providing rotational stability.

Retrograde placement of the pin avoids damage to the articular cartilage, but it may not always provide adequate purchase in the distal segment. If this method is used, the pin is placed along the caudal aspect of the femur to allow for maximum purchase in the distal segment.

Other methods of fixation include double pinning, modified Rush pinning, and cross-pinning (See Figure 61-11). With all methods, the pins are started just lateral and medial to the trochlear ridges

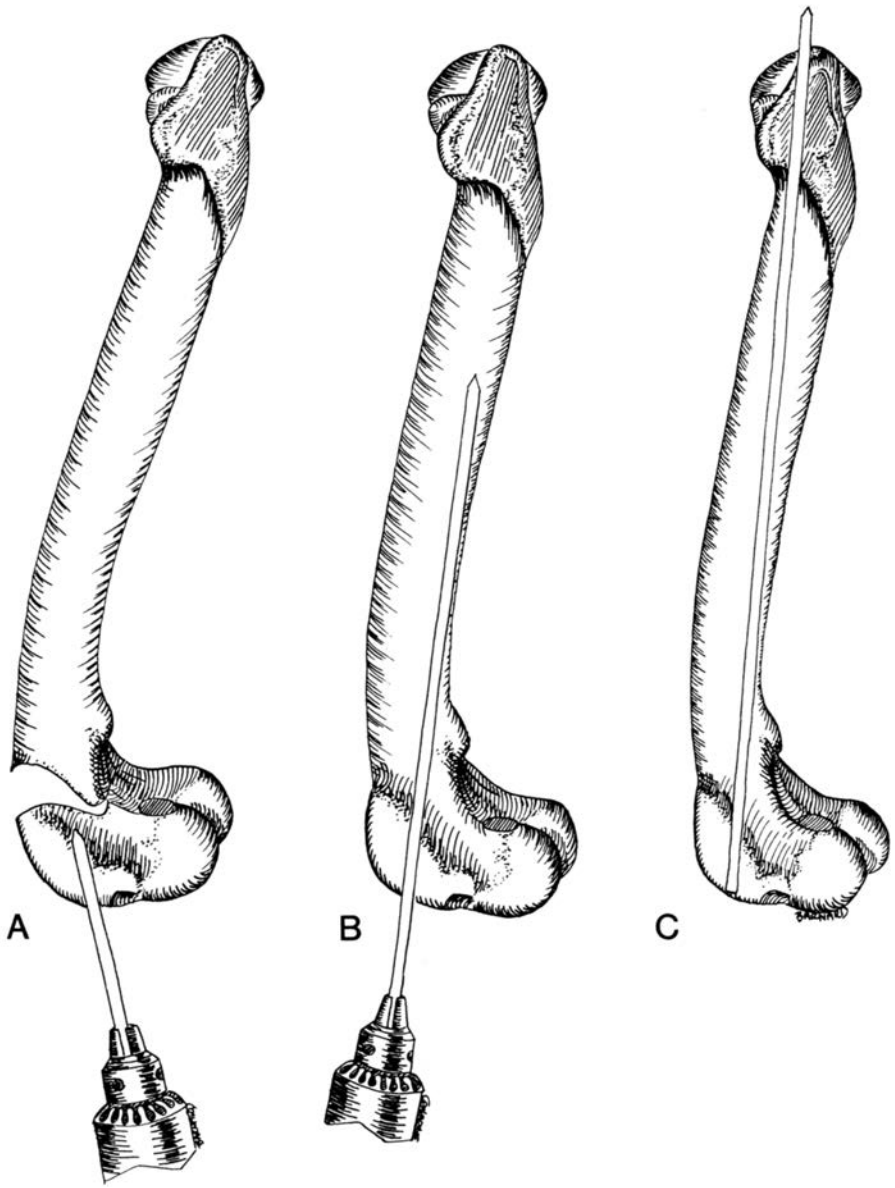


Figure 61-12. Single intramedullary pinning of a Salter I or II fracture of the distal femoral physis. **A.** The pin is placed through the epiphysis. **B.** After the fracture is reduced, the pin is driven up the caudal surface of the shaft, exiting through the trochanteric fossa. **C.** The pin is cut distally and retracted proximally until embedded below the articular surface.

and cranial to the collateral ligaments (Figure 61-13). Larger, less flexible pins are used with cross-pinning fixation. The pins must cross above the fracture line. Exiting of the pins too close to the fracture may lead to failure with weightbearing. Placement of the pins in retrograde fashion results in less than maximum purchase in the distal segment.

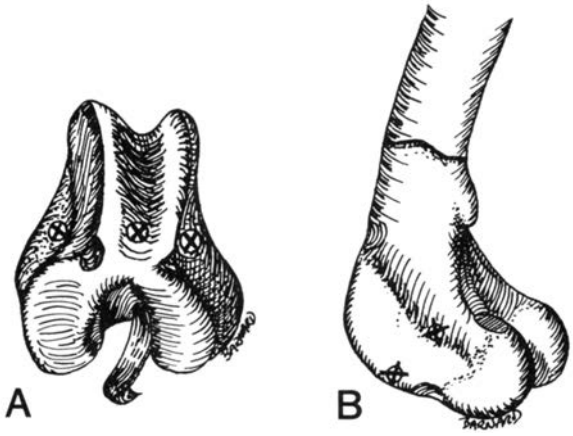


Figure 61-13. Craniocaudal **A.** and lateral views **B.** of the placement of intramedullary pins into the distal femoral segment. The lateral and medial pins are placed cranial to the collateral ligaments on either side of the trochlear ridges. The pin placed through the trochlea is just cranial to the origin of the cranial cruciate ligament. Normograde placement of these pins provides maximum purchase in the distal segment.

Epiphyseal Fractures

Excellent radiographic technique is required to demonstrate distal epiphyseal fractures because displacement is often minimal. If not stabilized, these fractures result in degenerative joint disease because of the articular involvement.

The medial condyle is most often involved. Exploration of the joint is required to remove any cartilage and bone fragments and to inspect the menisci and cruciate ligaments. Lag screw fixation, the recommended repair technique, achieves accurate realignment of the articular surfaces and compresses the fracture. In small dogs and cats, multiple Kirschner wires or a single wire and lag screw can provide good fixation (Figure 61-14).

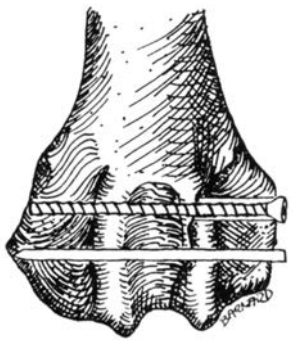


Figure 61-14. Condylar or epiphyseal fractures of the distal femur usually involve the articular surface. Lag screws and Kirschner wire fixation provide rigid fixation.

Postoperative Management and Complications

Physical therapy is an important part of the total treatment regimen in all animals with femoral fractures.

The soft tissue structures around a fracture also sustain trauma, and the bruised and swollen muscles require appropriate therapy after fracture fixation.

Fractures of the Femoral Head and Neck

All animals require strict confinement for the first 4 to 6 weeks after repair of a femoral head and neck fracture. The owner should be instructed on the method of physical therapy of the hip joint to help to restore early limb function.

Radiographic evaluation at 4 to 6 weeks usually reveals thinning of the femoral neck. In most cases, this thinning is normal, but if pronounced lameness is still apparent at this time, these findings suggest avascular necrosis and possible failure of the fixation. If the animal is recovering use of the limb, radiographic evaluation usually is delayed until 6 to 8 weeks after stabilization. Radiographic evaluation after complete healing has occurred usually reveals a thickening of the femoral neck and some evidence of degenerative joint disease. Removal of the implants is not recommended unless complications occur.

Other Femoral Fractures

Physical therapy should be instituted within 2 to 3 days of the surgical procedure. Gentle flexion and extension of the hip and stifle joints for 3 to 5 minutes, a minimum of three times daily, assist in the early return of limb function. This is especially important in an immature dog with a fractured femur, which is prone to quadriceps muscle contraction and tie-down. If this syndrome is allowed to progress to the stage of severe stifle hyperextension, the prognosis for return of limb function is poor. Walking the animal on a leash during the first 4 weeks postoperatively also encourages use of the limb and a return of the normal range of motion in all joints.

Pin migration into the stifle results in damage to the trochlear groove and the patella and, ultimately, in degenerative joint disease. Migration proximally may cause open wounds and possibly osteomyelitis. Sciatic nerve entrapment may result from pin migration or formation of fibrous tissue at the proximal end of adequately seated pins. Clinical signs include acute onset of lameness, pain in the hip region, and eventual knuckling of the paw and hypalgesia over the area of nerve distribution. Exploration and freeing of the nerve from the fibrous tissue are required to allow recovery; in addition, the pins should be shortened or removed if complete fracture healing has occurred. Return of normal limb function depends on the degree of nerve damage sustained in such cases.

Suggested Readings

Aron DN, et al. A review of reduction and internal fixation of proximal femoral fractures in the dog and man. J Am Anim Hosp Assoc 1979;15:455.

Daly WR. Femoral head and neck fractures in the dog and cat: a review of 115 cases. Vet Surg 1978;7:29.

Frey AJ, Olds R. A new technique for repair of comminuted diaphyseal fractures. Vet Surg 1981; 10:51.

Gambardella PC. Full cerclage wires for fixation of long bone fractures. Compend Contin Educ Pract Vet 1980,11:665.

Gilmore DR. Application of the lag screw. Compend Contin Educ Pract Vet 1983;5:217.

Grauer GF, Banks WJ, Ellison GW, et al. Incidence and mechanisms of distal femoral physeal fractures in the dog and cat. J Am Anim Hosp Assoc 1981; 17:579.

Hauptman J, Butler HC. Effect of osteotomy of the greater trochanter with tension band fixation on femoral conformation in beagle dogs. Vet Surg 1979;8:13.

Hulse DA, Abdelbaki YZ, Wilson J. Revascularization of femoral capital physeal fractures following surgical fixation. J Vet Or-thop 1981,2:50.

Hulse DA, et al. Use of the lag screw principle for stabilization of femoral neck and femoral capital epiphyseal fractures. J Am Anim Hosp Assoc 1974; 10:29.

Kaderly RE, Anderson WD, Anderson BG. Extraosseous vascular supply to the mature dog's coxofemoral joint. Am J Vet Res 1982;43:1208.

Kagan KG. Multiple intramedullary pin fixation of the femur of dogs and cats. J Am Vet Med Assoc, 182:1251, 1983.

Milton JL, Home RD, Goldstein GM. Crosspinning: a simple technique for treatment of certain metaphyseal and physeal fractures of the long bones. J Am Anim Hosp Assoc 1980; 16:891.

Milton JL, Newman ME. Fractures of the femur. In : Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1985.

Nunamaker DM. Repair of femoral head and neck fractures by interfragmentary compression. J Am Vet Med Assoc 1973,162:569.

Renegar WR, Leeds EB, Olds RB. The use of the Kirschner-Ehmer splint in clinical orthopedics. Compend Contin Educ Pract Vet 1982,4:381.

Rhinelander FW, Wilson JW. The blood supply of developing mature and healing bone. In: Sumner-Smith G, ed. Bone in clinical orthopedics. Philadelphia: WB Saunders, 1982.

Rivera LA, Aldelbaki YZ, Hulse DA. Arterial supply to the canine hip joint. J Vet Orthop 1979; 1:20.

Shires PK, Hulse DA. Internal fixation of physeal fractures using the distal femur as an example. Compend Contin Educ Pract Vet 1980; 11:854.

Stone EA, Betts CW, Rowland GN. Effect of Rush pins on the distal femoral growth plate of young dogs. Am J Vet Res 1981 ;42:261.

Repair of Patellar Fractures

Derek B. Fox

Pathophysiology

The patella is a large sesamoid bone which is responsible for redirecting the forces generated from the contraction of the quadriceps muscle group to the patellar ligament and tibia. As such, it is under continuous tension during pelvic limb weight bearing. Fractures of the patella are uncommon and constitute less than 1% of all fractured bones in the small animal. It is thought that patellar fractures occur by one of two injury mechanisms: either through hard falls during which the animal lands on its feet, thus causing a sudden overload of tensile forces across the patella, or from direct impact such as vehicular trauma. The mechanism of the injury often dictates the mode of failure of the patella and subsequent fracture type. Patellar fractures can be transverse, longitudinal or comminuted with varying degrees of displacement. Overloading injuries from high falls typically fracture the patella in a transverse fashion whereas direct trauma from impacts can lead to comminuted fractures.

Acutely, patellar fractures result in a non-weight bearing lameness of the affected limb. Swelling and crepitus is palpable over the distal quadriceps tendon, patella and patellar ligament. Animals with patellar fractures are usually unable to extend the stifle for some time following the injury. If left untreated, organizing fibrous tissue will eventually form within the fracture allowing the animal to minimally bear weight on the limb, however the swelling on the cranial surface of the stifle will persist. Direct palpation of the fractures is not possible due to abundant inflammation of the overlying soft tissues. Definitive diagnosis of patellar fractures can be achieved with standard radiography. In addition to orthogonal views, oblique positioning can be useful in tangentially highlighting subtle fissure fractures. In addition, the appearance of non-displaced fractures can be enhanced by stressing the patella by flexing the stifle while taking the radiograph.

Treatment

There are three objectives for patellar fracture repair: 1) re-establish the function of the quadriceps mechanism, 2) anatomically reduce the articular chondral surface of the patella to minimize secondary osteoarthritis and 3) apply appropriate fixation to the fracture to optimize osseous union.

Surgical Repair

Prior to surgical reduction of the fracture, the stifle must be examined either arthroscopically or via arthrotomy for evaluation of the articular surface of the patella as well as for additional injury, including cruciate or meniscal damage. Arthrotomies can be completed either medially or laterally without risk of patellar vascular impairment as the patella possesses a complex interior vascular network instead of being supplied through a single nutrient vessel. Because of the large tensile forces constantly applied to the patella, most fractures are displaced to some degree. Repair strategies must be directed at countering the distracting pull of the quadriceps. For most transverse and some comminuted fractures, this can be accomplished with a variety of tension band configurations (Figure 61-15). In each case, the wire must be placed on the cranial, or tension surface, of the patella. Placement of the tension band on either the medial or lateral surface will result in malreduction of the fracture. The extensiveness of the repair is often dictated by the size of the animal and the complexity of the fracture. Non-displaced transverse fractures in medium to smaller-sized animals can be treated with single cerclage wires placed through the quadriceps tendon and patellar ligament (Figure 61-15A and B). Larger and less compliant animals will benefit from the addition of Kirschner wires and the application of the orthopedic wire in a pin and tension band fashion (Figure 61-15C-F). Passage of orthopedic wire through the quadriceps tendon and patellar tendon should be kept as close to the patella as possible. This can most easily be accomplished by placing a hypodermic needle just proximal and distal to the patella through which the orthopedic wire can be passed. The tension band should be tightened sufficiently to provide compression across the fracture lines.

To combat individual bone segment rotation around a single wire (Figure 61-15C), the Kirschner wires can be applied in pairs in both parallel and crossed fashion. Kirschner wires can also be used to align separate fragments encountered with comminuted fractures (Figure 61-15E). When applying Kirschner wires to the patella, pre-drilling is necessary as the bone is very dense. Retrograde application allows greater placement accuracy. Fragment reduction is most optimally accomplished with the leg in extension and a bone holding forceps placed longitudinally across the patella. Although uncommon, pure longitudinal patellar fractures can occur and can be treated with modifications of the aforementioned techniques in addition to lag screwing.

Post-operative care for a standard repair includes keeping the limb immobilized and in extension within a soft padded-bandage for several days following surgery. The animal should have restricted activity for the ensuing 4 to 6 weeks to minimize repetitive cyclic tensile load on the repair. Gentle physical therapy, such as passive range of motion, is appropriate to help combat severe quadriceps muscle atrophy during the post-operative convalescent period. Additional radiographs should be completed to document healing and to examine for implant migration which is not uncommon. Implants can be removed following radiographic union if they are the source of pain or are unstable.

Patellectomy

If small chondral or osteochondral fragments are not able to be incorporated into the repair, or appear unstable following fracture reduction, they may be removed. In certain cases, there exist highly comminuted, irreparable fractures of the distal apical third of the patella only. In this situation, the proximal patella is salvaged while removing the distal fragments

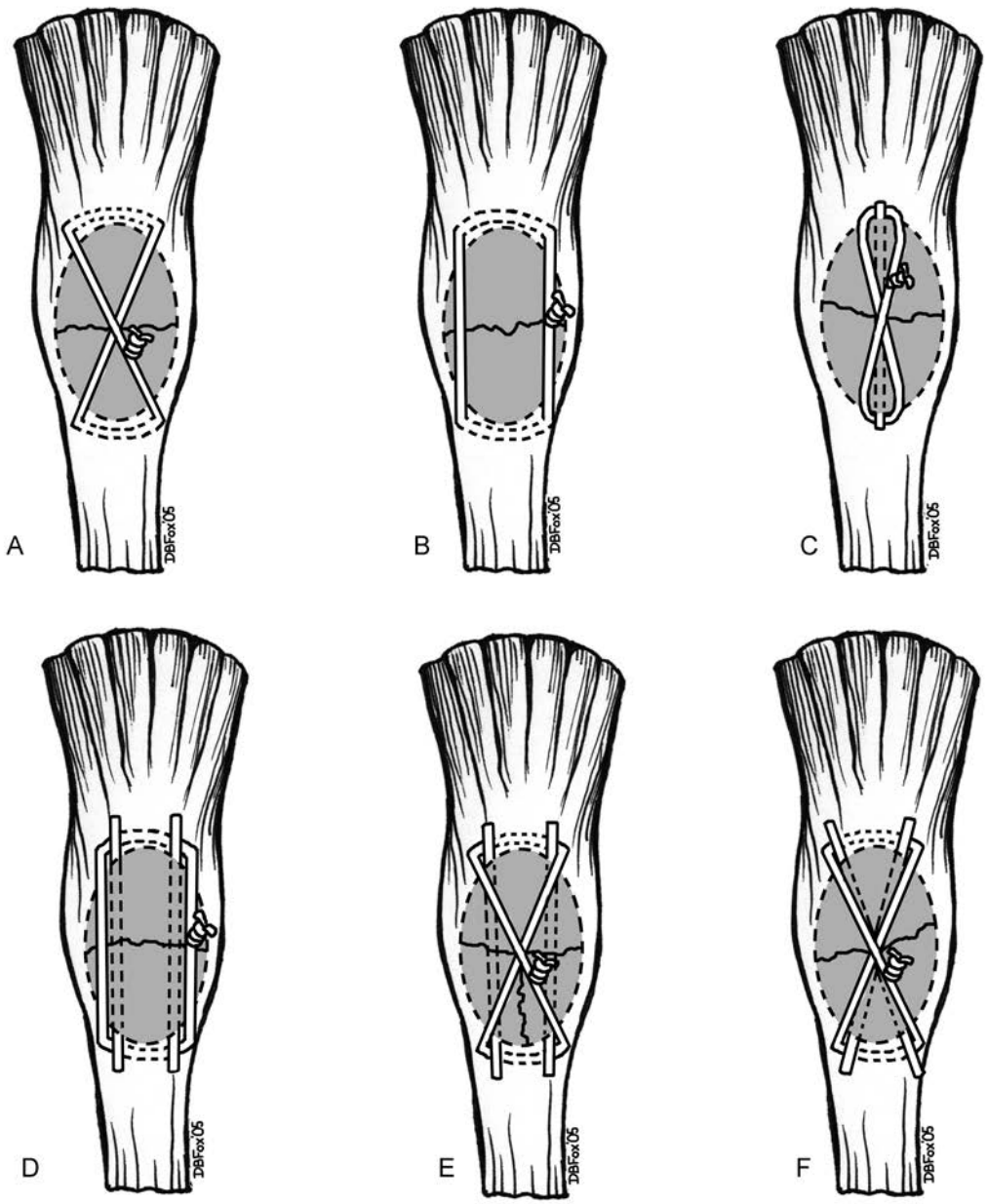


Figure 61-15. Techniques for patellar fracture repair. **A.** Figure-of-eight tension band fixation. **B.** Circumferential cerclage wire fixation. **C.** Single Kirschner wire with figure-of-eight tension band. **D.** Parallel Kirschner wires with circumferential cerclage wire. **E.** Parallel Kirschner wires with figure-of-eight tension band fixation of a comminuted fracture. **F.** Crossed Kirschner wires with figure-of-eight tension band.

constituting a partial patellectomy. This is completed from the articular surface of the patella with ronguers or forceps and scalpel. Because this may weaken the junction of the patellar ligament and potentially lengthen the quadriceps mechanism, surgical reinforcement and imbrication of the ligament may be indicated with 4-0 stainless steel or heavy gauge non-absorbable suture following partial distal patellectomy (Figure 61-16). Occasionally, partial patellectomy will result in the surgical transection of the patellar ligament which will require primary repair. Patellar ligament repair techniques can be reinforced with the placement of a temporary patello-tibial cerclage wire which protects the ligament from tensile forces during healing (Figure 61-17).

For large, highly comminuted and irreparable patellar fractures, total patellectomy can be completed. However with the propagation of degenerative joint disease and altered quadriceps function, the prognosis for return of normal function of the limb is very poor. Therefore, preservation and, if possible, reconstruction of the larger fragments of the fractured patella is advantageous over total patellectomy.

Non-surgical Treatment

If financial constraints prohibit surgical treatment of patellar fractures, conservative management may be considered. Non-surgical care consists of keeping the limb immobilized in extension for 4 to 6 weeks. Complications associated with this technique include advanced osteoarthritis associated with the non-anatomic reduction of chondral fractures on the articular surface of the patella and prolonged joint immobilization. In addition, non-unions and delayed unions may occur with the development of fibrous interpositional tissue within the fractures. These complications necessitate the need for diligent and aggressive physical therapy following the period of immobilization. The prognosis for non-surgically treated displaced patellar fractures is guarded.



Figure 61-16. Technique for reinforcement and shortening of the patellar ligament following distal partial patellectomy non-absorbable suture.

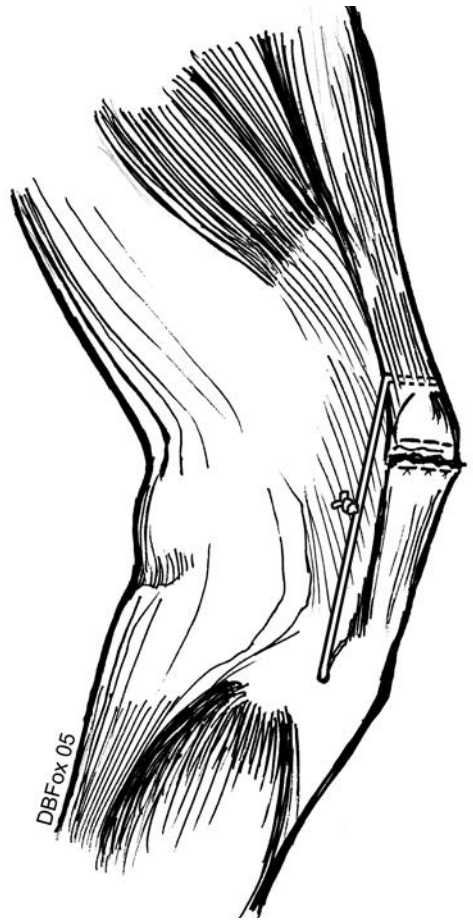


Figure 61-17. Illustration of a temporary patello-tibial cerclage wire used to protect a reconstructed patellar ligament following partial patellectomy. The wire is passed through the quadriceps tendon just proximal to the patellar remnant and through a bone tunnel created in the tibial crest.

Suggested Readings

Arnoczky SP, Tarvin GB: Surgery of the stifle: the patella. *Compend Contin Educ Pract Vet* 2:200, 1980.

Betts CW, Walker M: Lag screw fixation of a patellar fracture. *J Small Anim Pract.* 16:21, 1975.

Howard PE, Wilson JW, Robbins TA et al.: Normal blood supply of the canine patella. *Am J Vet Res* 47:401, 1986.

McLaughlin R: Intra-articular stifle fractures and arthrodesis. *Vet Clin North Am Small Anim Pract* 23:877, 1993.

Piermattei DL, Flo GL: Fractures of the Femur and Patella *In* Brinker WO, Piermattei DL, Flo GL, eds.: Handbook of Small Animal Orthopedics and Fracture Repair, Third edition. Philadelphia: W.B. Saunders, 1997, p 469.

Surgical Repair of Patellar Luxations

Guy B. Tarvin and Steven P. Arnoczky

Introduction

Problems involving the patella are frequent causes of lameness in small animals. The most common problem is patellar luxation. Medial luxation is the most frequent type occurring over 75% of the time and is the most prevalent type in small dogs and cats. Lateral luxation occurs most frequently in larger breed dogs and is much less common than medial luxation.[1] Although traumatic patellar luxations may occur, in the authors' experience they are very rare. There is strong evidence that the majority of patellar luxations are heritable in nature[2] and appropriate recommendations such as neutering/OHE and a removal of affected individuals from breeding stock should be part of the treatment regimen encouraged by the Veterinarian.

Functional Anatomy

The patella can be described as the ossified portion of the quadriceps tendon. Although the patella itself is a passive structure in the body, it plays an important role in a dynamic system referred to as the extensor mechanism of the stifle. Movement of the patella is under direct influence of this mechanism, and knowledge of the mechanics of this system is essential in the treatment of patellar dysfunctions.

The primary extensor group of muscles of the stifle is the quadriceps femoris. Three of the four muscles in this group, the vastus lateralis, the vastus medialis, and vastus intermedius, originate from the proximal femur, whereas the fourth, the rectus femoris, originates from the ilium; all four converge to form the quadriceps tendon.[3] This tendon primarily attaches to the proximal portion of the patella; however, a thin portion crosses over the cranial surface of the patella to blend with the patellar ligament.

The patellar ligament is a strong band of fibrous connective tissue that courses from the patella to the tibial tuberosity. When the quadriceps muscle group contracts, the resulting force pulls on the patella, the patellar ligament, and the tibial tuberosity, causing extension of the stifle. During this motion, the patella rides in the trochlear groove. A cross section of the patella reveals a convex articular surface. The corresponding trochlear groove is concave and therefore allows for an intimate articulation between the femur and patella. On both sides of the patella and attached to the joint capsule are the parapatellar fibrocartilages. These structures articulate with the trochlear ridges and increase the surface area and thus disperse the force of the quadriceps muscles.

Normal alignment of the extensor mechanism is necessary for stability of the stifle joint. Dysfunction of this mechanism results in abnormal joint mechanics and joint instability.[5] Such instability not only causes degenerative joint disease but also places increased stress on other supporting structures, such as the cranial cruciate ligament, the collateral ligaments, and the menisci.[3]

Pathogenesis and Diagnosis

Medial patellar luxation is one of the most common patellar problems presented to the veterinary practitioner.[1,5-7] This disorder can be either congenital or traumatic. The congenital form, which is more common, usually is observed in small breed dogs[1,8] and may cause minimal to severe gait abnormalities. The clinical picture often is one of an obese animal with varus (bow-legged) deformity of the rear limbs. The animal often crouches, owing to the inability to extend the stifles fully, with its toes pointed inward. Often, the owner describes a skipping or hopping type of gait in which the animal skips one or more steps on the involved limb. This gait, which is generally transient, is caused by the patella's riding up and over the medial trochlear ridge and being "trapped" on the medial aspect of the joint. Bilateral limb involvement is not unusual. Medial patellar luxations, unless traumatic, rarely cause acute lameness. Although medial patellar luxations sometimes coexist with acute lameness, these luxations usually are chronic; thus, other causes of acute lameness should be pursued. Those dogs with a history of patellar luxation and a sudden onset of pain in the stifle should be examined carefully to rule out cruciate ligament injury.

The incidence of medial patellar luxations in cats is much lower than that of dogs. Abyssinians and Devon Rex breeds may be predisposed to congenital medial patellar luxations.[1] The authors find that many of the same diagnostic and treatment protocols can be applied to cats suffering from medial patellar luxations.

Various causes of congenital medial patellar luxation have been proposed.[7,9-11] Its pathogenesis, however, probably involves a combination of underlying bony abnormalities, any of which may be a cause or an effect of the disorder. Any of the following abnormalities can result in congenital medial patellar luxation, coxa vara, medial displacement of the quadriceps tendon, external femoral torsion, medial deviation of the distal femur, shallow trochlear groove, internal rotation and medial deviation of the proximal tibia.[7,11] Some degree of each deformity may be present in all cases.

Diagnosis is primarily based on palpation. After observing the patient ambulate and assessing conformation, a thorough general and orthopedic evaluation of the patient is performed. To evaluate the patellar mechanism, the authors prefer to have the pet stand on the ground and approach it from the rear. Both stifles are palpated to assess the position of the patella. With one hand over the patella, the other hand gently flexes and extends the stifle. Internal and external rotation of the tibia can also be incorporated during this maneuver. Spontaneous luxation may occur. If no luxation occurs, gentle medial and then lateral pressure is applied to the patella to determine if it will luxate. In the normal stifle the patella may ride up on the trochlear ridge but should not easily luxate. In immature or young patients, some degree of joint laxity is normal. In the young patient, if the patella remains in place but can be luxated only with digital pressure, the authors recommend to follow that patient. In our experience, many of these patients will stabilize once mature. The surgeon should not forget to assess other structures of the stifle such as the cranial cruciate ligament for integrity.

Radiographs to include the hips and stifles are useful to assess for concurrent problems such as aseptic necrosis of the femoral head in young small breed dogs and hip dysplasia in larger breeds. They are also useful in assessing the amount of coxa vara, coxa valga, and femoral and tibial torsion.

Repair of Patellar Luxations

Because the presenting symptoms and signs of medial patellar luxation vary in severity, each patient should be handled individually. Numerous methods exist for the repair of medial patellar luxation,[5-7,12-16] and a single technique may not work or may not be indicated for all degrees of medial patellar luxations. The following discussion presents our treatment approach, which is based on the grading system of Putnam.[11]

Grade I Luxations

In a grade I medial patellar luxation, the stifle joint is almost normal, and the patella luxates only when the joint is extended and digital pressure is applied. Animals with grade I medial patellar luxation often have no clinical signs when presented. Indications for surgical treatment should be weighed carefully because it is difficult to suggest operating on a clinically normal animal. That these asymptomatic animals may be prone to future ligamentous or bony abnormalities,[17] owing to the abnormal pull across the joint, may justify them as surgical candidates. We recommend, however, that these animals not be operated on until they become clinically symptomatic for the disease.

The bony structures of the joint in grade I luxation are nearly normal; that is, the tibial tuberosity and the femoral trochlea are properly formed and have proper anatomic relationships within the joint. When surgical treatment is considered necessary, these two structures should be checked at the time of operation.

Surgical Approach and Assessment

For most medial patellar luxations(regardless of grade) a lateral parapatellar incision is made, and the extensor mechanism is visualized. Before opening the joint capsule, one should examine the alignment of the tibial tuberosity and the patella. These structures should be in a straight line and be parallel to the long axis of the limb when viewed from a craniocaudal direction. In grade I medial patellar luxation, these structures usually line up well. The lateral joint capsule is then opened, and the patella is retracted medially to permit visualization of the trochlear groove. The groove is examined for depth and any degenerative changes. If the groove is normal in appearance, no reconstructive procedures are needed for the trochlea.

Creation of Lateral Restraint

In most cases of grade I medial patellar luxation, the only repair required is the creation of a lateral restraint to prevent medial displacement of the patella. This can be accomplished by imbricating the lateral joint capsule with an interrupted Lembert suture pattern. In smaller animals (15 kg or less), 2-0 monofilament synthetic absorbable suture is used; in larger animals, 1-0 monofilament synthetic absorbable suture usually suffices. Another technique that has worked well is the use of a single suture of 1-0 or 2-0 nylon passed around the lateral fabella and through the quadriceps tendon just proximal to the patella. The suture is then directed distally along the medial border of the patella and is passed through the patellar ligament immediately distal to the patella. The suture is tied on the lateral aspect of the joint and restricts medial displacement of the patella. This technique works especially well in large dogs.[4]

The patella is now examined by placing a varus stress on the stifle and by internally rotating the tibia. If the patella does not luxate through a range of motion with the limb in this position and with digital pressure applied to the patella, the repair is sufficient. If the patella still has a tendency to luxate, a medial releasing incision is created by making a longitudinal parapatellar incision through the fibrous portion of the joint capsule; this incision is not closed. These procedures work well if the tibial tuberosity and femoral trochlea are normal. If these structures are abnormal, soft tissue procedures alone are not capable of overcoming the problem.

Grade II Luxations

The patella usually lies in its normal position in grade II luxation, but luxates with flexion of the joint and remains luxated until relocated by manual pressure or extension of the joint. Animals with grade II medial patellar luxation usually have some form of gait disturbance. They are also more likely to develop degenerative changes than are animals with grade I luxation because of the greater degree of malarticulation.

Trochleoplasty

The tibial tuberosity and trochlear groove are evaluated as described for grade I luxations. If the trochlear groove is shallow, it is corrected first. There are several options to deepen the trochlea. One is to perform a trochleoplasty. This is performed by first making two parallel incisions into the trochlear cartilage with a scalpel blade. These incisions delineate the medial and lateral boundaries of the new trochlear groove. The groove should be wide enough to permit proper seating of the patella while maintaining an adequate lateral and, especially, medial trochlear ridge. The cartilage between the incisions is removed with a bone rongeur or a high-speed drill.[7] In younger dogs, the cartilage can easily be removed with a No. 15 scalpel blade. The groove must be deepened uniformly to the level of bleeding subchondral bone to ensure the regeneration of fibrocartilage.[16] The new groove should be of sufficient width to accommodate the patella, it should have a well-developed medial ridge, and it should be of sufficient depth to discourage luxation (Figure 61-18).

After this type of trochleoplasty, fibrocartilaginous tissue forms over the articulating surface of the deepened trochlear groove.[16] Although this newly generated fibrocartilage surface does not possess the same physical properties of articular (hyaline) cartilage, it was thought to be sufficiently similar to be clinically effective, and indeed this technique has given good results over the years. Nonetheless, preservation of the normal hyaline cartilage surface of the trochlear groove would be expected to enhance the results of the deepening procedure.[18] To that end, a newer procedure, the trochlear wedge recession technique, was developed to deepen the trochlear groove without destroying the cartilage present.[18,19]

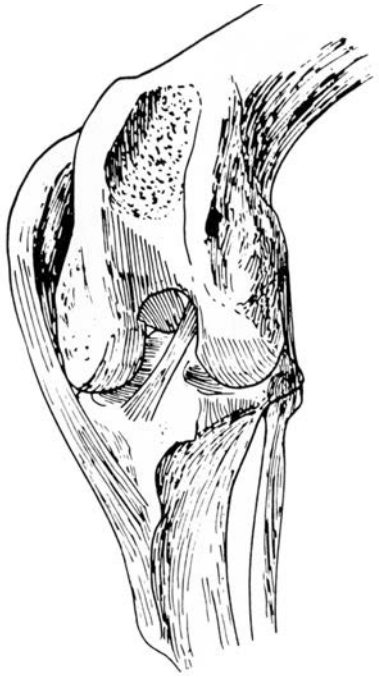


Figure 61-18. Trochleoplasty is performed to widen and deepen the femoral trochlear groove. (From Arnoczky SP, Tarvin GB: Surgery of the stifle: the patella. *Compend Contin Educ Pract Vet* 2:200, 1980.)

Trochlear Wedge Recession Technique

In this technique, an osteochondral wedge is removed from the trochlear groove with a fine-tooth bone saw. As in the previously described trochleoplasty, an adequate trochlear ridge must be maintained on the medial and lateral aspect of the trochlear groove. To accomplish this, the saw cuts are started at the highest point on the medial and lateral trochlear ridges (Figure 61-19A). The cuts are then directed to intersect at a point just proximal to the femoral origin of the caudal cruciate ligament. Care is taken not to extend the osteochondral wedge into the intercondylar notch. The osteochondral wedge is then removed to reveal a V-shaped trochlear bed (Figure 61-19B). Owing to the width of the saw blade used to remove the wedge, the wedge of bone is actually smaller than the created bed, therefore, when the osteochondral wedge is replaced into the groove, the wedge is naturally recessed, resulting in a deepened trochlear groove. If additional depth is required (at least 50% of the patellar depth should be seated in the groove), approximately 1 to 1.5 mm of additional bone can be removed by making another set of saw cuts parallel to the first (Figure 61-19C). The wedge is then replaced in the bed, so the original cartilage surface is recessed (Figure 61-19D). The friction of the cancellous bone surfaces (plus the compressive force of the articulating patella) keeps the wedge in place, and no fixation appliances are needed. Even more recently, a third option (Figure 61-20) the rectangular recession trochleoplasty has been suggested as an improvement on the trochlear wedge recession.[20] An experimental in vitro study indicates that the rectangular recession has increased patellar articular surface contact, less subchondral bone exposure, recesses a larger percentage of the trochlea, and results in greater resistance to patellar luxation with the stifle extended as compared to the trochlear wedge recession.[21] However the rectangular recession is more technically difficult to perform. To date no clinical studies comparing the two have been performed.

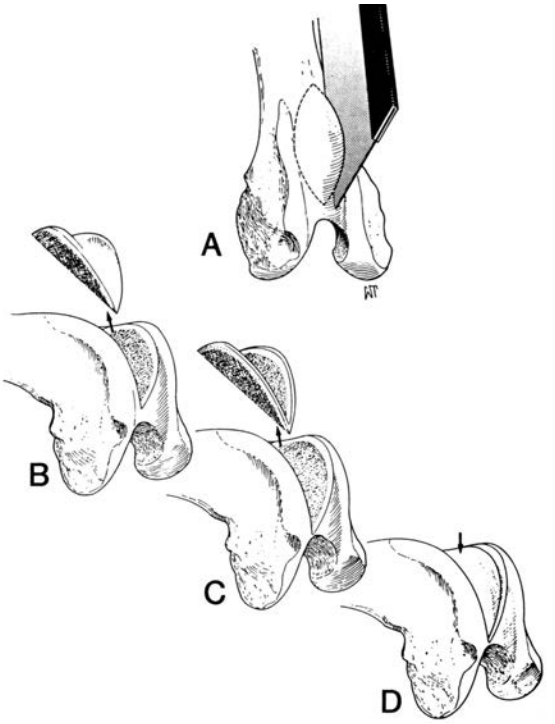


Figure 61-19. Trochlear wedge recession technique. **A.** Location of medial and lateral saw cuts. **B.** Removal of osteochondral wedge **C.** Deepening of trochlear bed by removal of a second wedge. **D.** Replacement of osteochondral wedge with original cartilage surface into the trochlear bed. See text for details. (Adapted from Boone EG Jr, Hohn RB, Weisbrode SE: Trochlear recession wedge technique for patellar luxation: an experimental study. *J Am Anim Hosp Assoc* 19:735, 1983.)

Transposition of Tibial Tuberosity, Lateral Imbrication, and Medial Releasing Incision

If the tibial tuberosity is deviated medially, this deviation is corrected by transplanting the attachment of the patellar ligament to a more lateral position. This transplantation is done by osteotomy of the tibial tuberosity. Care is taken to preserve the distal fascial attachment of the osteotomized portion of the tibial tuberosity to the distal tibia as this enhances stability to the repair. The osteotomized portion of tibial tuberosity is placed more lateral under the cranial tibialis muscle.[5,6,12,14,15] The tibial tuberosity is then fixed in place by one or two small Kirchner wires (Figure 61-21). The patella is then tested in the previously described manner for stability. Little, if any, tendency for luxation should be noted. If some tendency for medial luxation still exists, the tibial tuberosity can be moved farther laterally, or the joint capsule can be imbricated laterally. A medial releasing incision can be added if necessary (Figure 61-22).

Transposing the tibial tuberosity with the aforementioned technique, does result in rotation of the patellar ligament and caudalization of the insertion of the ligament on the tibia (Figure 61-23A). It has been proposed that this rotation and caudalization may predispose the patellar articular cartilage to abnormal wear with subsequent degenerative joint disease. A modification of the tibial tuberosity transplant has therefore been proposed by L'Eplattenier and Montavon[2] in which the osteotomy is created further caudally and is angled rostrally from medial to lateral in a transverse plane (Figure 61-23B). This allows the osteotomized

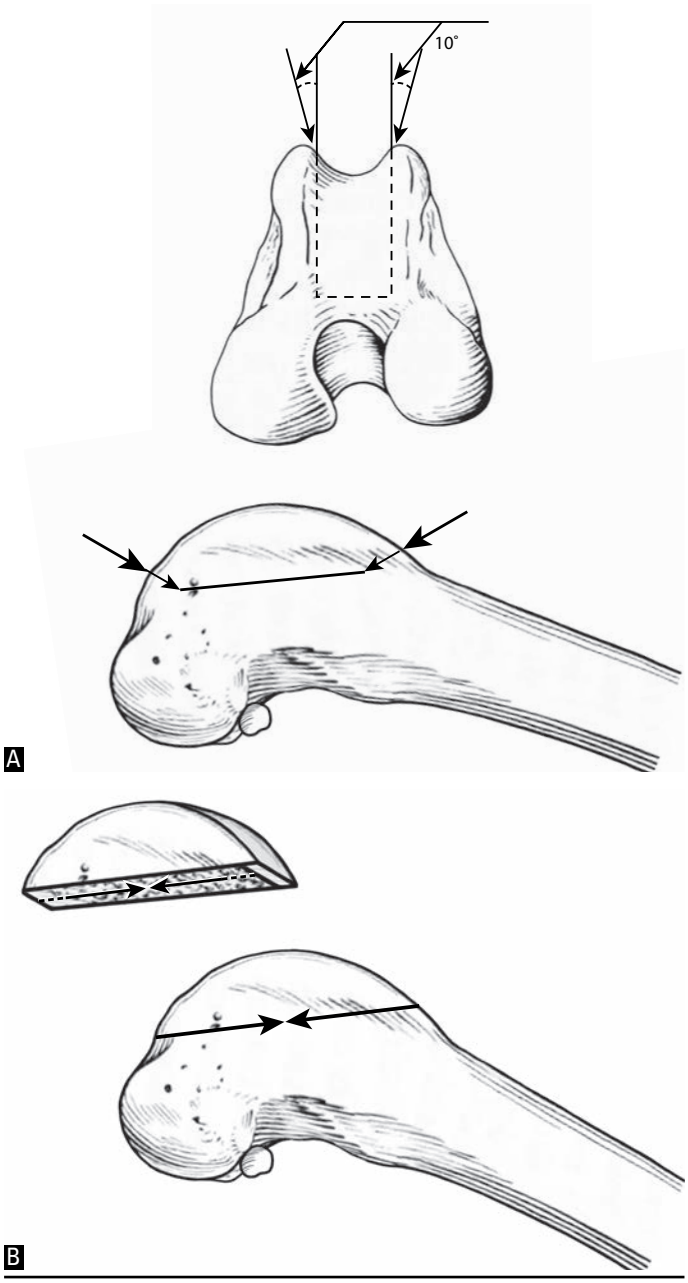


Figure 61-20. Talcott, et. al. described a rectangular recession trochleoplasty. **A.** Two views indicating location and angulation of the cuts. In the skyline view on the left, the cuts are made at an angle of about 10 degrees to perpendicular. In the lateral projection on the right the transtochlear cuts are made at 90 degrees to the trochlear surface. Talcott, et. al recommend making the proximal transtrochlear cut proximal to the patellar articulation. **B.** The rectangular wedge is undermined by alternating between the proximal and distal ends and eventual completely elevated. The bed is then deepened by removing more subchondral bone and the wedge is then replaced.

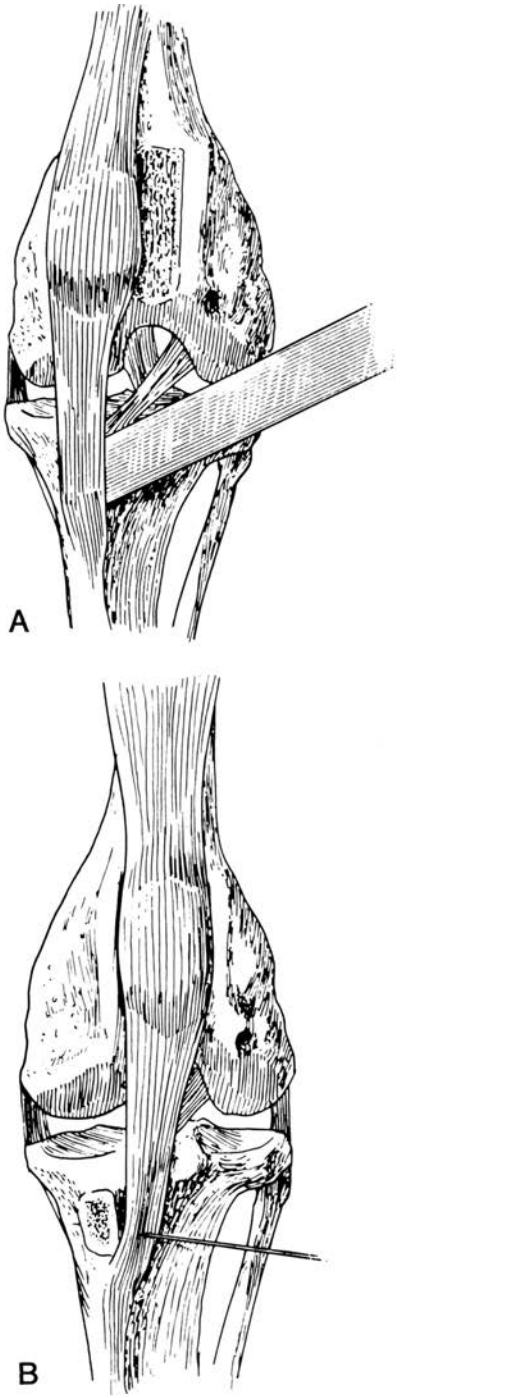


Figure 61-21. Transposition of tibial tuberosity. **A.** Osteotomy of the tibial tuberosity. The fascial extension of the patellar ligament onto the tibial crest is left intact. **B.** Lateral transplantation and fixation of the tibial tuberosity with a Kirshner wire. (From Arnoczky SP, Tarvin GB: Surgery of the stifle: patella. *Compend Contin Educ Pract Vet* 2:2000, 1980.)

portion of the tibial tuberosity to be "slid" laterally to realign the patella within the trochlear groove(See Figure 61-23B). If performed correctly, it also allows for cranialization of the patellar ligament insertion. This cranialization may actually relieve stress on the articular surface of the patella.[2] Tibial tuberosity transposition has worked well in our hands. L'Eplattenier and Montavon report good success with this technique but admit that at this time there is no comparative data to demonstrate any superiority of this technique over the first technique described in this chapter for tibial transposition. At this time, we recommend using either technique as good results can be expected from both. Perhaps future scientific data may become available to determine if one is superior to the other.

Grade III Luxations

The patella is luxated most of the time, but it may be reduced with the limb in the extended position in grade III medial patellar

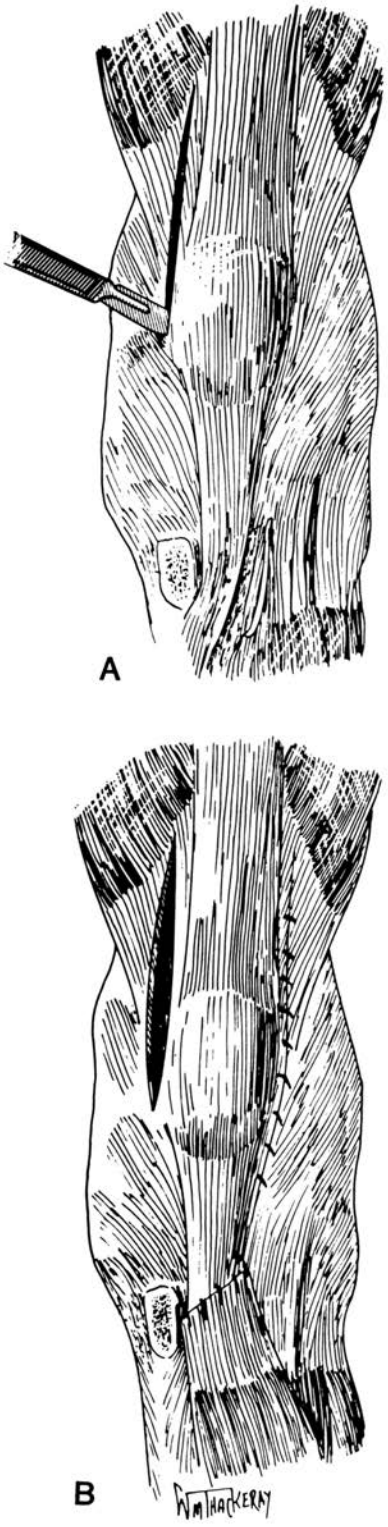


Figure 61-22. A. Medial releasing incision. **B.** Lateral imbrication of the joint capsule (From Arnoczky SP, Tarvin GB: Surgery of the stifle: patella. *Compend Contin Educ Pract Vet* 2:2000, 1980.)

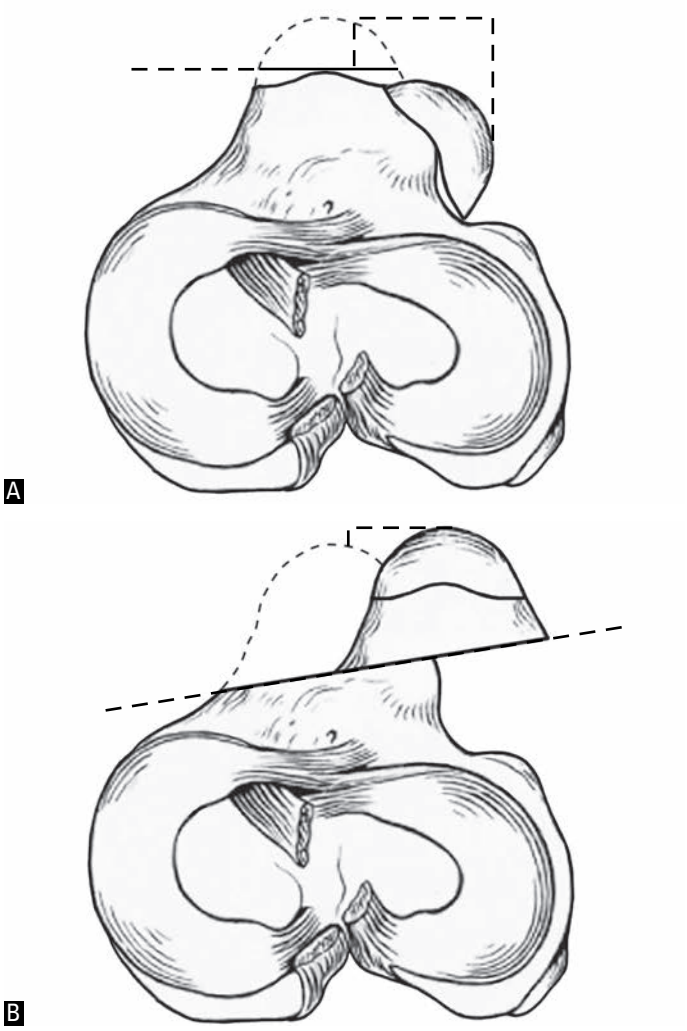


Figure 61-23. A. In the standard tibial tuberosity transposition caudalization and rotation of the fragment occurs. **B.** By creating a more caudal and angled osteotomy, the fragment can be slid to redirect the patellar tendon without caudalizing or rotating the fragment. (Redrawn with permission from L'Eplattenier H, Montavon P, Patellar luxations in dogs and cats: management and prevention. *Compend Cont Educ Pract Vet* 2002;24, 292.)

luxation. All the techniques used in treating grade II medial patellar luxations will probably be needed to correct grade III luxations. The same format for examining the structures should be followed to assess the necessity of each procedure.

If the tendency for luxation remains after correction with these techniques, the medial releasing incision may be inadequate or medial rotary instability of the tibia may be present. The medial releasing incision can be extended proximally to incise a portion of the vastus medialis muscles. If rotational instability is present, it can be corrected with a lateral suture of heavy nonabsorbable material placed around the lateral fabella and though a drill hole in the tibial crest (Figure 61-24). This suture is tightened to externally rotate the tibia and thus help realign the extensor mechanism. Usually, a combination of the aforementioned techniques are sufficient to correct a grade III medial patellar luxation.

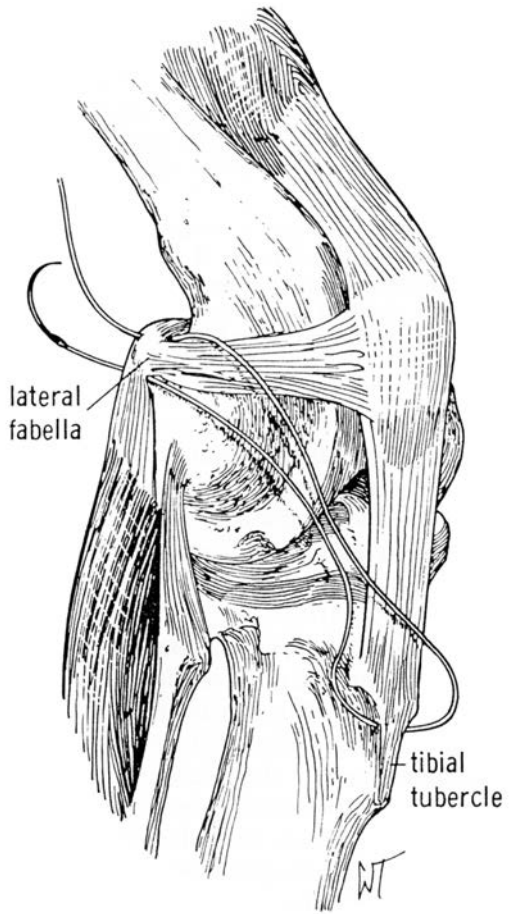


Figure 61-24. Placement of lateral derotational suture. (Arnoczky SP, Tarvin GB: Surgery of the stifle: patella. *Compend Contin Educ Pract Vet* 2:2000, 1980.)

Grade IV Luxations

The patella is dislocated and cannot be reduced without surgical intervention in grade IV medial patellar luxation. If diagnosed early, this least common type of luxation should be corrected at an early age to prevent the resulting bony deformities of the femur and tibia. In most cases; however, the patients already have severe bony deformities and the previously discussed techniques are inadequate to correct the disorder. These patients usually require osteotomies (derotational, cuneiform) of the tibia or femur to correct the anatomic structures and thereby the mechanics of the patella.[5,6]

Lateral Patellar Luxations

Lateral patellar luxations, which are not as common as medial patellar luxations, occur most often in large breed dogs.[1,5,6] The disorder can be congenital of traumatic. In the congenital form, this condition is often associated with hip dysplasia, and thus simple correction of the resulting patellar alignment may eliminate the signs and symptoms but may not correct the underlying problem. Isolated deformities, such as genu valgum, also may cause lateral patellar luxations. The deformities causing lateral malalignment of the extensor mechanism are coxa valga, increased anteversion angles, lateral displacement of the quadriceps tendon, internal femoral torsion, laxity of medial fascia and contraction of lateral fascia, and external rotation and lateral deviation of the proximal tibia. These disorders are, for the most part, the opposite of those causing medial luxations.

As in medial patellar luxations, the severity of the lesion varies widely. Affected animals usually have a valgus (knock-knee) deformity of the rear limbs and are first seen in a crouched stance with the toes pointing outward. Correction of this disorder is based on the grading system described for medial luxations. In each case, the structures of the stifle are assessed and are corrected in the same stepwise manner as for medial patellar luxation with the following obvious modifications to the procedures: 1) medial (not lateral) imbrication; 2) lateral (not medial) releasing incision; 3) medial (not lateral) transposition of the tibial tuberosity; and 4) medial (not lateral) derotational suture.

The prognosis for grades I to III medial and lateral patellar luxations is good and success has been reported as high 90%.[2] Most patients improve clinically but degenerative joint disease does progress in a majority of cases. In our experience, grade IV luxations offer a poor prognosis, may require several surgeries including osteotomies, and still remain lame.

Postoperative Care

After surgical repair of both medial and lateral patellar luxations, patients should be fitted with a soft, padded bandage for 2 weeks and have restricted exercise for a minimum of 6 to 8 weeks. In the case of bilateral patellar luxations, the most severely affected limb is usually operated on first, and at least a 4 week healing period is observed before the second limb is treated. In the authors' opinion, simultaneous bilateral repairs have a higher degree of failure and are seldom recommended.

References

1. L'Eplattenier H, Montavon P: Patellar luxation in dogs and cats: pathogenesis and Diagnosis. *Compend Contin Educ Prac Vet* 24:234, 2002.

2. L'Eplattenier H, Montavon P: Patellar luxation in dogs and cats: management and prevention. *Compend Contin Educ Prac Vet* 24:292, 2002.

3. Evans HE: Miller's anatomy of the dog. 2nd ed. Philadelphia: WB Saunders, 1993.

4. Arnoczky SP, Tarvin GB: Surgery of the stifle: patella. *Compend Contin Educ Pract Vet* 2:20001980.

5. Rudy RL: Stifle joint. *In:* Archibald J, ed.: Canine surgery. 2nd ed. Santa Barbara, Ca: American Veterinary Publications, 1974.

6. Harrison JW: Patellar dislocation. *In:* Bojrab MJ, ed.: Current techniques in small animal surgery. Philadelphia: Lea & Febiger, 1975, 714.

7. Trotter E: Medical Patellar luxation in the dog. *Compend Contin Educ Pract Vet* 2:58, 1980.

8. Priester WA: Sex, size, and breed as risk factors in canine patellar dislocation. *J Am Vet Med Assoc* 160:740, 1973.

9. Hobday F: Congenital malformation and displacement of the patella. *Vet J* 60:216, 1905.

10. Lacroix JV: Recurrent luxation of the patella in dogs. *North Am Vet* 2:47, 1930.

11. Putman RW: Patellar luxation in the dog. Master's thesis, University of Guelph, Ontario, Canada, 1968

12. Brinker WO, Keller WE: Rotation of the tibial tuberosity for correction of luxation of the patella. *Mich State Univ Vet* 22:92, 1962.

13. DeAngelis MP: Patellar luxations in dogs. *Vet Clin North Am* 1:403, 1971.

14. Flo G, Brinker WO: Fascia lata overlap procedure for surgical correction of recurrent medial luxation of the patella in the dog. *J Am Vet Med Assoc* 156:595, 1970.

15. Singleton WB: Transplantation of the tibial crest for treatment of congenital patellar luxation. *In:* Proceedings of the 27th Annual Meeting of the American Animal Hospital Association.: American Animal Hospital Association, 1967.

16. Vierheller, RC: Grooving the femoral trochlea. *In:* Proceedings of the 34th Annual Meeting of the American Animal Hospital Association.: American Animal Hospital Association, 1970.

17. O'Brian TR: Developmental deformities due to arrested epiphyseal growth. *Vet Clin North Am* 1:441, 1971.

18. Slocum B, Slocum DB, Devine T, et al.: Wedge recession for treatment of recurrent luxations of the patella. *Clin Orthop* 164:48, 1982.

19. Boone EG Jr, Hohn RB, Weisbrode SE: Trochlear recession wedge technique for patellar luxation: an experimental study. *J Am Anim Hosp Assoc* 19:735, 1983.

20. Talcott KW, Goring RL, de Haan JJ: Rectangular recession trochleoplasty for treatment of patellar luxation in dogs and cats. *Vet Comp Orthop Traumatol* 13:39, 2000.

21. Johnson AL, Probst CW, DeCamp, et al.: Comparison of trochlear block recession and trochlear wedge recession for canine patellar luxation using a cadaver model. *Vet Surg* 30:140, 2001.

Fabellar Suture Stabilization Technique for Treatment of Cranial Cruciate Ligament Rupture

Susan L. Schaefer

Introduction

The purpose of the Fabellar Suture Stabilization Technique is to provide extracapsular stabilization of the stifle following partial or complete rupture of the cranial cruciate ligament. The technique described here is a modification of Flo's original modified retinacular imbrication technique[1] as the fabellar-patella stabilizing suture is no longer incorporated and the location of the tibial suture hole has been revised. The overall objective is to place stabilizing sutures from the lateral and medial fabella to the tibial tuberosity. The intention is for these sutures to mimic the activity of the cranial cruciate ligament in the sagittal plane, eliminating cranial drawer movement when tightened. The lateral suture alone should eliminate most drawer movement. The medial suture plays a more secondary role in stifle stabilization. While these sutures stabilize the stifle acutely, it is theorized that fibrous tissue laid along the suture track maintains long term stability. Suture size and the number of sutures used vary on a per case basis and will be reviewed in the discussion.

Surgical Technique

Prior to extra-articular stabilization of the stifle an arthrotomy should always be performed and the joint thoroughly examined. A medial or lateral arthrotomy may be used. A medial arthrotomy generally allows for easier access to the medial meniscus if a menisectomy is indicated. Any remaining tags of the cranial cruciate ligament are removed and both menisci are examined. Damage to the medial meniscus is seen in over 50% of cases with cranial cruciate ligament rupture.[2] Damage to the lateral meniscus has also been reported but is more commonly limited to small radial tears in the cranial horn.[3] The damaged portion of affected menisci should be removed. The joint capsule is then closed with a synthetic absorbable suture in a simple interrupted pattern.

The fabellar suture stabilization technique is begun by identifying both fabellae. The fabellae are located along the caudomedial and caudolateral aspect of the distal femur. In surgery, their position can be approximated by moving either medially or laterally at the level of the distal third of the patella. An incision is made through the insertions of the sartorius medially and the biceps femoris laterally for fabella identification and suture placement. Medially, a longitudinal incision is made in the fibrous insertion of the caudal head of the sartorius muscle at the level of the patella (Figure 61-25). With the caudal sartorius muscle retracted caudally, the medial fabella should be palpable under the medial head of the gastrocnemius muscle (Figure 61-26). Laterally, a slightly curved longitudinal incision is made in the fibrous insertion of the biceps femoris muscle (Figure 61-27). With this muscle retracted caudally,

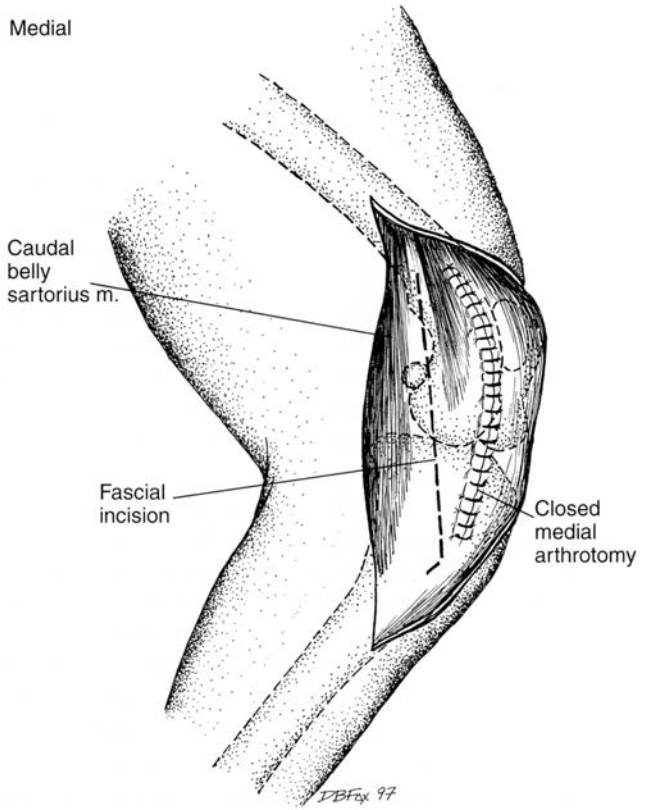


Figure 61-25. Medial aspect of the left stifle. Approach to the medial fabella is made through an incision in the fascia along the cranial boarder of the caudal belly of the sartorius muscle. A medial arthrotomy has been performed and closed.

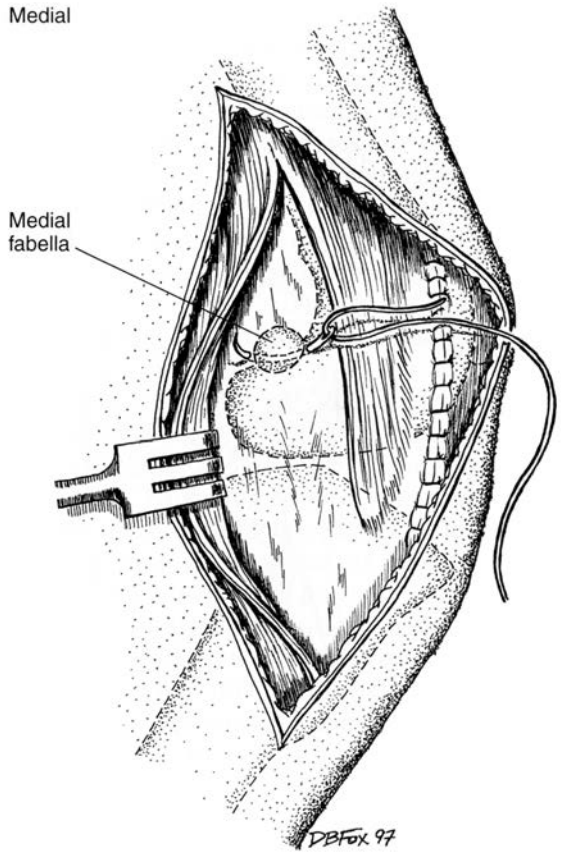


Figure 61-26. Medial aspect of the left stifle. Retraction of the caudal head of the sartorius muscle allows for palpation of the medial fabella and for medial suture placement. The needle should be passed in a cranial-to-caudal direction. The suture should anchor behind the proximal aspect of the fabella to avoid suture pullout into the soft tissue distally.

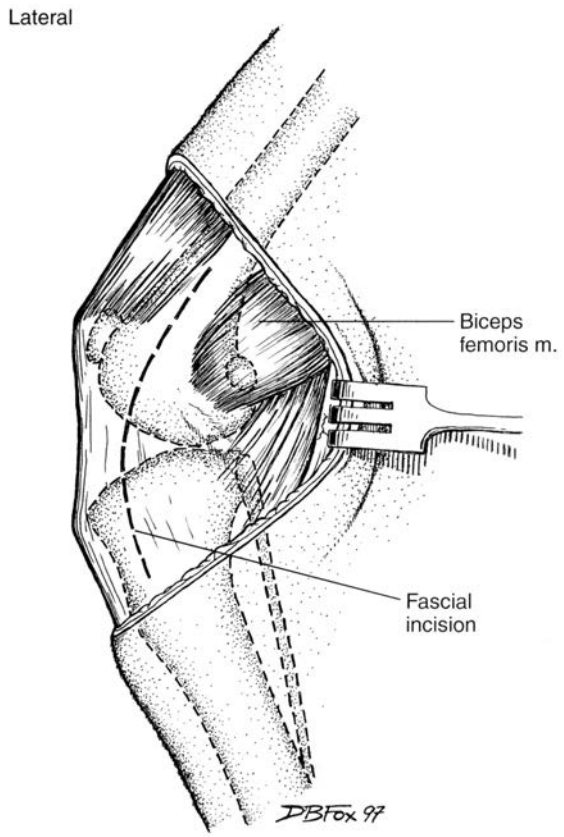


Figure 61-27. Lateral aspect of the left stifle. Exposure to the lateral fabella is made through an incision in the fibrous insertion of the biceps femoris muscle.

the lateral fabella should be palpable under the lateral head of the gastrocnemius muscle (Figure 61-28). On the lateral aspect of the stifle joint the peroneal nerve should then be identified. This nerve lies underneath the biceps femoris muscle and runs in a caudo-proximal - craniodistal direction. Locating this nerve is essential to avoid damaging it during suture placement.

To place the fabellar sutures, the stifle is held in moderate flexion with the overlying muscle (sartorius or biceps femoris) retracted. The fabellar-femoral junction is identified by placing a curved hemostat around the caudal aspect of the fabella and rocking the sesmoid up or outward, away from the femur. Once the junction is identified the needle is passed around the proximal third of the fabella in a cranial to caudal direction (See Figure 61-27 and 61-28). Care must be taken on the lateral side to avoid the peroneal nerve. Correct suture placement is confirmed by lifting up on both ends of the suture and palpating the fabella to insure that the suture is well locked behind the bone. If two sutures are to be placed on a side, a double length of the suture material is threaded through the needle to the midpoint. Heavy, non-absorbable suture should be used. Ethylene oxide sterilized, monofilament nylon fishing leader (20-80# test, Hard Nylon leader, Mason Tackle Co, Otisville, MI) with a heavy, half curved Martin's uterine needle is commonly used.

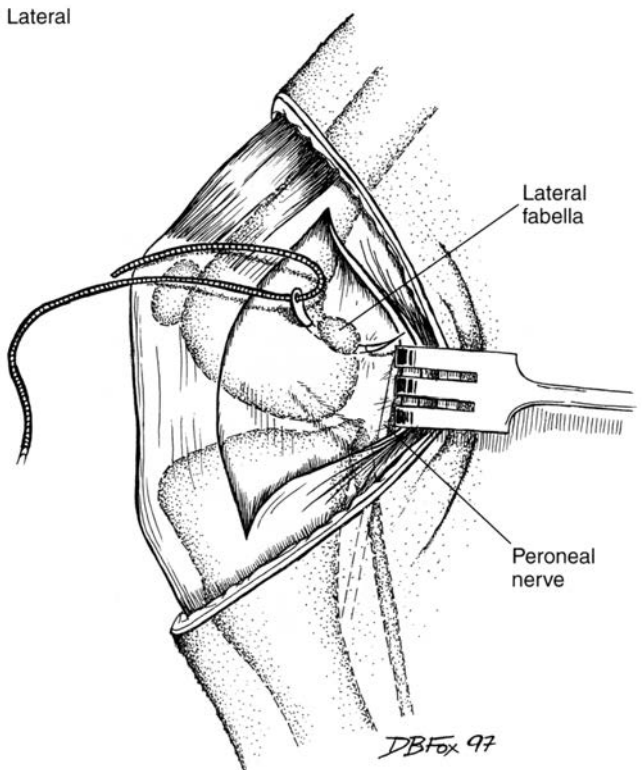


Figure 61-28. Lateral aspect of the left stifle. Retraction of the biceps femoris muscle allows for palpation of the lateral fabella and for lateral suture placement. The peroneal nerve, running in a craniaodistal direction from behind the joint, should be avoided during suture placement.

A hole is then drilled in the tibial tuberosity for fabellar suture anchoring. This hole is placed just caudal to the patella tendon insertion and in line with (distal to) the cranial edge of the extensor groove (Figure 61-29). This is a more isometric point than previously described distal locations.[4] This should place the tibial hole just below the tibial attachment of the cranial cruciate ligament. With the tibial suture hole at the approximate isometric point, slacking of the suture during either flexion or extension should be minimal (Figure 61-30). The caudal strand of each suture is then passed through this hole with either the Martin's uterine needle or threaded through a 14 or 16 gauge needle. All sutures can be passed through the same hole. Once a suture is brought through the tibia it is then passed back under the patella tendon. For example, the caudal strand of a lateral fabellar suture is first passed through the tibia from lateral to medial and then passed under the patellar tendon from medial to lateral. To confirm correct tibial hole placement, the sutures are threaded into position and the matching ends can be wrapped lightly around one another and held under tension. The stifle is then gently put through a range of motion. The sutures should move less than 2 mm relative to one another with correct tibial placement.[5] The lateral sutures are tied or secured with a crimp tube first as they alone should eliminate most drawer movement. To tie the lateral suture, the limb is held at the angle of flexion which produces the most "cranial drawer" with an assistant externally rotating the tibia and pushing it in "caudal drawer". This manipulation removes any instability while the sutures are being secured. Following lateral stabilization the medial sutures are secured with the stifle held in mild flexion (Figure 61-31).

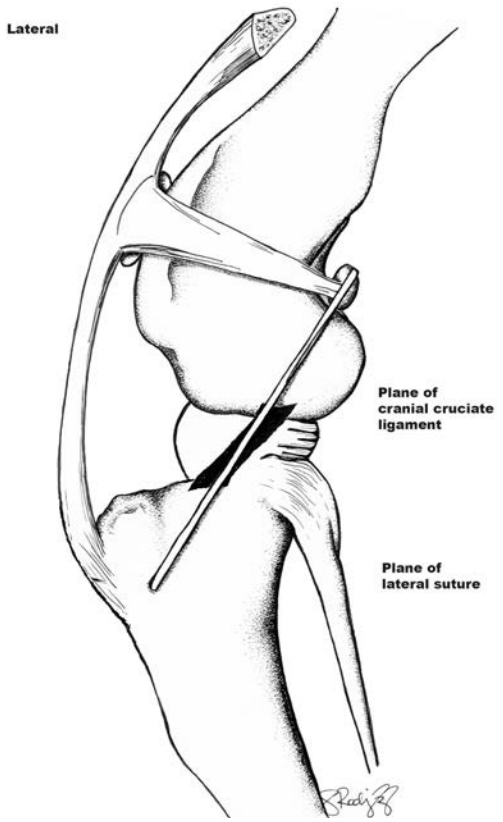


Figure 61-30. Lateral aspect of the left stifle. Correct placement of the tibial hole ensures that the plane of the fabellar suture approximates the plane of the cranial cruciate ligament.

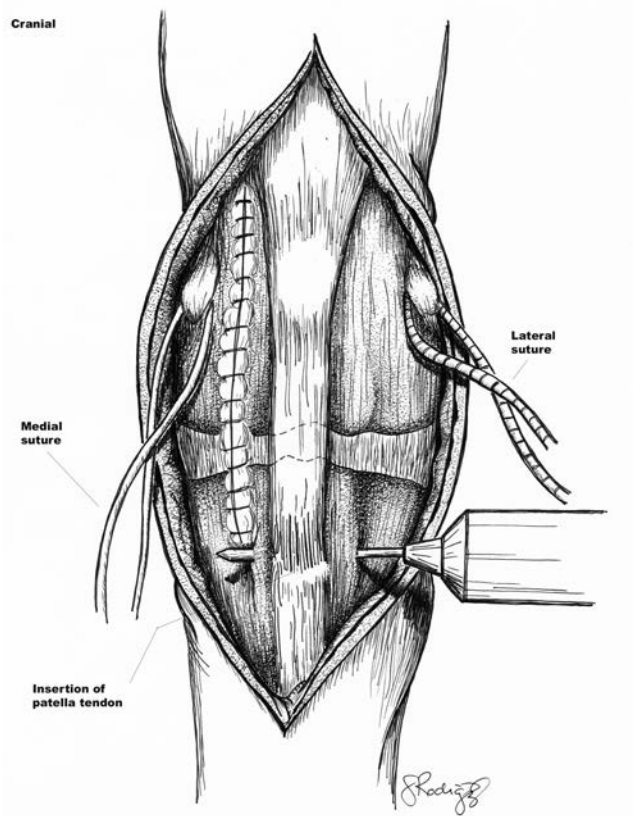


Figure 61-29. Cranial aspect of the left stifle. The hole in the tibial tuberosity is placed just caudal to the insertion of the patella tendon and just distal to the cranial aspect of the extensor groove.

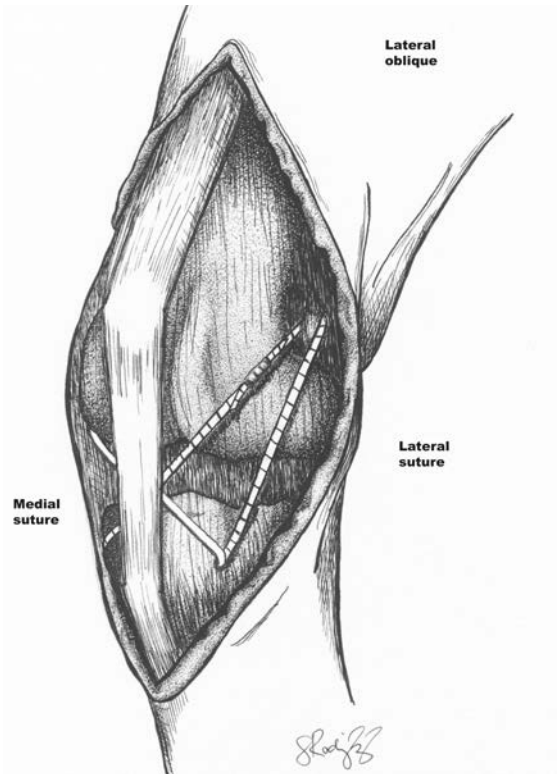


Figure 61-31. Lateral oblique of the left stifle. Both sutures have been placed using the isometric point in the tibial tuberosity.

The suture can be secured by using either two interlocking slip knots, a surgeons throw or a crimp tube. If monofilament nylon is used with a knot, a smooth faced needle holder may be applied to lightly hold the first throw while the second throw is being prepared. No less than four throws should be used. Alternatively, an aluminum crimp tube can be used to secure monofilament nylon sutures (Securos, Charlton, MA.) The advantage of the crimp tube is that it has a low profile and is less likely to produce a seroma than a large suture knot. In addition, the position of the crimp tube can be monitored radiographically. If crimp tubes are used postoperative radiographs should be taken to confirm post-op location of each tube. Following suture placement both the sartorius fascia and biceps femoris fascia are closed in an imbricating fashion. The subcuticular tissue and skin are closed in a routine fashion.

Postoperative Care

The incision should be iced 3x/day for 10 to 15 min for the first 3 to 5 days. This can begin as the animal is recovering from anesthesia. The animal's activity should be restricted for 6 to 8 weeks with no running or jumping and short leash walks only. Animals will benefit from specific physical therapy of the limb during this 6 to 8 week period 6. (See Table 61-1 for a recommended postoperative activity regime.) Following this 6 to 8 week period the dog is slowly reintroduced to normal levels of activity over a 4 week period. If animals are overactive during the recovery period immature fibrotic tissue can be stretched resulting in joint instability. Adequate exercise restriction is essential for clinical success. Weight loss should be recommended if indicated and owners should also be advised that contralateral cranial cruciate ligament rupture may occur in 30 to 40% of cases.

Discussion

Although some surgeons reserve this technique for smaller dogs, consistent success has been reported over a wide range of weights. The number of sutures placed is determined by the weight of the animal, body condition, activity level and the degree of joint instability. The following are only general guide lines for the number of sutures placed. Dogs weighing under 40 pounds receive two fabellar sutures (two lateral). Dogs weighing 40 to 80 pounds receive three sutures (two lateral, one medial). In dogs weighing greater than 80 pounds or in those with severe instability four sutures are placed (two lateral, two medial). Dogs with chronic cruciate ligament rupture and minimal instability may only receive one or two sutures (one lateral or one lateral and one medial). If monofilament nylon (fishing leader) is used, the strength of the material selected should roughly correspond to the weight of the animal (40 pound test for a 40 pound animal, 80 pound test for an 80 pound animal). On rare occasions, in cases of chronic cruciate injury with no "drawer" movement present, fabellar stabilization sutures are unnecessary following arthrotomy. The

Table 61-1. Activity Guide for Post-op Fabellar Suture Stabilization Technique

Post-Op Week 1-2	1. Slow walking on short leash to urinate or defecate.
	2. Passive Range of Motion (PROM) exercises – 10-15 reps, 3x/ day slowly.
	3. Massage leg (from toes to hip) before and after both walks and PROM.
	4. Ice surgical area 15 min 3x/day after walks and PROM.
	5. Starting day 6 apply a warm compress for 10-15 min before massage and PROM. If at any time the warm compress increases swelling, return to ice only.
Post-Op Week 3-4	1. Therapeutic activities are progressed slowly.
	-Continue PROM and massage as needed.
	-Multiple short, slow walks – (5-15 min) 3x/day, to tolerance.
	-Begin walking on inclines when there is consistent use of the leg.
	-Begin underwater treadmill exercises
	2. Initiate gentle strengthening and proprioceptive exercises.
	3. Use warm compress before PROM and walking and then ice after activity.
Post-op Weeks 5-7	1. Continue gentle strengthening and proprioceptive exercises.
	2. Continue to progress slow leash walks (15-20 min) 3x/day, to tolerance.
	3. Ascend / Descend stairs in controlled fashion.
	4. May initiate straight line trotting on a long lead and swimming with gentle water entry.
Post-Op Weeks 8-12	1. Increase intensity / duration of leash walks: 20-30 min on long lead 3x/day, to tolerance.
	2. Gradually introduce and return to off-leash activity.
	3. Begin running in straight line on long lead.
	4. Return to prior level of activity at end of 12 weeks.

Neuromuscular Electrical Stimulation (NMES) can also be incorporated into the rehabilitation plan immediately after surgery. Recommended frequency is 2-3x/week for 3-4 weeks. (Used with permission: Courtney Arnoldy, PT, CCRP).

primary causes of lameness in these animals is often chronic inflammation, meniscal damage or osteophyte formation.

Complications are uncommon (less than 10%) but include suture rupture, meniscal damage and seroma formation due to suture irritation. Suture rupture and meniscal damage are the most common causes of poor recovery. Clinically these patients may show either lack of full recovery or full recovery followed by a return of lameness. Meniscal damage should be suspected if a popping or clicking noise is heard on ambulation or palpated on examination. If a meniscectomy has already been adequately performed suture rupture should be suspected. If poor recovery is seen with the formation of large seromas over the suture knots suture irritation should be suspected. In dealing with animals with poor or inadequate recovery from the Fabellar Suture Technique simple fabellar suture removal should be attempted first if meniscal damage is not suspected or a meniscectomy has been previously performed. Suture removal as early as 12 weeks postoperatively should not increase drawer movement. Lameness usually resolves within two weeks if it was the result of suture problems. Suture replacement is rarely required and only in cases of gross stifle instability. If lameness persists following suture removal and a meniscectomy has not been previously performed, a repeat arthrotomy and medial meniscectomy are advised.

References

1. Flo G: Modification of the lateral retinacular imbrication technique for stabilizing cruciate ligament injuries. *J Am Anim Hosp Assoc* 11:570, 1975.

2. Flo G: Meniscal Injuries. *Vet Clin North Am Small Anim Prac* 23:831, 1993.

3. Ralphs SC, Whitney WO: Arthroscopic evaluation of menisci in dogs with cranial cruciate ligament injuries: 100 cases (1999-2000). *J Am Vet Med Assoc* 221:1602, 2002.

4. Roe SC: Optimizing the attachment sites of an extracapsular suture used for stabilizing a cruciate deficient stifle. Proceedings of the 10th Annual American College of Veterinary Surgeons Symposium, Washington DC,:19, 2000.

5. Roe SC: Personal Communication, July 2005.

6. Marsolais GS, Dvorak G, Conzemius MG: Effects of Postoperative Rehabilitation on Limb Function after Cranial Cruciate Ligament Repair in Dogs. *J Am Vet Med Assoc* 220:1325, 2002.

Tibial Plateau Leveling Osteotomy for Treatment of Cranial Cruciate Ligament Rupture

Ross H. Palmer

Introduction

Cranial cruciate ligament incompetence is a leading cause of lameness in the dog. Many surgical treatments have been described that aim to restore stifle joint stability and minimize the progression of subsequent osteoarthritis. Historically, most surgical techniques were designed to replace the function of the pathologic cranial cruciate ligament through some means of substitution using autologous tissues or synthetic materials and these methods have been described exhaustively elsewhere. More recently, tibial plateau leveling osteotomy (TPLO) was described by Dr. Barclay Slocum utilizing techniques that alter the mechanical forces acting upon the stifle in order to render the cranial cruciate ligament unnecessary.[1] The biomechanics of the TPLO have been discussed elsewhere.[2-5] The purpose of this chapter is to provide a detailed description of the TPLO procedure and its preoperative planning.

Preoperative Planning

Precise patient positioning is required when making radiographs for accurate measurement of tibial plateau angle (TPA) and other aspects of preoperative planning.[6-8] These mediolateral and caudocranial radiographs are most commonly performed with the patient under general anesthesia immediately prior to the TPLO surgery. TPA is measured on a mediolateral radiograph of the stifle with the tibia parallel to the radiographic film (Figure 61-32). The dog is placed in lateral recumbency with the affected limb down. The lateral surface of the hip, stifle, and hock are placed on the same surface. When using table-top radiographic technique, all these structures can be placed upon a large radiographic cassette or upon a smaller cassette with an adjacent spacer. The "up" leg is pulled cranially (rather than abducted at the hip) in order to keep all three structures in contact with the cassette. The "down" leg is positioned with the stifle and hock flexed to approximately 90 degrees. It is essential to center the



Figure 61-32. Dog positioned for mediolateral radiograph of stifle for preoperative TPLO planning. Dog in lateral recumbency with the affected limb down. Stifle and hock flexed to approximately 90 degrees with lateral surface of hip, stifle and hock at same level (in contact with radiographic cassette). Radiographic beam is centered on stifle but includes stifle and hock. Contralateral limb is pulled cranially.

beam upon the center of the tibial plateau while collimating the beam to include the tarsus. A cranial or proximal shift of the stifle from the center of the beam erroneously increases the measured TPA.[7] A caudal or distal shift of the stifle from the center of the radiographic beam erroneously decreases the measured TPA. Properly positioned radiographs display superimposition of the medial and lateral femoral condyles (unless there is a significant varus/valgus and/or torsional deformity of the femur) and distinct visualization of the medial condylar portion of the tibial plateau. The slope of the tibial plateau is defined by a line joining a point at the cranial-most edge of the medial tibial condyle with its caudal-most point (Figure 61-33). The tibial functional axis is defined by a line joining a point at the intersection of the superimposed medial and lateral intercondylar tubercles with a point at the center of the talus. Next, a line is drawn perpendicular to the tibial functional axis. The TPA is defined as the angle formed between the perpendicular and the tibial plateau line. The author has measured TPA's varying from 10° to 53° in dogs with cranial cruciate ligament incompetence, but the majority of TPA measurements in large breed dogs fall between 18° and 30°.[6,8,9]



Figure 61-33. Mediolateral TPLO planning radiograph shows superimposition of femoral condyles and approximately 90 degrees of flexion in stifle and hock. Tibial plateau slope (TPS) is defined by a line joining a point at the cranial-most edge of the medial tibial condyle with its caudal-most point. The tibial functional axis is defined by a line joining points at the intersection of the superimposed medial and lateral intercondylar tubercles and at the center of the talus. The line drawn perpendicular to the tibial functional axis represents the theoretic orientation of a completely level tibial plateau. Tibial plateau angle (TPA) is measured as the angle formed between the perpendicular and the TPS.

In addition to TPA measurement, the mediolateral radiograph is used for detailed preoperative planning.[3,10-12] Imaging Software or transparent templates are superimposed on the radiograph to evaluate the suitability of the various sizes of TPLO saw blades, jigs and bone plates. The desired point of insertion of the most proximal jig pin into the tibia is along the tibial functional axis immediately distal to the articular surface of the tibia. This critical point is marked on the mediolateral radiograph for intraoperative reference (Figure 61-34). Next, templates of available saw blade sizes (varying radius and circumference) are used to determine appropriate saw blade size. A properly sized blade should allow centering of the osteotomy about the most proximal end of the tibial functional axis, while the proximal end of the osteotomy is positioned midway between the cranial point of the tibial plateau and the tibial tuberosity. The distal end of the proposed osteotomy should be perpendicular to the tibial functional axis. The proposed osteotomy is marked upon the film for intraoperative reference. Next, a template for the appropriate size of bone plate is used to be certain that the planned osteotomy position will permit the desired implant placement (Figure 61-35). The extent of "coving" of the caudal tibial surface (created by the popliteal notch) is noted on the medio-lateral radiograph as the separation of the two cortical lines extending distally from the tibial plateau. This



Figure 61-34. A template corresponding to various sizes of TPLO saw blades is superimposed on mediolateral radiograph to select proper size of saw blade and to plan its orientation centered about the most proximal point of the tibial functional axis *(white arrow)*. The intersection of the three lines *(black arrow)* indicates the proposed insertion point of the proximal jig pin (as close to the proximal point of the tibial functional axis as the anatomy will permit).



Figure 61-35. Imaging software or a transparent template corresponding to different sizes of TPLO plates (3.5 mm Slocum-style plate shown) is used to plan the position of the implants relative to the stifle joint and the planned positions for osteotomy and the proximal jig pin.

observation helps the surgeon avoid inadvertent laceration of the popliteal vessels during periosteal elevation of the tissues from the caudal surface of the tibia and know how to best position the screws through the bone plate to maximize screw purchase.

The caudocranial TPLO radiograph is used to evaluate the alignment of the tibia, the degree of attachment of the fibular head to the proximal tibia, and identify palpable landmarks that can help the surgeon avoid intra-articular placement of screws and jig pins. The stifle is locked in full extension to minimize physiologic rotation in the stifle and the contralateral hip is abducted by suspending the thigh over a rolled towel (or foam block) to position the limb for caudo-cranial radiography (Figure 61-36). When the stifle is properly positioned (patella superimposed in the center of the distal femur and the fabellae are bisected by their respective femoral cortex), the medial margin of the tuber calcis on the superimposition of the center of the distal tibia suggests the absence of internal or external tibial torsion (Figure 61-37). On a properly positioned radiograph, lateral shifting of the medial margin of the talus suggests internal tibial torsion. Conversely, external tibial torsion shifts the medial margin of the tuber calcis medially. These radiographic observations should be correlated with direct visualization of limb alignment because internal rotation of the stifle cannot be definitively distinguished from internal tibial torsion on properly positioned caudocranial radiographs of cranial cruciate ligament deficient stifles.[13] Fibular head-proximal tibial synostosis is noted, if present, as this can restrict rotation of the tibial plateau and can lead to iatrogenic fibular fracture. The radiographic position and contour of the



Figure 61-36. Dog positioned for caudocranial stifle radiograph for TPLO planning. The stifle is locked in full extension to minimize physiologic rotation in the stifle and the contralateral hip is abducted by suspending the thigh over a rolled towel to position the limb for caudocranial radiography.



Figure 61-37. Caudocranial radiograph of stifle shows corresponding position of the medial margin of the tuber calcis *(black arrowheads)* superimposed on the center of the distal tibia *(arrow)*, suggesting the absence of tibial torsion. Note also the position of the fibular head relative to the articular surface of the tibia. This is correlated with palpation of the fibular head.

fibular head with respect to the stifle articular surface is noted and correlated with palpation findings. In some patients the fibular head is very palpable and extends proximal to the stifle joint while in others it is barely palpable at a point a centimeter or more distal to the articular surface. The position of the fibular head relative to the proposed insertion point of the proximal jig pin is noted so that proper jig pin position can be confirmed at the time of placement.

Surgical Technique

Patient Preparation

The affected hindquarter is shaved from the dorsal and ventral midlines to the mid-metatarsus. The patient is positioned in dorsal recumbency and the patient's midline is shifted slightly from the middle of the surgical table toward the affected limb to minimize the need for the surgical assistant to lean across the table. The foot is wrapped routinely being sure to keep the wrap distal to the hock so that the talocrural joint can be fully flexed and extended. The surgeon should closely evaluate limb alignment and correlate palpation observations to radiographs positioned on a radiographic viewer in the operating room. A routine hanging limb preparation is then performed. Draping is performed in a routine manner being sure to leave the hip, stifle and hock freely mobile and palpable.

Surgical Approach

A craniomedial skin incision is made from the suprapatellar joint pouch proximally to a point several centimeters distal to the distal end of the tibial crest. The subcutaneous tissues are gently dissected to reveal the cranial and caudal bellies of the sartorious muscles and the patellar ligament. A fascial incision is made starting between the sartorius muscle bellies proximally and extends through the tendinous insertion of the pes anserinus muscle group (caudal belly of the sartorius, gracilis, and semitendinosus muscles) approximately 6 to 10 mm medial to the tibial crest. Distally, the fascial incision shifts to the cranial midline of the tibia to release the medial border of the cranial tibial muscle. The cranial tibial muscle is elevated from the lateral surface of the proximal tibia. Starting at the distal end of the surgical field, thumb forceps are used to lift the semitendinosus from the medial tibial surface while the back of a scalpel handle is used to bluntly elevate it to reveal the firm insertions of the gracilis and sartorius muscles on the medial aspect of the tibial crest (just cranial to the medial collateral ligament). The shiny white insertion of the medial collateral ligament is visualized. The insertions of the gracilis and sartorius muscles are sharply incised using care to protect the medial collateral ligament. The elevated pes anserinus is preserved as a distinct layer as it is separated from its firm adherence to the underlying fascia of the stifle using sharp dissection (Figure 61-38.).

Arthrotomy and Meniscal Procedures

A medial parapatellar arthrotomy is performed routinely (not necessary with diagnostic and therapeutic arthroscopy). Care is taken to avoid incising the cranial belly of the sartorius and vastus medialis as the arthrotomy is extended proximally. The cranial and caudal cruciate ligaments, medial and lateral menisci, long digital extensor tendon and joint cartilage are evaluated. TPLO should be aborted if the caudal cruciate ligament (CdCL) is ruptured because the technique is reliant upon an intact CdCL for stifle stabilization.[4,5] The cranial cruciate ligament is debrided as appropriate. Placement of a small Hohmann retractor between the caudal cruciate ligament and the tibial plateau facilitates visualization of the menisci while protecting the caudal cruciate ligament from inadvertent laceration. Frequently medial meniscal pathology is present and can vary from partial-thickness tearing to a full-thickness "bucket-handle" tear to a severe crushing injury. The pathologic segment of the medial meniscus should be excised with a #11 blade or a Beaver blade using caution to protect the caudal cruciate ligament in the process. Suction is essential and headlight illumination is helpful. Surgical "release" of the caudal body of the medial meniscus has been theorized

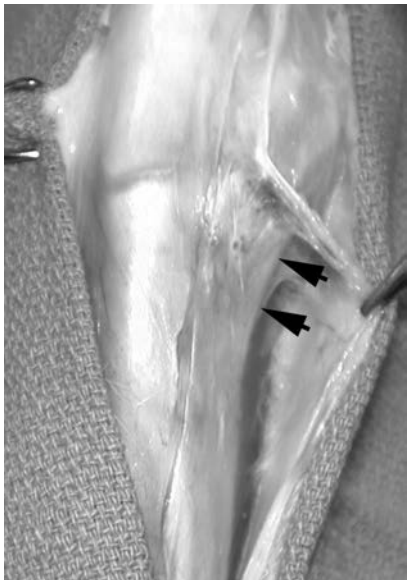


Figure 61-38. A canine pelvic (right) limb specimen. The pes anserinus muscle group is preserved as a distinct layer as it is elevated from the tibia and fascia of the stifle. The medial collateral ligament *(arrows)* is visualized deep to the pes anserinus muscle group.

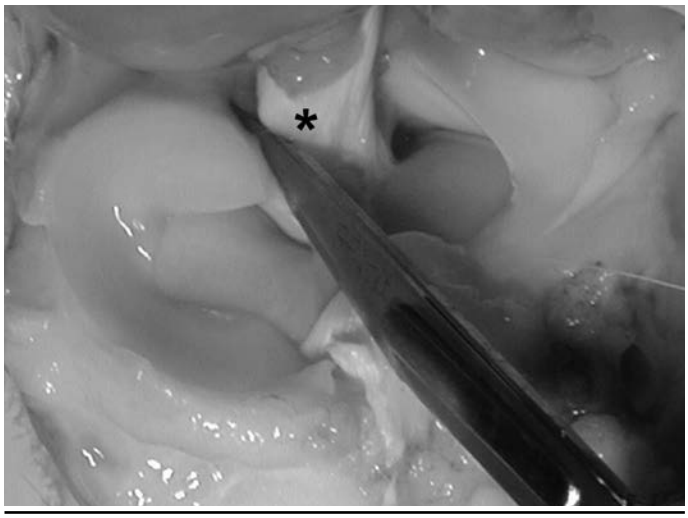


Figure 61-39. A canine (left) stifle specimen. Meniscal release being performed by transection of the caudal tibial ligament of the intact medial meniscus. Note the cutting surface of the scalpel blade is directed away from the caudal cruciate ligament *(*)*. At surgery, the caudal cruciate ligament is further protected by placing a Hohmann retractor between it and the caudal horn of the medial meniscus.

to decrease the incidence of delayed meniscal injury, but the associated risks and benefits are still debated.[14-16] Release of the medial meniscus is performed by transecting its caudal tibial insertion with a #11 blade. Caution is used to preserve the caudal cruciate ligament during medial meniscal release (Figure 61-39). Alternatively, the medial meniscus can be released via a mid-body transection as described later. The caudal body of the medial meniscus should snap caudally as the release is completed. If the caudal body folds cranially, it should be removed.

TPLO Preparation

In preparation for the TPLO, a deep incision is made along the caudal edge of the tibial insertion of the medial collateral ligament effectively separating it from the popliteus and semimembranosus muscles. Next, the muscles are elevated from the caudal surface of the tibia using great care. First, the index finger of one hand is placed between the cranial tibial muscles and the lateral margin of the tibia to identify the caudolateral edge of the tibia. Next, an AO elevator in the opposite hand is used to slowly and deliberately elevate the muscles from the caudal surface of the tibia using care to keep the elevator blade in firm contact with the "coved" caudal surface of the tibia until it reaches the surgeon's opposite index finger at the tibia's caudo-lateral edge (Figure 61-40). Laceration of the popliteal vessels may occur if the elevator is not kept in contact with the tibia. Soft tissue elevation adequate to safely perform the osteotomy is confirmed by correlating surgical landmarks with the preoperative planning radiographs. If indicated, release of the medial meniscus can be performed at mid-body at this time by directing a #11 scalpel blade from the caudal margin of the medial collateral ligament toward the tubercle of Gerdy along the craniolateral margin of the tibial plateau. Opening the tips of a small hemostat within the medial meniscal incision confirms that the release incision is complete. Next, radio-opaque marked gauze sponges are packed around the tibia to retract the surrounding soft tissues from the tibia.

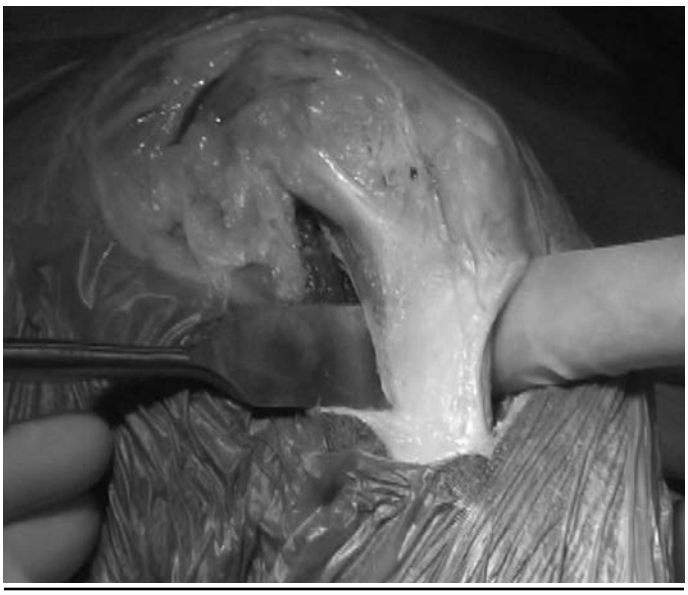


Figure 61-40. Muscles are elevated from the caudal surface of the (left) tibia using great care to prevent laceration of the popliteal vessels. First, the index finger of one hand is placed between the cranial tibial muscles and the lateral margin of the tibia to identify the caudo-lateral edge of the tibia. Next, a broad elevator in the opposite hand is used to slowly and deliberately elevate muscles from the caudal surface of the tibia using care to keep the elevator blade in firm contact with its "coved" contour until the elevator reaches the surgeon's opposite index finger at the tibia's caudolateral edge.

Jig Placement

Proper insertion point and orientation of the most proximal jig pin are essential because it functions as the axis around which the tibial plateau will rotate and as a visual guide for orientation of the osteotomy. Regional landmarks should be correlated to the radiographs to determine the desired insertion point for the pin. Often, the properly positioned pin must penetrate the fibers of the medial collateral ligament just distal to the articular surface of the tibial plateau. The exact location of the proximal tibial articular surface can be identified by sliding a freer periosteal elevator under the tibial surface of the caudal body of the medial meniscus starting immediately caudal to the medial collateral ligament (Figure 61-41). An assistant holds the limb with stifle and tarsus flexed to approximately 90 degrees and the hip in a neutral position such that the stifle is pointed directly upward. The jig is assembled and a slow-speed, high-torque, power drill is used to insert the proximal jig pin from medial to lateral into the tibia. The jig pin should be perpendicular to the sagittal plane of the stifle in both the craniocaudal direction and proximodistal direction (Figure 61-42). When the jig pin is properly oriented, the proximal joint of the jig will be in the same sagittal (flexion/extension) plane as the stifle joint. The distal joint of the jig will be 'out of plane' with the talocrural joint if there is notable tibial varus/valgus or torsional malalignment. After seating the pin into or through the lateral tibial cortex, it must be cut flush with the surface of the jig to allow for proper passage of the saw blade in later stages of the procedure. Next, a small soft tissue corridor is established for the distal jig pin being sure to avoid the medial saphenous vessels. The distal jig pin is inserted in a similar manner using care to keep it parallel to the proximal pin

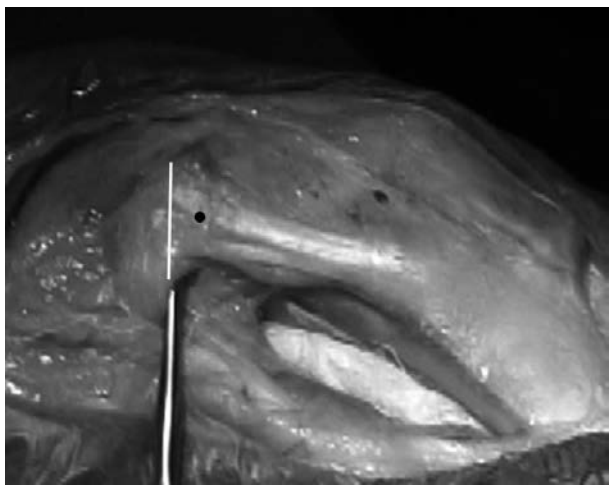


Figure 61-41. Intraoperative photo of (left) stifle. Note placement of gauze sponges to isolate the tibia from all caudal and lateral soft tissues. The exact location of the proximal tibial articular surface can be identified *(white line)* by sliding a freer periosteal elevator under the tibial surface of the caudal body of the medial meniscus starting immediately caudal to the medial collateral ligament. This maneuver helps define the desired point for insertion of the proximal jig pin *(black dot)*.

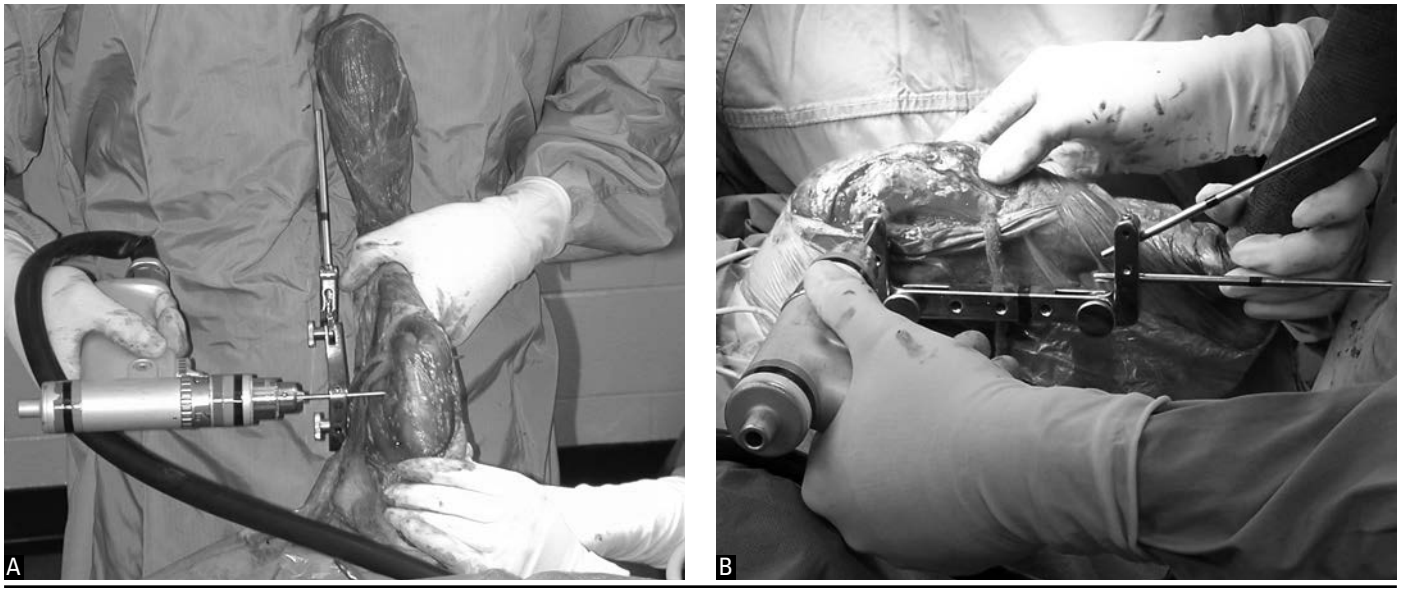


Figure 61-42. A. and **B.** The TPLO jig is assembled and slow-speed, high-torque, power drilling is used to insert the proximal jig pin from medial to lateral into the tibia. The jig pin should be perpendicular to the sagittal plane of the stifle in both the cranio-caudal direction and proximo-distal direction. Note that an assistant holds the limb with stifle and tarsus flexed to approximately 90 degrees and the hip in a neutral position such that the stifle is pointed directly upward.

in all planes. The jig is secured firmly to each of the jig pins by tightening appropriate set screws. The desired position for the osteotomy is determined by comparison of the regional anatomy to the marked radiograph. A small zone of periosteal elevation is used to mark this location and to prepare the tibia for osteotomy. The surgeon temporarily places the bone plate upon the medial tibial cortex to confirm that the plate will fit appropriately with the position of the planned osteotomy.

Osteotomy

The limb can either be positioned with the hip in the neutral position and the stifle pointed upward (as for jig placement) or the hip can be abducted to place the limb as flat as possible on the surgical table. The assistant places a small Hohmann retractor under the patellar ligament to retract it away from the saw blade. An appropriately sized TPLO saw blade is positioned in the desired location upon the medial tibial cortex. The surgeon uses one hand to stabilize the saw blade until the kerf of the osteotomy begins to stabilize the blade. At this point, the axis of the saw blade (like the most-proximal jig pin) should be perpendicular to the sagittal plane of the stifle in both the craniocaudal direction and proximodistal directions. Surgical assistant(s) help the surgeon to keep the saw blade properly aligned while cooling it with an irrigation solution. Before completing the osteotomy, the saw blade is temporarily removed and a small, sharp osteotome is used to create reference marks indicating the displacement needed along the osteotomy to accomplish satisfactory tibial plateau leveling (Figure 61-43). This chord length is geometrically derived and has been recorded in chart form for simplicity. Leveling the tibial plateau to an angle of approximately 6.5° eliminates cranial tibial subluxation by converting cranial tibial thrust into caudal tibial thrust that must be constrained by the intact caudal cruciate ligament.[5] Progressive leveling from 6.5° toward 0° further increases caudal cruciate ligament strain. The currently recommended postoperative TPA is 5°.[17] The preoperative TPA and the radius of the saw blade influence the amount of tibial plateau rotation required to achieve a TPA of 5°. The osteotomy is completed and the gauze sponges are removed. An appropriately sized Steinmann pin is temporarily inserted into the plateau segment from cranio-medial toward the popliteal notch of the tibia with a slight proximal to distal orientation being sure to engage but not penetrate the caudal tibial cortex to minimize risk of popliteal hemorrhage. A Jacob's chuck is applied to the temporary pin such that the pin can be used as a "handle" and the tibial plateau is slowly rotated about the proximal jig pin until the reference marks are aligned. The surgeon verifies that

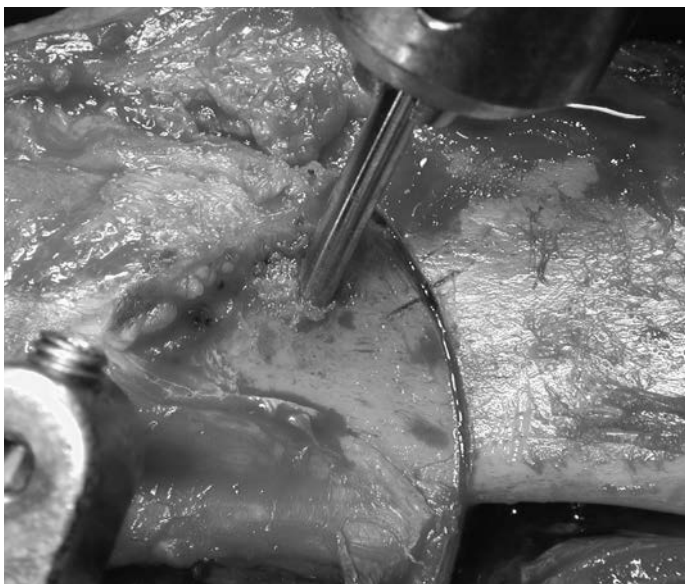


Figure 61-43. Before completing the osteotomy, the saw blade is temporarily removed and a small, sharp osteotome is used to create reference marks indicating the displacement needed along the osteotomy to accomplish satisfactory tibial plateau leveling. This chord length is geometrically derived and has been recorded in chart form for simplicity. After the osteotomy is complete, the tibial plateau segment is rotated about the proximal jig pin until the reference marks are aligned.

cranial tibial thrust instability is satisfactorily controlled. No effort is made to keep the medial surface of the tibial segments flush as this will typically create tibial malalignment.[9] Instead, as the tibial plateau is rotated about the proximal jig pin, the surgeon may slightly translate the distal segment medially or laterally to ensure a normal proximal-to-distal course of the patellar tendon. An appropriately sized Kirschner wire is passed across the osteotomy from the proximal-most end of the tibial tubercle into the tibial plateau to provide temporary stabilization during subsequent bone plate application. It is very important that this K-wire penetrate the tibial tubercle proximal to the insertion of the patellar ligament in order to minimize the risk of tibial tubercle fracture (Figure 61-44). The K-wire must also penetrate the medial tibial cortex to effectively maintain the rotation during plate application. The surgeon should verify proper plateau rotation and secure fixation before removing the temporary Steinmann pin ("rotation handle"). Next, the surgeon should extend and flex the stifle while evaluating the tibia for torsional or varus/valgus mal-alignment. Varus/valgus mal-alignment is corrected by sliding the jig out or in on the distal jig pin. Torsional mal-alignment can be corrected by bending the distal jig pin either cranially or caudally (Figure 61-45). Large tibial alignment adjustments create large osteotomy gaps and/or medial cortical surface "stair-steps". Large gaps may require autogenous cancellous bone grafting. The edge of the saw blade can be used to level out any "stair-steps" at the osteotomy site in the region of the proposed plate placement.



Figure 61-44. An appropriately sized Kirschner wire is passed across the osteotomy from the proximal-most end of the tibial tubercle into the tibial plateau to provide temporary stabilization during subsequent bone plate application. It is very important that this K-wire penetrate the tibial tubercle proximal to the insertion of the patellar ligament in order to minimize the risk of tibial tubercle fracture. The K-wire must also penetrate the medial tibial cortex to effectively maintain the rotation during plate application. Note the alignment of the reference marks indicating that the calculated TPA correction has been achieved.

Bone Plate Application

A variety of TPLO-specific plate designs are commercially available. The following discussion pertains to the original Slocum-style TPLO plate design. The bone plate is contoured for a precise fit against the medial tibial cortex to avoid inducing tibial malalignment. Typically this requires two bends and a twist within the plate. The first bend is placed between the third and fourth screw holes in the plate. A second, more-subtle, bend is often needed through the second hole in the plate. Next, an internal twist of the proximal section of the plate is made between the third and fourth holes. Occasionally, a slight bend and/or twist are needed through the fifth hole to keep the distal end of the plate in contact with the bone. The plate is held in the desired location and a cortical screw is placed in the fourth hole using standard screw insertion techniques. Next, cortical screws are placed in the fifth and sixth holes. Next, cortical or cancellous screws (as appropriate) are placed in the second, third and first holes respectively. The screws in the proximal section of the plate are inserted in compression mode provided no tibial alignment adjustments were made. If, however, tibial alignment corrections were made, the screws in the proximal segment are inserted in neutralization mode to avoid shifting the osteotomy. Occasionally, it is necessary to remove the jig, jig pins, and/or Kirschner wire before inserting a screw into the most proximal hole of the plate. Care must be used to avoid placement of these proximal screws into the stifle joint. An aiming guide can be used if needed, but judicious correlation of palpable landmarks (such as the fibular head) to the preoperative radiographs is usually efffective. Cancellous bone grafting is not necessary for most congruent osteotomies, but may be indicated for incongruent osteotomies. The jig is removed. Stifle stability, limb alignment,



Figure 61-45. Varus/valgus mal-alignment is corrected by sliding the jig in or out on the distal jig pin. Torsional mal-alignment can be corrected by bending the distal jig pin either cranially or caudally. Example: Sliding the jig out on the distal pin (white arrow) will correct tibial varus. Bending the distal jig pin cranially (black arrow) will correct internal tibial torsion.

and implant placement are assessed (Figure 61-46). The surgical field is lavaged thoroughly with a physiologic irrigation solution. The joint capsule is apposed routinely with a continuous suture pattern. The popliteus muscle is apposed to the medial collateral ligament. The pes anserinus muscle group is apposed to the insertion remnant left on the tibial crest using stifle flexion to ease tension during closure. Subcutaneous tissues may be closed in one or two layers. Skin is apposed routinely.

Postoperative mediolateral and caudocranial radiographs are made using the same patient positioning described previously and the TPA is measured. The radiographs are evaluated for proper jig pin, osteotomy, and implant placement. Some surgeons prefer to apply a soft padded bandage to minimize patient self-mutilation and to reduce swelling and bruising in the region of the surgical site.



Figure 61-46. Illustration of completed TPLO using an anatomically pre-contoured, locking TPLO plate. (Images courtesy of Synthes Inc, West Chester, PA. © 2010 Synthes, Inc. or its affiliates.)

Postoperative Care

Recovery from TPLO consists of three stages: 1) incisional healing, 2) bone healing, and 3) physical rehabilitation/reconditioning. During the two week incisional healing, self-mutilation must be prevented through the use of a protective bandage and/or a restraint collar. The duration for bone healing is variable, but typically lasts 8 to 12 weeks. During this time, running, jumping, free access to furniture, stairs, slippery surfaces, other pets, and the yard must be avoided. Confinement to a large crate in a quiet room works nicely when the patient is unsupervised. Short walks at a slow pace on a short leash are encouraged several times per day. Sling support of the hindquarters may be indicated for patients with multi-limb disability, poor strength or balance, and for patients who are required to traverse slippery surfaces or steps. Bone healing is monitored radiographically in 4 to 8 week intervals until healing is documented. As bone healing is progressing, slow and methodical increases in patient activity are encouraged as part of their physical rehabilitation. This begins with increasing lengths of leash walks each week progressing to slow and methodical increases in supervised time off of the leash.

Complications

A wide variety of complications have been reported for the TPLO.[12,18,19] Intra-operative complications including extreme hemorrhage, intra-articular placement of screws and jig pins, and iatrogenic fracture of the tibial crest can be avoided with attentive preoperative planning and surgical technique. Postoperative soft tissue complications include seroma/hematoma, dehiscence, infection, and bandage irritation and can usually be treated routinely.

More severe postoperative complications including tibial crest fracture, fixation failure, and patellar desmitis typically cause a sudden and sustained increase in patient discomfort and lameness. Tibial crest fracture is predisposed by the tension of the patellar ligament on the tibial tubercle. Improper placement of the temporary K-wire distal to the insertion of the patellar ligament on the tibial tubercle creates a stress-riser that increases the risk of tibial crest fracture. Likewise, a shift of the osteotomy too far cranially (not centered appropriately or too large a saw blade) creates a thin tibial crest segment that is at risk of fracture. Placement of a tension band may prevent this complication in "at risk" patients. It has been suggested that tibial plateau rotation should not be performed to such an extent as to leave the tibial tubercle unsupported and that a cranial closing wedge ostectomy should supplement TPLO when patients with excessive tibial plateau angles are encountered.[11] This surgical treatment is quite complex and is beyond the scope of this chapter.

TPLO fixation failure may result from catastrophic loading of the limb in excess of fixation strength or from repetitive low-energy loading leading to fatigue failure. Improper orientation of the osteotomy may increase the relative loading on the implants (less load borne by the bone segments). Likewise, iatrogenic fibular fracture during TPLO likely increases mechanical demand on the implants due to loss of the caudolateral buttressing effect of the fibula. Osteomyelitis often causes increased lameness, patient discomfort and draining tracts or incisional drainage. Bacterial culture and antimicrobial sensitivity testing of fluids obtained by deep surgical site aspirate are used to select appropriate antimicrobial therapy. Implant removal may be indicated upon completion of osteotomy healing.

Neoplasia has been reported at the site of previously performed

TPLO procedures.[20-22] It is unclear, currently, if this is related to the procedure, the implants, or is an incidental location of the disease. The benefit of elective plate removal following bone healing has not been established.

Technique Variations

Many variations of the surgical technique have been described including minimal dissection around the tibia, no application of surgical sponges, jig-less application, and the use of pre-contoured and locking plate systems.

References

1. Slocum B, Slocum TD. Tibial plateau leveling osteotomy for repair of cranial cruciate ligament rupture in the canine. *Vet Clin North Am-Small Anim Pract* 23:777, 1993.

2. Dejardin LM. Tibial Plateau Leveling Osteotomy In: Slatter D, ed. *Textbook of Small Animal Surgery.* 3 ed. Philadelphia: Saunders, 2002; p 2133-2143.

3. Palmer R. Understanding tibial plateau leveling osteotomies in dogs. *Vet Med* 100:426, 2005.

4. Reif U, Hulse DA, Hauptman JG. Effect of tibial plateau leveling on stability of the canine cranial cruciate-deficient stifle joint: an in vitro study. *Vet Surg* 31:147, 2002.

5. Warzee CC, Dejardin LM, Arnoczky SP, et al. Effect of tibial plateau leveling on cranial and caudal tibial thrusts in canine cranial cruciate-deficient stifles: an in vitro experimental study. *Vet Surg* 30:278, 2001.

6. Caylor KB, Zumpano CA, Evans LM, et al. Intra- and interobserver measurement variability of tibial plateau slope from lateral radiographs in dogs. *J Am Anim Hosp Assoc* 37:263, 2001.

7. Reif U, Dejardin LM, Probst CW, et al. Influence of limb positioning and measurement method on the magnitude of the tibial plateau angle. *Vet Surg* 33:368, 2004.

8. Reif U, Probst CW. Comparison of tibial plateau angles in normal and cranial cruciate deficient stifles of Labrador retrievers. *Vet Surg* 32:385, 2003.

9. Wheeler JL, Cross AR, Gingrich W. In vitro effects of osteotomy angle and osteotomy reduction on tibial angulation and rotation during the tibial plateau-leveling osteotomy procedure. *Vet Surg* 32:371, 2003.

10. Kowaleski MP, McCarthy R.J. Geometric analysis evaluating the effect of tibial plateau leveling osteotomy position on postoperative tibial plateau slope. *Vet Comp Orthop Traumatol* 17:30, 2004.

11. Kowaleski MP. Technique and indications for TPLO/CCWO. ACVS Veterinary Symposium 449, 2005.

12. Palmer R. Postoperative TPLO Complications. ACVS Veterinary Symposium 2004; p 378.

13. Apelt D, Kowaleski MP, Dyce J. Comparison of computed tomographic and standard radiographic determination of tibial torsion in the dog. *Vet Surg* 34:457, 2005.

14. Pozzi A, Kowaleski MP, Apelt, D, Johnson KA. Motion of the caudal pole of the medial meniscus after meniscal release. ACVS Veterinary Symposium 2005; p 20.

15. Pozzi A, Litzky AS, Field J, Apelt, D, Meadows C, Johnson KA. In vitro effect of meniscal release on load transmission in stifles with and without tibial plateau leveling osteotomy. ACVS Veterinary Symposium 2005; p 21.

16. Slocum B, Devine-Slocum, T. Meniscal release In: Bojrab M, ed. *Current Techniques in Small Animal Surgery.* 4th ed. Philadelphia: Lea & Febiger, 1998; p 1197.

17. Slocum B, Devine-Slocum, T. Tibial plateau leveling osteotomy for cranial cruciate ligament rupture In: Bojrab MJ EG, Slocum B, ed. *Current techniques in small animal surgery.* 4 ed. Baltimore: Williams & Wilkins, 1998; p 1209.

18. Pacchiana PD, Morris E, Gillings SL, et al. Surgical and postoperative complications associated with tibial plateau leveling osteotomy in dogs with cranial cruciate ligament rupture: 397 cases (1998-2001). *J Am Vet Med Assoc* 222:184, 2003.

19. Priddy NH, 2nd, Tomlinson JL, Dodam JR, et al. Complications with and owner assessment of the outcome of tibial plateau leveling osteotomy for treatment of cranial cruciate ligament rupture in dogs: 193 cases (1997-2001). *J Am Vet Med Assoc* 222:1726, 2003.

20. Boudrieau RJ. Corrosion of the Slocum TPLO plate. ACVS Veterinary Symposium 2005; p 324.

21. Boudrieau RJ, McCarthy RJ, Sisson RD, Jr. Sarcoma of the proximal portion of the tibia in a dog 5.5 years after tibial plateau leveling osteotomy. *J Am Vet Med Assoc* 227:1613-1617, 2005.

22. Punke J. Clinical occurence of sarcoma post tibial plateau leveling osteotomy (TPLO). ACVS Veterinary Symposium 2005; p 318.

"Over-the-Top" Patellar Tendon Graft for Cranial Cruciate Ligament Repair

Guy B. Tarvin and Steven P. Arnoczky

Introduction

The cranial cruciate ligament constrains joint motion. It prevents cranial subluxation of the tibia on the femur (cranial drawer sign), hyperextension of the stifle joint, and, along with the caudal cruciate ligament, excessive internal rotation of the tibia on the femur.[1] Excessive forces during extremes of any of these movements may damage this ligament.[2] Although excessive trauma causes acute rupture of the cranial cruciate ligament, most cruciate ligament lesions are thought to result from chronic degenerative changes within the ligaments themselves.[2,3] Variations in conformation, valgus (knock-knee) and varus (bowleg) deformities of the stifle, and repeated minor stresses can result in progressive degenerative joint disease. As these joint changes develop, the cruciate ligaments undergo alterations in their microstructure and may be more susceptible to damage from minor trauma.[4]

Because rupture of the cranial cruciate ligament results in progressive degenerative joint changes within the joint,[3,5,6] most such injuries should be repaired. In the authors' experience, many large breed dogs present with partial cranial cruciate ligament tears. The authors currently recommend repair in these cases even though they may not be grossly unstable (see diagnostics below). The cranial cruciate ligament has poor healing capabilities and eventually will completely tear. During that process, degenerative joint disease will progress leading to a poorer prognosis. We must stress; however, that each patient needs to be assessed individually as other factors may make surgical repair either unnecessary or not in the best interests of the patient. For example in some chronic cases of cranial cruciate ligament rupture, severe degenerative joint changes are present and these patients have an unfavorable prognosis after

surgical repair. In these patients, conservative management with anti-inflammatory drugs and somatic pain relievers may provide adequate palliative care and an equal, if not superior, result than surgical intervention. Moreover, concurrent joint diseases such as rheumatoid arthritis and systematic lupus erythematosus, may obviate the repair of the ligament insufficiently. A final exception would be the smaller patients, such as cats and small dogs (less than 15 kg.), with isolated cranial cruciate ligament injuries. One study demonstrated that conservative therapy(nonsurgical) had a high degree of clinical success.[7]

Diagnosis of cranial cruciate ligament insufficiency is based on historical and clinical evidence of rear limb lameness. Palpation of the stifle is the most useful tool to make a diagnosis of cranial cruciate ligament insufficiency. In acute complete ruptures, instability of the stifle is present when applying the cranial drawer test or tibial compression test.[7] In incomplete tears or chronic complete tears with secondary periarticular fibrosis, these tests will not be as dramatic and may not be conclusive. In many chronic cases, medial collateral ligament hypertrophy secondary to the injury may be palpated. This finding can support the diagnosis of cranial cruciate ligament disease. Radiographs are usually not necessary to establish a diagnosis but can be useful in assessing secondary degenerative joint disease and stifle effusion.[7] In early partial tears joint effusion is a helpful finding to establish a diagnosis. In the rare case in which all these diagnostic tests fail to establish a diagnosis, nuclear scintigraphy can be used to pinpoint the cause of lameness. The clinician should always evaluate the entire limb for other abnormalities. The contralateral limb should also be evaluated because bilateral cranial cruciate ligament disease is not uncommon.[7]

Many methods of repair have been devised to treat cranial cruciate ligament insufficiency. These can be categorized as either extra-articular or intra-articular repairs. Whereas extra-articular repairs stabilize the joint by tightening or altering the position of extra-articular structures, intra-articular repairs anatomically replace the cranial cruciate ligament with some type of graft. The over-the-top procedure[8] is an intra-articular repair that uses a patellar tendon graft to replace the cranial cruciate ligament. This procedure was designed for use in dogs weighing more than 15 kg. In our experience, the over-the-top patellar tendon graft provides a functional replacement for the cranial cruciate ligament and thereby limits any abnormal joint motions.

Surgical Technique

The animal is placed in lateral recumbency, and the affected limb is prepared for an aseptic surgical procedure. A lateral parapatellar skin incision is made extending from the midshaft of the femur to the proximal tibia. The subcutaneous and fascial tissues are dissected free, and the patellar ligament is clearly defined. The patellar ligament is incised longitudinally between the junction of the middle and medial thirds of its width. The incision is extended over the patella and into the patellar tendon, where it is directed in a proximo-lateral direction to incorporate the fascia lata (Figure 61-47A). The incision proximal to the patella should be made 1 to 1.5 times the distance from the patella to the tibial tuberosity; this incision ensures an adequate length of graft in dogs of all sizes. The incision into the fascia is also made 1 to 2 centimeters lateral to the medial boundary of the fascia lata with the vastus medialis.

An osteotome is placed in the groove of the patella created by the scalpel blade. A handsaw can also be used to deepen this groove to allow better purchase with the osteotome. A craniomedial wedge of bone is removed with the medial third of the patellar tendon with the ligament attatched (Figure 61-47B). If power equipment is available, use of an oscillating saw can also be employed to make the patellar wedge. Extreme care should be taken during the osteotomy to preserve the entire articular surface of the patella. To complete the harvest of the graft, the surgeon begins at the proximal extent of the incision in the fascia lata. A scissors is used to cut the fascia lata transversely in a medial direction to where it blends into the vastus medialis. The distal portion of the fascia lata is then elevated from the underlying muscle and grasped with a thumb forceps. The scissors is used to cut the medial border of the fascia strip distally in a direction parallel to the first fascial incision. As the incision approaches the suprapatellar joint pouch, the scissors can be directed medially if necessary to incorporate more joint capsule and parapatellar fibrocartilage. This can be employed if the surgeon feels that the graft needs reinforcing in this area. The medial third of the patellar ligament is then dissected free to the level of the tibial tuberosity. In doing so a medial arthrotomy is created. An incision through the infrapatellar fat pad is necessary to mobilize the graft, but the fat pad should not be stripped from its ligamentous attachments because it provides much of the blood supply to the patellar ligament graft. An autogenous graft consisting of fascia, patellar tendon, a patellar bone wedge, and patellar ligament with a distal attachment to the tibial tuberosity is thus created (Figure 61-47C).

The remnants of the ruptured cranial cruciate ligament are then removed through the medial arthrotomy, and the joint is inspected for further pathologic features. The authors find it useful to use a curette to debride the intercondylar notch of osteophytes and cranial cruciate ligament remnants. This aids in graft passage. The patella, joint capsule, and soft tissues are retracted laterally to expose the lateral femoral condyle and fabella (Figure 61-47D). The lateral fabella is located by palpation, and a small vertical incision is made in the femorofabellar ligament. With the joint in extreme flexion, curved hemostatic forceps are inserted into the incision and passed over the top of the lateral femoral condyle and into the intercondylar notch; one must take care to preserve the causal joint structures by staying close to the bone. The tips of the hemostatic forceps are gently manipulated until they can be seen within the joint (Figure 61-47D and E). The surgeon then grasps the free end of the graft directly or grasps a suture that has been placed in the free end of the graft with the hemostat. The graft is pulled through the joint and over the top of the lateral condyle by gentle traction on the hemostat. Flexing and extending the joint during this maneuver facilitates passage of the graft.

After the graft has been pulled though the joint, it is held under gentle traction, and the joint is tested for craniocaudal stability. Once cranial drawer motion has been eliminated, the graft is attached to the lateral femoral condyle. The authors feel that the graft should be tightened and attached to the lateral femoral

condyle with the stifle in full extension. Functional studies of the canine cranial cruciate ligament indicate that its maximum length and therefore its most taut state occur at full extension.[1] Since the graft's attachment sites closely mimic those of the normal cranial cruciate ligament, it is logical to assume that the graft should also be most taut in extension. If the graft would be tightened with the stifle in some degree of flexion, the graft would become more taut as its attachment sites become farther apart in extension. In this scenario, extension would be constrained by the graft or the graft would be stretched and be more prone to fail. Therefore, the authors secure the graft with traction maintained and the stifle in full extension. The graft is sutured to the tissues of the lateral femoral condyle with simple interrupted sutures of nonabsorbable suture material (Figure 61-47F). The authors also find that a small titanium bone staple and belt loop also offers secure and quick fixation of the graft (Figure 61-48). In our experience using bone staples, implant complications (i.e. reaction, irritation, or loosening) are extremely rare.

The arthrotomy is closed in a routine manner. During closure of

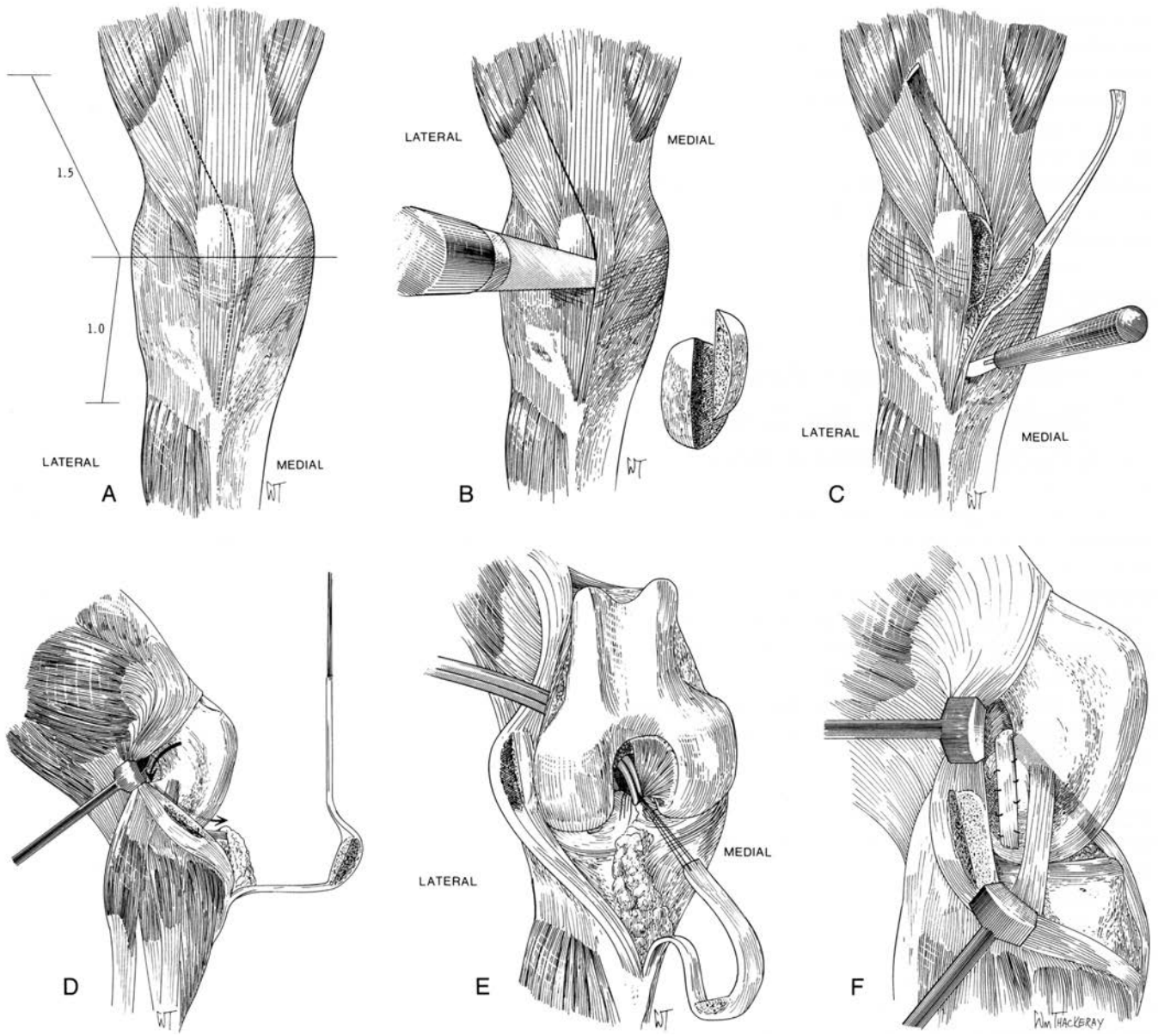


Figure 61-47. Over-the-top patellar tendon graft. **A.** Cranial view of the stifle showing the location of the initial incision for the proposed graft. The proximal portion of the incision is directed laterally to incorporate the fascia lata. **B.** Placement of osteotome to remove craniomedial wedge of patella with accompanying soft tissue. The inset shows cranial view of the patella indicating the extent of the osteotomy, which does not extend to the caudal articular surface of the patella. **C.** The graft is completed by incising the joint capsule, patellar tendon, and fascia lata parallel to the initial incision and by freeing the graft at its proximal end. **D.** Lateral view of the stifle showing retraction of the patella and soft tissues of the joint laterally to expose the lateral femoral condyle and fabella. Arrows indicate the path of the hemostatic forceps over the top of the lateral femoral condyle and into the joint. **E.** Cranial view of flexed stifle showing tips of the hemostatic forceps emerging lateral to the caudal cruciate ligament and grasping the sutures in the free end of the graft. Also note that a notchplasty has previously performed. **F.** Lateral view of the stifle showing the graft passing through the joint and over the top of the lateral femoral condyle. The graft is then sutured to the soft tissues of the lateral femoral condyle. (From Arnoczky SP, Tarvin GB, Marshall JL, et al. The over-the-top procedure: a technique for anterior cruciate ligament substitution in the dog. J Am Anim Hosp Assoc 1979;15:283.)

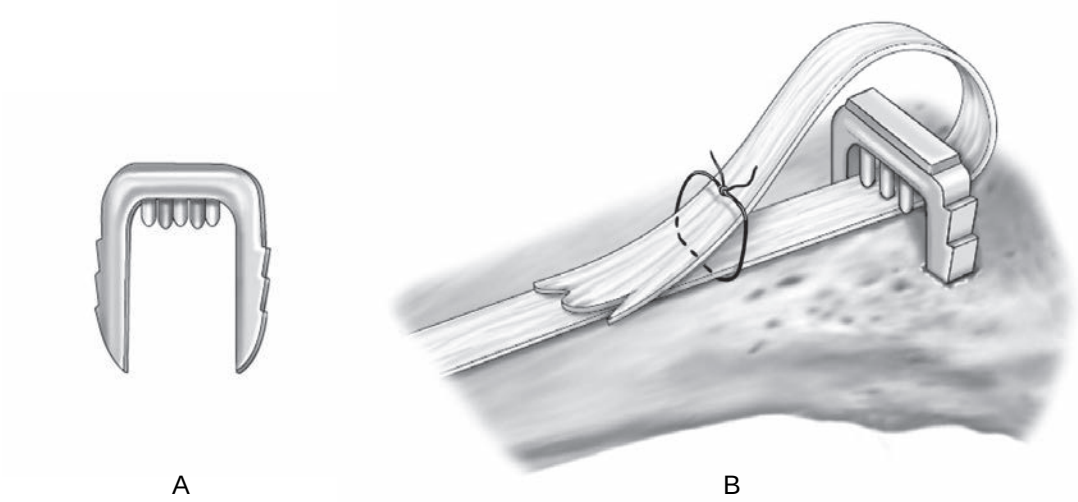


Figure 61-48. A. Another method of attaching the proximal portion of the graft utilizes a 6mm wide by 15 mm long ACL staple(VeterinaryInstrumen tation, 62 Cemetery Road, Sheffield, U.K.). **B.** The staple is placed over the graft and driven into the bone of the lateral femoral condyle. The distal end of the graft is folded back on itself in a manner similar to a belt loop and suture on itself with 2-0 nonabsorbable suture material.

the medial arthrotomy, care should be taken to avoid excessive tension on the patella and patellar ligament, which may predispose the joint to a medial luxation of the patella. If tension is a problem, loose approximation sutures should be placed in the joint capsule, and the subcutaneous soft tissues should be used to cover the arthrotomy defect.

Postoperatively, the limb is placed in a modified Robert Jones dressing for 2 weeks, and the animal's activity is restricted for a total of 8 to 12 weeks. In larger dogs (over 30 kg) a lateral splint may be added for the first 2 to 4 postoperative weeks.

The biologic fate of the patellar tendon graft within the joint was investigated in an experimental study.[9] The results of this study demonstrate that the blood supply of the graft is disrupted at the time of surgery, and approximately 20 weeks are needed for the graft to become completely revascularized. During this period, the graft undergoes ischemic necrosis, and its strength may be at risk. In an effort to minimize this revascularization process, one of the authors (SPA.) and his colleagues proposed a modification of the over-the-top technique in which the medial vascular supply of the patellar tendon graft was carefully preserved and maintained.[10] They suggested that if a "vascularized" patellar tendon graft were used to reconstruct the cranial cruciate ligament, the revascularization and remodeling process would be eliminated, or at least minimized. Furthermore, the use of vascularized patellar tendon graft would prevent, or at least minimize, any changes in the material strength of the graft secondary to the ischemic changes or revascularized process. However, a subsequent study evaluating the strength of vascularized and non-vascularized patellar tendon grafts failed to demonstrate any significant differences in any of their biomechanical parameters with time.[11] It thus appears that there is no inherent advantage of preserving the blood supply to the graft at the time of surgery.

Several other modifications of the over-the-top graft technique have been proposed and have produced good results[8,10,12] Although these techniques use other tissues for the graft (fascia lata, lateral aspect of the patellar tendon) and may include the addition of other ancillary stabilization procedures (lateral imbrication suture), they all incorporate the over-the-top femoral positioning of the intra-articular graft. The over-the-top positioning allows the most consistent placement of the graft in the most biomechanically and anatomically correct position (Figure 61-49). In our opinion, this positioning may be the most important consideration in intra-articular reconstructions of the cranial cruciate ligament. Indeed, an evaluation of two over-the-top techniques by Denny and Barr suggests that this biomechanically correct placement

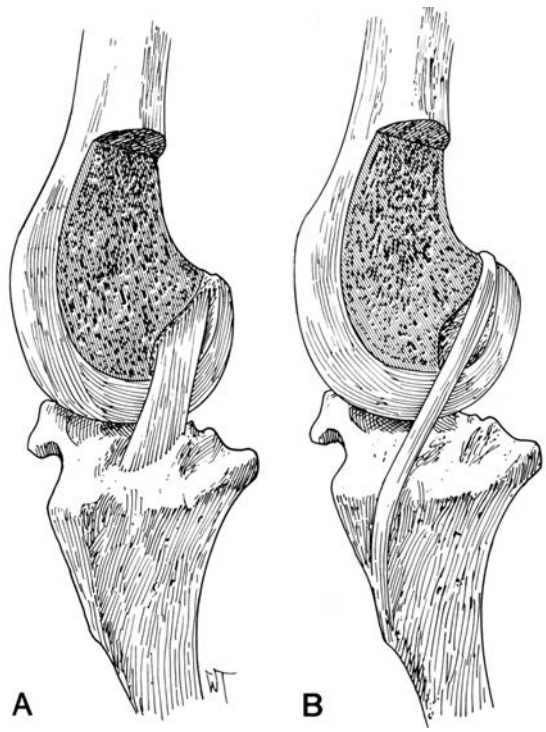


Figure 61-49. Schematic illustration of the normal anatomy and spatial orientation of the cranial cruciate ligament **A.** and the orientation of the patellar tendon graft within the joint that is achieved with the over-the-top technique **B.** (From Arnoczky SP, Tarvin GB, Marshall JL, et al. The over-the-top procedure: a technique for anterior cruciate ligament substitution in the dog. J Am Anim Hosp Assoc 1979;15:283.)

of the graft, and not the type of graft used, is responsible for the success of this repair technique.[13]

In summary, successful repair of insufficiency of the cranial cruciate ligament depends on the reestablishment of joint stability. Although this end can be accomplished by the aforementioned techniques, other components of the stifle (patella, menisci, collateral ligaments) must not be overlooked when evaluating the joint. These structures work in concert to allow normal joint motion, and failure to recognize concurrent patellar malalignment or meniscal injury in cranial cruciate ligament insufficiency may result in less than optimal postoperative function.

References

1. Arnoczky SP, Marshall JL: The cruciate ligaments of the canine stifle: an anatomical and functional analysis. *Am J Vet Res* 38:1807, 1977.

2. Arnoczky SP, Marshall JL: Pathomechanics of cruciate and meniscal injuries. *In* Bojrab MJ, ed.: Pathophysiology of small animal surgery. Philadelphia: Lea & Febiger, 1981, p 590.

3. Arnoczky SP: Surgery of the stifle: the cruciate ligaments. *Compend Contin Educ Pract Vet* 2:106, 1980.

4. Vasseur PB, Pool RR, Arnoczky SP, et al.: Correlative biomechanical and histologic study of the cranial cruciate ligament in dogs. *Am J Vet res* 46:1842, 1985.

5. Hulse DA, Michaelson F, Johnson C. et al.: A technique for reconstruction of the anterior cruciate ligament in the dog: preliminary report. *Vet Surg* 9:135, 1980.

6. Strande A.: Repair of the ruptured cranial cruciate ligament in the dog. Baltimore: Williams & Wilkins, 1967.

7. Vasseur PB: Stifle joint. *In* Textbook of small animal surgery. Philadelphia: W. B. Saunders, 1993, 1817.

8. Arnoczky SP, Tarvin GB, Marshall JL, et al. The over-the-top procedure: a technique for anterior cruciate ligament substitution in the dog. *J Am Anim Hosp Assoc* 15:283, 1979.

9. Arnoczky SP, Tarvin GB, Marshall JL.: Anterior cruciate ligament replacement using patellar tendon: an evaluation of graft revascularization in the dog. *J Bone Joint Surg [Am]* 64A:217, 1982.

10. Boudrieau RJ, Kaderly RE, Arnoczky SP, et al.: Vascularized patellar tendon graft technique for cranial cruciate ligament substitution in the dog: vascular evaluation. *Vet Surg* 14:196, 1985.

11. Butler DL, Grood ES, Noyes FR, et al.: Mechanical properties of primate vascularized vs. nonvascularized patellar tendon grafts: changes over time. *J. Orthop Res* 7:68-79, 1989.

12. Shires PK, Hulse DA, Liu W: The under-and-over fascial replacement technique for anterior cruciate ligament rupture in dogs: a retrospective study. *J Am Anim Hosp Assoc* 20:69, 1984.

13. Denny HR, Barr ARS: An evaluation of two "over the top" techniques for anterior cruciate ligament replacement in the dog. *J Small Anim Pract* 25:759, 1984.

Treatment of Caudal Cruciate Ligament Rupture by Lateral and Medial Imbrication

Joseph Harari

Surgical Technique

The primary purpose of these extracapsular procedures is to reduce caudal displacement of the tibial plateau relative to the femoral condyles, and the secondary purpose is to reduce excessive internal tibial rotation.

The animal is placed in dorsal recumbency, and a lateral parapatellar approach is used for a stifle joint arthrotomy. The joint is examined for concurrent ligamentous or meniscal injuries, which are treated accordingly. The remnants of the caudal cruciate ligament (CaCL) are resected, and the joint is lavaged with sterile saline or lactated Ringer's solution. Joint capsule closure is performed using 2-0 or 3-0 monofilament nylon, polypropylene, or polydioxanone suture material placed in a continuous pattern while a cranially directed force on the tibia is used to reduce caudal drawer motion.

Extracapsular imbrication is performed by placing a single mattress suture of size 1 or 2 nonabsorbable suture (polypropylene or nylon) on the lateral and medial aspects of the joint between the head of the fibula (laterally) or proximal tibial (medially) and just proximal or distal to the patellar (Figure 61-50). The direction of these sutures mimics the orientation of the CaCL to reduce abnormal caudal displacement and internal rotation of

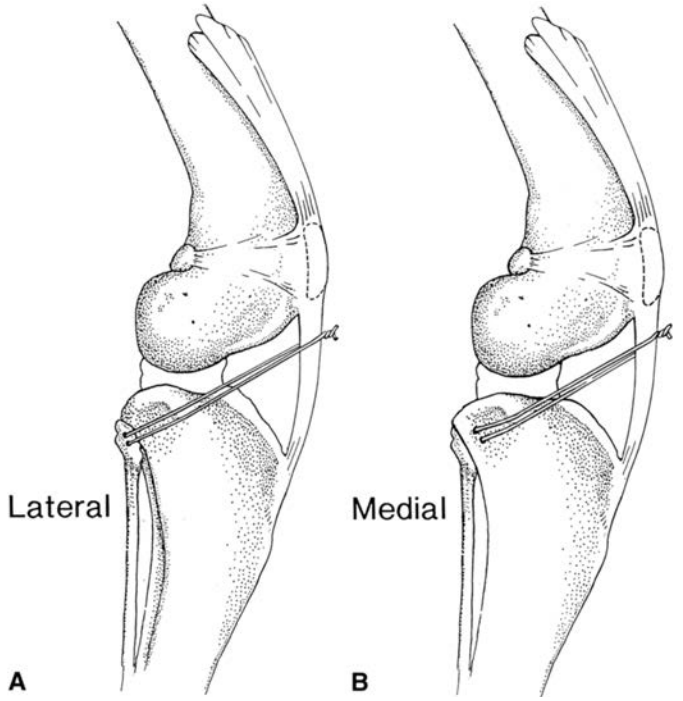


Figure 61-50. Extracapsular imbrication of a caudal cruciate ligament-deficient stifle joint using nonabsorbable mattress sutures. **A.** Lateral view. **B.** Medial view. (From Harari J. Caudal cruciate ligament injury. Vet Clin North Am Small Anim Pract I993;23:826.)

the proximal aspect of the tibia. To perform lateral imbrication, the suture is passed into the quadriceps tendon above or below the patella, is directed caudodistally under or through the head of the fibula, and then is directed cranioproximally to be tied along the lateral aspect of the stifle joint while caudal drawer motion and internal tibial rotation are reduced and the normal standing angle of the joint is maintained. To place the medial imbrication suture, the skin incision is displaced medially, and subcutaneous tissues are dissected to reveal the medial retinaculum of the stifle joint. The mattress suture is placed in the quadriceps tendon above or below the patella and is oriented caudodistally through the caudal aspect of the proximal tibia. The suture is then directed cranioproximally and is tied along the medial aspect of the stifle joint. Placement of medial and lateral sutures in the quadriceps tendon prevents unilateral displacement of the patella or tendon.

The lateral retinaculum opened during the arthrotomy can be closed with 0 or 2-0 nonabsorbable sutures placed in a mattress pattern resembling the direction of the lateral imbrication suture. The subcutaneous tissues and skin are closed in a routine manner. Postoperatively, a soft, padded limb bandage is used for 2 weeks, and exercise is restricted for 1 month to protect soft tissue healing.

Lateral and medial imbrications are recommended for midsubstance ligamentous tears. Bone avulsion injuries involving the origin or insertion of the CaCL can be repaired by stabilization of bone fragments with a small bone screw or with Kirschner or orthopedic wires (Figure 61-51).[1] Small unattachable fragments can be removed (along with the CaCl), and extracapsular imbrication can be performed. Alternatively, medial collateral ligament and popliteal tendon entrapment with bone screws have been described for midsubstance Ca CL tears.[2]

Surgical stabilization of a CaCL-deficient stifle joint is variable for human and veterinary patients. In human patients, unidirectional (anteroposterior) instability due to in-continuity tears is treated with physical therapy designed to strengthen the quadriceps muscles while surgical stabilization of avulsion injuries is recommended.[3] In animals, persistent caudal drawer motion in experimental and clinical patients after resection with or without surgical stabilization has not been consistently associated with lameness or lack of limb function.[4-6] This finding has been attributed to the lack of importance in stabilization of the canine stifle joint by the CaCL at normal angles of the limb. At our clinic, therefore, surgical stabilization of tears of this ligament is not routinely performed. An arthrotomy or arthroscopy is performed to remove proliferative ends of the damaged ligament and to inspect the joint for concurrent meniscal or cranial cruciate ligament lesion.[6] Bone avulsions are reattached if technically feasible. A caudomedial stifle joint arthrotomy is necessary to attach or resect avulsion of the CaCL tibial insertion.[1] Long-term, objective clinical evaluations of affected stifle joints, therefore, are warranted to delineate the natural progression of CaCL-deficient canine stifle joints. Recently, a high incidence (88%) of dogs with CrCL injury Synovitis, and concomitant CACL lesions has been described.[7]

References

1. Reinke JD. Cruciate ligament avulsion injury in the dog. J Am Anim Hosp Assoc 1982; 18: 257 – 264.

2. Schulz K. Caudal cruciate ligament injury. In Fossum TW, Small Animal Surgery. 4th ed. St. Louis. Mosby/Elsevier, 2013; 1344 – 1345.

3. Abate J. Dislocations and soft tissue injuries of the knee. In: Brouner BD. Sletel Trauma. 4th ed. Philadelphia, PA. Saunders/Elsevier. 2009; 2167 – 2201.

4. Pournaras J, Symeonides PP, Karkavalas G. The significance of the posterior cruciate ligaqment in the stability of the dog's knee. J Bone Joint Surg Br 1983; 65: 204 – 209.

5. Harari J, Johnson AL, Stein LE, Evaluation of experimental transection of the caudal cruciate ligament in dogs. Vet Surg 1987, 16: 151 – 154.

6. Johnson AL, Olmstead ML. Caudal cruciate ligament rupture: a retrospective analysis of 14 dogs. Vet Surg 1987; 16: 202; 16: 202 – 206.

7. Sumner JP, Markel MD, Muir P. Caudal cruciate ligament damage with cranial cruciate ligament rupture. Vet Surg 2010; 39: 936 – 941.

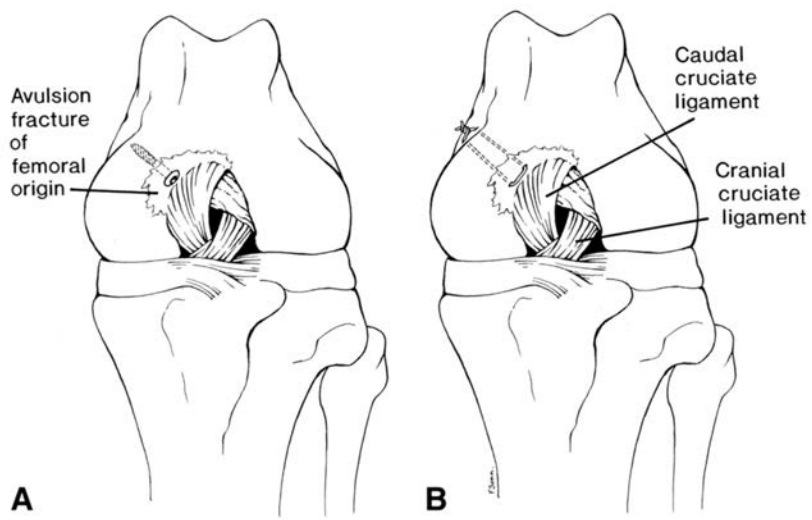


Figure 61-51. Repair of a femoral avulsion fracture in a caudal cruciate ligament-deficient stifle joint using a bone screw **A.** or orthopedic wire **B.** (From Harari J. Caudal cruciate ligament injury. Vet Clin North Am Small Anim Pract I993;23:826.)

Treatment of Collateral Ligament Injuries

Erick L. Egger

The collateral ligaments are important stabilizing elements in the stifle joint. Injury to the collateral ligaments usually is caused by trauma and often is associated with disruption of either the cranial or caudal cruciate ligament.

Anatomic Features

The medial collateral ligament originates on the medial epicondyle of the femur and passes distally in the joint capsule. It passes over the medial lip of the tibial plateau, where an underlying bursa allows the ligament to slip back and forth as the joint moves. The ligament attaches to the medial shaft of the tibia with a long, narrow insertion.[1] The medial collateral ligament is positioned over the central axis of the stifle to remain tight throughout flexion and extension of the joint.[2] The lateral collateral ligament originates on the lateral epicondyle of the femur and passes distally in the joint capsule to insert on the fibular head.[1] The lateral collateral ligament is caudal to the central axis of the joint.[2] This results in a tight ligament in extension, which limits internal rotation and contributes to craniocaudal stability. The ligament loosens as the joint flexes, allowing the tibia to rotate internally.

Diagnosis and Treatment Options

The clinical diagnosis of isolated collateral injuries can be difficult. With the joint held in full extension, varus and valgus forces occasionally result in angulation away from the side with ruptured ligament. However, if both cruciate ligaments are intact, they will greatly reduce or prevent this instability. Some increase in rotational movement may occur. Evidence of a widened joint space on one side on radiographs taken while the joint is stressed may aid in the diagnosis. Collateral rupture in the presence of a cruciate disruption is readily revealed by the presence of varus or valgus angulation of the joint when stress is applied and a dramatic increase in rotational instability with the stifle extended.

Management of collateral ligament injuries varies with the severity of injury and resultant instability. A stretched or isolated torn collateral ligament without gross instability can often be managed with external coaptation. A contoured lateral splint fashioned of plaster or Hexcelite (Hexcel Medical Products, Dublin, CA) in a padded bandage is used to stress the joint toward the injured collateral ligament. This coaptation must be maintained for at least 3 to 4 weeks. Collateral ligament injuries resulting in gross instability are repaired by suturing or other internal fixation procedures.

Surgical Technique

Because the collateral ligaments are extrasynovial, blood supply is adequate to allow simple ruptures to heal if the ends are adequately apposed. A three-loop pulley pattern of monofilament nonabsorbable material such as nylon or polypropylene can be used to suture collateral ligaments[3] (Figure 61-52). Each pass of the suture is a different distance from the torn ends and axially at a 120° rotation from the previous passage. In one study,

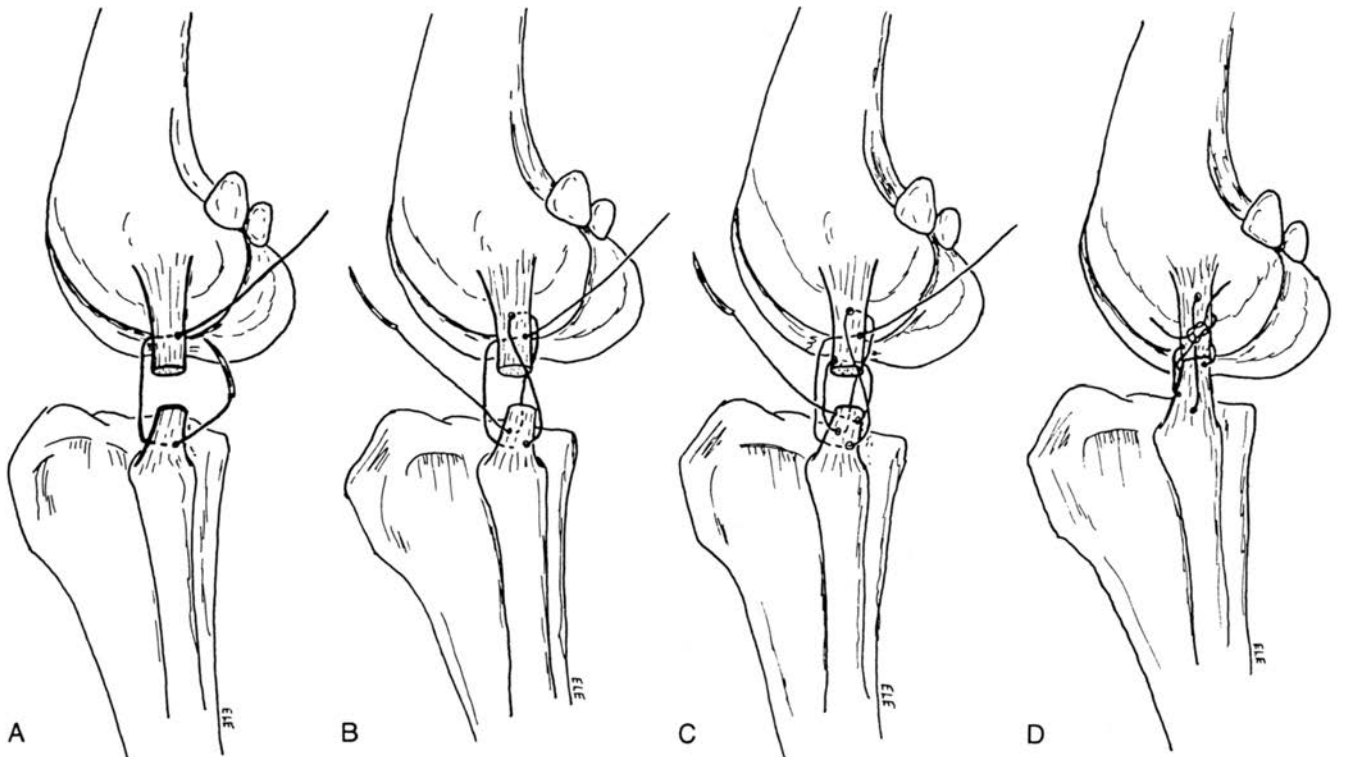


Figure 61-52. Primary suturing of a collateral ligament rupture. **A.** First loop of suture pattern. **B.** Second loop of suture placed at 120° rotation to the first. **C.** Third loop of suture again rotated. **D.** Suture pulled tight and tied.

this three-loop pulley pattern tolerated approximately 25% more tensile load and allowed only 34% as much distraction before failure under tension as the locking-loop pattern in canine collateral ligaments.[4]

Suturing of severely traumatized ligaments may not provide adequate support. For these cases, a large figure-of-eight suture of nylon or polypropylene can be placed between bone screws seated at the collateral ligament's attachments to provide additional support while the tissues heal (Figure 61-53).

Care must be taken to tighten a lateral collateral ligament repair only in moderate extension because overtightening of this area prevents normal range of motion. Cases in which the ligament has been torn away from the bone are best managed by fixation with bone screws. A spiked washer (Synthes, Paoli, PA) can be used to trap the ligament without compromising its vascularity (Figure 61-54). Any concurrent injury (e.g., a torn meniscus or cruciate ligament rupture) should be dealt with, and then the joint should be externally supported with a lateral splint for 3 to 4 weeks while the collateral ligament heals.

Avulsion fractures of the ligament's bony attachments are best handled by surgical reduction and fixation (Figure 61-55). One or two Kirschner wires are driven through the fragment to hold reduction. A figure-of-eight tension band wire is then passed behind the Kirschner wires and through a transverse hole in the bone. This wire is tightened to counteract the pull of the ligament. The Kirschner wires should be cut off and bent back to reduce soft tissue irritation. Alternatively, a bone screw can be

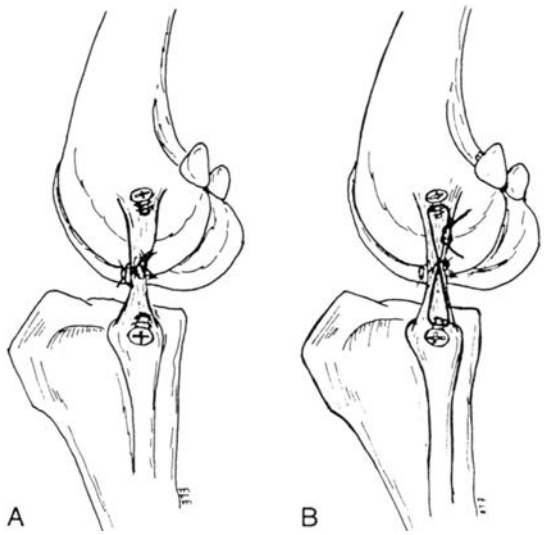


Figure 61-53. Figure-of-eight support of weak collateral ligament repair. **A.** Collateral ligament repaired as well as possible and bone screws placed at both attachments of the ligament. **B.** Figure-of-eight suture placed around the screw head.

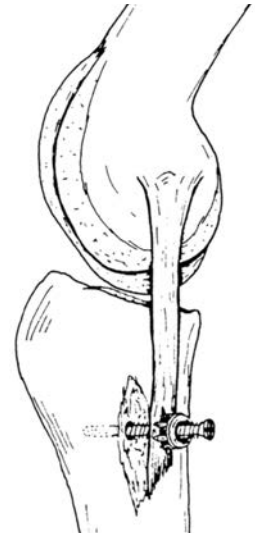


Figure 61-54. Reattachment of an avulsed ligament with a spiked washer and a bone screw.

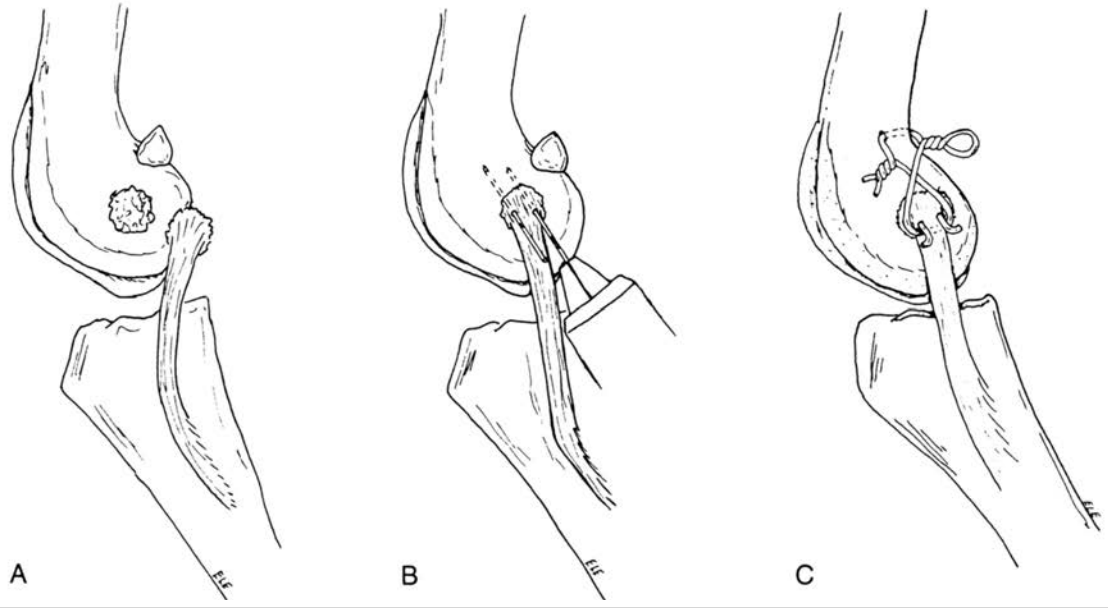


Figure 61-55. Fixation of an avulsion fracture of the attachment of a collateral ligament. **A.** Avulsion of the proximal attachment of the medial collateral ligament. **B.** Fixation of the fragment with two Kirschner wires. **C.** Placement of a figure-of-eight wire to counteract the ligament pull.

used if the avulsion fragment is large enough. Because internal fixation of a fracture should result in a stable repair, extended external coaptation is usually not indicated. However, a soft, padded bandage may be used for several days postoperatively to control soft tissue swelling.

References

1. Evans HE, Christensen CG. Miller's anatomy of the dog. 2nd ed. Philadelphia: WB Saunders, 1979.

2. Arnoczky SP, Tarvin GB, Vasseur P. Surgery of the stifle: the menisci and collateral ligaments. Compend Contin Educ Pract Vet 1980;2:395.

3. Griffiths RC. Collateral ligament injuries. In: Proceedings of the 7th annual surgical forum.: American College of Veterinary Surgeons, 1979.

4. Berg RJ, Egger EL. In vitro comparison of the three loop pulley and locking loop suture patterns for repair of canine weightbearing tendons and collateral ligaments. Vet Surg 1985; 15:107.

Osteochondritis Dissecans of the Canine Stifle

Ron Montgomery

Overview of OCD of the Stifle

Osteochondritis dissecans (OCD) in dogs occurs most often at the humeral head (~ 75% of OCD cases). OCD of the stifle has been reported to be the second most common location in European dogs, but in the U.S.A. the stifle is a less common site than the elbow or hock. Either frequency of OCD in the stifle differs due to unknown factors at different geographic locations, or OCD of the stifle is underdiagnosed in the U.S.A.

OCD can only occur in dogs with a systemic defect in endochondral osteogenesis called osteochondrosis. Since only juvenile bones grow, OCD necessarily develops in juveniles, although diagnosis may be after osseous maturity. Rapid growth is part of the pathogenesis of OCD. Consequently, OCD almost exclusively affects large breed dogs, and about 75% of the cases are in males. In addition, OCD affects the same joint bilaterally in at least half of the cases, even if the lameness is unilateral. OCD in two different joints of a single patient (stifle and shoulder), however, is uncommon.

Diagnosis

The presenting complaint for dogs with OCD of the stifle is unilateral or bilateral rear leg lameness, usually with an insidious onset. The signalment is almost exclusively a young, large dog (generally one less that 12 months old and greater than 30 pounds). The differential list includes trauma (Salter-Harris fractures, avulsions, luxations, fractures, etc.), and the juvenile bone and joint diseases of the rear limbs of large breed dogs (hip dysplasia, panosteitis, patella luxation, OCD of the stifle or hock, HOD, and Osgood-Schlatter's disease). Under diagnosis of stifle OCD may occur due to its insidious onset, often mild clinical signs, and/or inappropriately stopping examination once another diagnosis has been made. A complete orthopaedic examination is indicated because multiple orthopaedic problems can, and often do, occur concurrently.

Examination of a canine stifle with OCD may yield pain at full extension or full flexion, have an audible click while going through a range of motion, and have joint effusion palpable on either side of the patellar tendon. Arthrocentesis is a simple procedure that can confirm that the stifle does have pathology based only on the gross characteristics of the synovial fluid (volume > 0.5 ml, yellow color, decreased viscosity). Stifle pathologies such as patella luxation, collateral ligament rupture, avulsion of a cruciate ligament or fracture are readily diagnosed or ruled out. The remaining stifle diagnoses that could present like stifle OCD are rare (e.g. avulsion of long digital extensor origin or popliteus insertion, isolated meniscal tears, etc.).

Confirmation of stifle OCD can usually be accomplished by radiographs (Figure 61-56). However, not visualizing an OCD lesion on radiographs does not rule out the diagnosis, especially if the lesion is small and/or not depicted in skyline view. The lateral view should be oblique to avoid superimposition of the femoral condyles, with the lateral femoral condyle more caudal. OCD lesions have been reported most often on the lateral femoral condyle (94%), but have also been reported on the medial femoral condyle, the patella, and the trochlear ridge. CT is highly reliable in diagnosing or ruling out OCD. Other imaging modalities reported as useful for diagnosis of OCD of the stifle include MRI and ultrasonography. Exploratory arthrotomy, either via arthroscope or open procedure, is also reasonable if some type of pathology of the stifle is indicated by orthopaedic examination and synovial fluid analysis.

Surgical Technique

Arthroscopy involves the lowest morbidity for exploring the stifle and treatment of an OCD lesion. A limited arthrotomy (Figure 61-57) provides much less morbidity than a full arthrotomy of the stifle, if the parapatellar fibrocartilage is not transected and the patella is not dislocated. The parapatellar skin incision extends from the mid-patella level to just distal to the tibial plateau. Incisions through the retinaculum and then the joint capsule are successively slightly shorter to facilitate complete closure. A self retaining retractor (e.g. Gelpi, Wallace) is placed and firmly distracted to provide visibility of the femoral condyle and intercondylar notch area. Flexion and extension will facilitate visualization of the weight bearing surface of the condyle. Preoperative identification of the OCD location (i.e. medial or lateral condyle) is beneficial when using a limited arthrotomy. If necessary for exploration, the incision can be extended to a standard parapatellar approach to the stifle. OCD flaps are removed in most cases. However, some OCD lesions of the stifle can be quite large, and reports of fixing them in situ with bone pegs, pins, etc. has been reported. Once the OCD flap has been removed, the defect ("bed") from which it originated should be evaluated. The defect will likely fill with fibrocartilage, if a blood supply is present. If the OCD bed is red, then granulation tissue is present and it should not be significantly disturbed. If the bed is white (e.g. eburnated bone), then forage into the medullary cavity with a 0.062" K-wire (or smaller) at multiple locations will supply blood to the site with considerably less morbidity than curettage.



Figure 61-56. Radiographs of stifles with OCD lesions. The lesion may appear flat (craniocaudal image) or concave (mediolateral image). Oblique mediolateral projection with the lateral femoral condyle more caudal helps visualizing an OCD lesion. Not visualizing an OCD lesion on radiographs does not rule out the diagnosis.



Figure 61-57. Limited arthrotomy to the lateral femoral condyle. The same approach can be performed medially, or on either side of the patellar tendon.

Prognosis

Long term prognosis depends primarily on the amount of preexisting degenerative joint disease, plus the size and location (weight bearing vs. non-weight bearing areas) of the OCD lesion. Short term morbidity is most affected by the surgical technique. Morbidity from arthroscopy is typically only a few days at most. Limited arthrotomy morbidity is only slightly longer than for arthroscopy, if the patella is not destabilized. Deeply curetting the OCD bed rather than forage can extend the postoperative morbidity for weeks.

Suggested Readings

Kramer M, Stengel H, Gerwing M., et al: Sonography of the canine stifle. *Vet Rad & Ultrasound* 40:282, 1999.

Necas A, Dvorak M, Zatloukal J: Incidence of osteochondrosis in dogs and its late diagnosis. *Acta Veterinaria Brno* 68:131, 1999.

Montgomery RD, Milton JL, Henderson RA, Hathcock JT: Osteochondritis dissecans of the canine stifle. *Compendium on Continuing Education for the Practicing Veterinarian* 11:1199, 1989.

Morgan JP, Wind A, Davidson AP: Bone dysplasias in the Labrador retriever: a radiographic study. *J Am Animal Hosp Assoc* 35:332, 1999.

Shealy PM, Milton JL: Limited arthrotomy of the canine stifle for osteochondritis dissecans. *Vet Comp Ortho & Trauma* 4:134, 1991.

Chapter 62

Tibia and Tarsus

Repair of Tibial Fractures

Ann L. Johnson

Introduction

Tibial fractures commonly occur in dogs and cats. Specifically, tibial fractures range from 9 to 18% of fractures occurring in dogs.[1] Proximal and distal fractures in immature animals are generally physeal fractures, most often Salter-Harris Type I or II. In mature dogs, proximal metaphyseal fractures may be single or comminuted and may cause loss of integrity of the tibial plateau. Distal tibial fractures in mature dogs often involve malleolar fractures, and are generally associated with road trauma. (See next section on malleolar fractures). Tibial diaphyseal fractures encompass the following: greenstick or incomplete fractures in immature animals; transverse, short oblique, long oblique and spiral reducible fractures; and comminuted fractures which may be reducible (one butterfly fragment) or nonreducible (multiple fragments). The tibia may be treated with cast, intramedullary pins and orthopedic wire, interlocking nail, external fixator, or bone plate and screw fixation. The surgeon should consider the mechanical, biological and clinical environment of the fracture and the patient before choosing the appropriate implant system for treating diaphyseal fractures.[2]

Preoperative Assessment and Management of Animals with Tibial Fractures

Animals that have received an external blow severe enough to cause a tibial fracture often have concurrent external or internal organ system injury. Cardiovascular, pulmonary, urinary, and neurologic systems should be examined thoroughly to detect any abnormalities prior to anesthesia and surgical repair of the fracture. A minimum database should include a complete blood count, chemistry profile, urinalysis and radiographs of the affected tibia. It is often useful to take radiographs of the contalateral tibia for comparison and to serve as a template for plate contouring. Because 33 to 42% of fracture patients have some degree of pulmonary injury, preoperative evaluation should include thoracic radiographs.[3] Fractures of the tibia are best managed preoperatively with a modified Robert Jones bandage to reduce or prevent soft tissue swelling which interferes with landmark identification. Prophylactic antibiotics should be administered in contaminated cases (open injuries), cases with severe trauma (significant soft tissue bruising and swelling or multiple bone fractures), and cases requiring lengthy operative times (2 hours or longer). Prophylactic antibiotics are also effective in closed tibial fractures and should be administered intravenously at the time of anesthetic induction, repeated every 2 to 4 hours, and discontinued at completion of surgery.[3]

General Issues with Tibial Fracture Management

Issues unique to the tibia include the presence of minimal soft tissue coverage on the medial surface of the bone. The paucity of soft tissues increases the possibility of open fractures and potentially decreases the extra-osseous blood supply, both of which can delay bone healing. Minimal soft tissue coverage of bone plates results in tissue irritation and cold hypersensitivity which may require plate removal to resolve. However, the minimal muscle coverage on the medial side is an advantage for placing an external fixator while minimizing muscle trauma.

The tibia is an ideal bone for external fixator application because it is straight from the lateral perspective and allows the potential for all frame constructions including use of the circular and hybrid fixators. Conversely, the tibia can be a difficult bone for placing an intramedullary pin or nail because of the S shaped curve apparent from the cranial perspective and the presence of the joints directly above and below the bone. In order to prevent untoward stifle joint penetration with intramedullary implants, only antegrade implant pin placement is recommended. The S shape of the tibia also contributes to the requirement for accurate plate contouring to avoid angular deformity.

Clinically Relevant Anatomy of the Tibia

The tibia articulates with the femur proximally, the tarsus distally and the fibula both proximally and distally on the lateral side. The lateral collateral ligament of the stifle inserts on the fibular head. The medial collateral ligament of the stifle inserts on the caudal proximal portion of the medial surface of the tibia. The proximal epiphysis of the tibia is triangular in shape with the articular surface on the caudal half. The tibial tuberosity where the patella ligament inserts encompasses the cranial half of the proximal epiphysis. The tibial tuberosity continues distally forming the tibial crest on the cranial surface of the tibia. The proximal tibial metaphysis is flat medially with minimal soft tissue coverage and concave laterally where the extensor muscles are located. The tibial diaphysis is round in cross section and describes an S shaped curve when viewed from the cranial aspect. The tendons of the cranial tibial and long digital extensor muscles cross the cranial surface and the medial saphenous vein crosses the medial surface of the distal tibia. The medial malleolus of the distal tibia and lateral malleolus of the fibula extend distal to the articulating surfaces of the distal tibia and talus. The long and short parts of the medial and lateral collateral ligaments arise from the medial malleolus of the tibia and the lateral malleolus of the fibula respectively and are essential for hock stability.

Proximal Tibial Fractures

Physeal Fractures

Salter I and Salter II fractures of the proximal tibial physis occur in immature dogs and cats. Animals usually present with a nonweight bearing lameness of the affected limb subsequent to a traumatic episode. Palpation of the proximal tibia reveals soft tissue swelling, instability and crepitus. Radiographs are used to confirm the diagnosis of proximal physeal fracture. The epiphysis is generally displaced caudally to the metaphysis.

Physeal fractures which are minimally displaced may be stabilized with a cast applied to the leg with the stifle in extension. However, in many cases adequate fracture reduction cannot be obtained without surgical manipulation. Surgical treatment consists of open reduction and stabilization with two or three Kirschner wires. A medial approach through skin, subcutaneous tissue and crural fascia over the proximal diaphysis of the tibia may be used to expose the fracture.[4] The fracture is reduced by extending the stifle and gently levering the epiphysis into position. Reduction is maintained with pointed reduction forceps while the fracture is stabilized with two or three Kirschner wires or small intramedullary pins (Figure 62-1). The implants may be bent to prevent migration and aid removal.[5]

Postoperatively, the patient should be confined to a small area with activity limited to leash walking. Follow up radiographs may be made at 3 and 6 weeks after treatment. Physeal fractures generally heal within three to four weeks. If a cast is used, it should be removed as early as possible. Physical therapy may be necessary to restore range of motion to the stifle. Premature closure of the physis usually occurs because of the trauma inflicted on the growing cells during the initial injury. Owners of very immature animals should be warned of the potential for growth deformities.

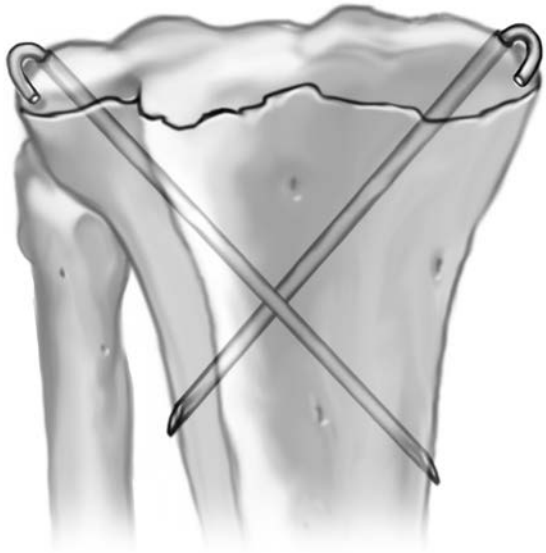


Figure 62-1. Fractures of the proximal tibial physis may be stabilized with two Kirschner wires or small intramedullary pins.

Avulsion of the Tibial Tuberosity

Avulsion of the tibial tuberosity also occurs in immature dogs and cats. The tibial tuberosity is the insertion point for the patella ligament and is subjected to avulsion forces when the quadriceps muscle is contracted. Animals usually present with considerable joint effusion, soft tissue swelling and lameness. Radiographs are made to confirm the diagnosis. In some cases, confusion may exist over the appearance of the physis. Radiographs should be made of the opposite limb to verify the presence of an avulsion versus irregular ossification of the tuberosity. Obtaining flexed and extended stifle views may be useful to confirm the mobility of the avulsed fragment.

Avulsions of the tibial tuberosity which are minimally displaced may be stabilized with a cast applied to the leg while the stifle is extended. Surgical treatment consists of open reduction and stabilization with two Kirschner wires and figure of eight orthopedic wire functioning as a tension band. A medial approach is used to expose the fracture.[4] The avulsed tibial tuberosity is reduced by extending the stifle and securing the tuberosity to the tibia with a pointed reduction forceps. The tuberosity is secured with a tension band wire (Figure 62-2).[5] Postoperative radiographs should be evaluated for fracture reduction and implant placement.

Postoperatively, the patient should be confined to a small area with activity limited to leash walking. Follow up radiographs may be made at 3 and 6 weeks after treatment. If a cast is used, it should be removed in 3 to 4 weeks. Physical therapy may be necessary to restore range of motion to the stifle. In very immature animals, the tension band wire should also be removed at 3 weeks to allow physeal growth. Premature closure of the tibial tuberosity physis in a very young animal may adversely affect stifle conformation. Additional implant removal may be required if soft tissue irritation occurs.

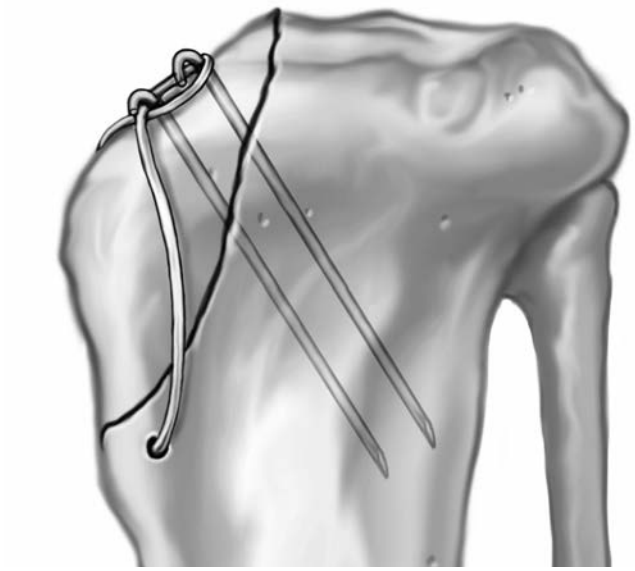


Figure 62-2. An avulsion fracture of the tibial tuberosity may be stabilized with two Kirschner wires and figure of eight orthopedic wire functioning as a tension band.

Proximal Metaphyseal Fractures

Proximal metaphyseal fractures in mature dogs are uncommon. These fractures may involve the articular surface, and may be either single or comminuted fractures. They are generally managed with a buttress plate application to shore up the tibial plateau.(Figure 62-3) The addition of a cancellous bone autograft may be necessary if there is bone loss.

Tibial Diaphyseal Fractures

Tibial diaphyseal fracture stabilization has been described using casts, intramedullary pins and orthopedic wire, interlocking nails, bone plates and screws, and linear and circular fixators. The keys to optimal fracture fixation include accurate decision

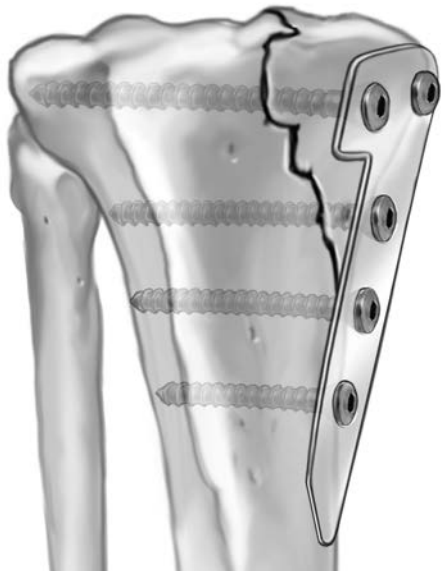


Figure 62-3. Tibial plateau fractures are usually managed with buttress plate application to shore up the tibial plateau.

making to guide reduction technique and implant choice, and preoperative fracture planning for the procedure.

Implant systems are chosen after an assessment has been made of the mechanical, biological and clinical environments of the fracture and the patient. The mechanical environment is influenced by the size and activity of the patient, the type and reducibility of the fracture, and the presence or absence of multiple limb injury or pre-existing disease. The mechanical environment dictates how much load the implant must support. The biological environment is influenced by the age and health of the animal, the location of the fracture, the energy involved in creating the fracture, and the presence and condition of the surrounding soft tissues. The biologic environment can also be disturbed with open anatomic reduction techniques. The biologic environment dictates the length of time the implant must function. The clinical environment includes the intended function of the animal, the attitude of the animal and the client's ability to care for the animal. If the mechanical environment is poor, the implant system must be relatively strong. If the biological environment is poor, the implants must be able to function for a prolonged time period and should purchase the bone with an interlocking hold (bone screws and positive profile threaded pins). Some fixation systems, especially external fixation systems are inappropriate for certain animals and clients.[2]

After the appropriate implant system has been selected, preoperative fracture planning includes selecting a reduction technique and predetermining where implants will be placed. Epidural anaesthesia with a local anaesthetic agent and a narcotic, combined with general anaesthesia, provides analgesia and profound relaxation of the muscles of the rear limb and is a useful aid to tibial fracture reduction. Reducible fractures, single fractures and fractures with one or two large fragments are treated with open reduction, anatomical reconstruction and rigid stabilization to restore the bone column and promote load sharing between the bone and the implant, and enhance the mechanical environment. Transverse and short oblique fractures may be reduced by exposing the fracture and tenting the bone ends out of the incision then pressing the reduced fracture back into position. Alternatively, a limited approach may be made and a lever used to manipulate the bone back into position. Long oblique or spiral fractures may be reduced by exposing the fracture and distracting the bone segments to approximate the fracture surfaces while using pointed reduction forceps to manipulate the bone segments into reduction.[6]

Non-reducible fractures, or comminuted fractures with multiple small or large fragments where fragment reconstruction would not restore the bone column should be treated with closed indirect reduction or "open but do not disturb the fragments" indirect reduction techniques to preserve the biological environment.[7] The tibia is particularly suitable for the indirect reduction techniques essential to the success of "biologic" treatment of non-reducible fractures. Distraction of the major bone segments may be achieved with the hanging limb technique or by using an intramedullary pin to push the distal segment away from the proximal segment. As the bone ends are distracted the tension on the surrounding soft tissues guides the fragments into alignment.[6]

In addition to choosing the reduction technique, it is helpful for preoperative planning for the surgeon to draw the fracture lines on an outline of the intact tibia. The implants should then be drawn onto the tibia in the order and location in which the surgeon intends to place them. The fracture plan may be taken into the operating room to serve as a guide.[8,9]

Diaphyseal tibial fractures which are treated with open reduction will often benefit from the addition of a cancellous bone autograft, or cancellous bone allograft with demineralized bone matrix. Cancellous bone autograft may be harvested from the ipsilateral proximal humerus which is accessible when the animal is positioned for surgery. The donor site must be prepared for aseptic surgery prior to moving the animal into the operating room. The graft is usually harvested after the fracture has been stabilized. Alternatively, cancellous bone allograft with demineralized bone matrix is available commercially and eliminates the the need for preparing a donor site.

Treatment of Tibial Diaphyseal Fractures with a Cast

Full cylinder casts which incorporate the hock and the stifle are a very effective fixation for stable fractures in young dogs or cats when the fracture shares the load of weight bearing with the cast and will heal quickly. Greenstick or incomplete fractures of the tibia fit these criteria. The cast should be applied with the limb positioned slightly in extension and with varus angulation to overcome the contraction of the extensor muscles lying on the lateral side of the tibia.[10] Postoperatively the animal must be confined to a small area with very limited activity allowed. The client must be willing to protect the cast from adverse environments. Weekly rechecks will minimize cast related complications.

Operative Treatment of Tibial Diaphyseal Fractures

Treatment of Tibial Diaphyseal Fractures with Intramedullary Pins and Orthopedic Wire

An intramedullary (IM) pin may be combined with multiple cerclage wires to stabilize long oblique or spiral tibial fractures in immature animals (Figure 62-4). A medial approach is made to the fracture area. The IM pin is placed in an antegrade manner starting at a point on the edge of the tibial plateau midway between the tibial tuberosity and the medial tibial condyle. The pin is driven into the medullary canal to exit at the fracture. The fracture is reduced and secured with pointed reduction forceps. The cerclage wire is applied. The IM pin is then driven distally to insert in the distal metaphysis. Care must be taken to avoid penetrating the articular cartilage. Using a similar length pin as a guide pin can help the surgeon determine the location of the inserted pin. The exposed end of the pin is cut below the level of the skin.[11]



Figure 62-4. An intramedullary pin may be combined with cerclage wires to stabilize long oblique fractures in immature dogs and cats.

Treatment of Tibial Diaphyseal Fractures with an Interlocking Nail

Interlocking nails can be used effectively to treat a wide variety of mid diaphyseal tibial fractures. Because the screws or bolts securely lock the nail to the respective bone segment, the interlocking nail not only provides resistance to bending, but also resists rotational and axial loading forces and can effectively bridge a nonreducible fracture. An open approach is used to reconstruct reducible fractures. An open but don't touch approach is used when major segment alignment is the goal. The nail selected should correspond to the width of the medullary canal at the isthmus of the bone. The interlocking nail is inserted in a normograde manner starting at the cranio-medial aspect of the tibial plateau. A medial parapatellar approach is used to expose the point of insertion. Flexing the stifle 90 degrees facilitates nail insertion. The medullary canal is prepared for nail placement by inserting a series of progressively larger Steinmann pins or by using a hand reamer. The nail is inserted using the extension and the insertion tool. The insertion tool is removed and the drill-guide jig attached to the extension. Using the drill guide jig, the interlocking nail is secured in place with two screws each placed through the proximal and distal fracture segments and the nail[12] (Figure 62-5).



Figure 62-5. An interlocking nail can be used to treat comminuted nonreducible fractures of the tibial diaphysis.

Treatment of Tibial Diaphyseal Fracture with External Fixators

External fixators may be applied to stabilize most tibial diaphyseal fractures. The stiffness of the fixator may be manipulated by adding fixation pins and using biplaner or bilateral frames to manage a wide variety of fractures in most dogs and cats. The hanging limb technique may be used for positioning the limb and to aid reduction of the fracture.[6] The patient is placed in dorsal recumbency and the affected limb is suspended from the ceiling and draped out in the hanging position. The table can be lowered to allow the animal's weight to fatigue the muscles and help align the joints. For single fracture lines the fragments may be levered into position through a limited surgical approach to the fracture. For closed reduction of comminuted fractures, proximal and distal fixation pins may be placed initially and then manipulated to align the joint surfaces. The reduction is maintained by securing the connecting bars.

A type Ia external fixator is applied to the cranial medial surface of the tibia. Positive profile or Duraface end threaded fixation pins are placed in the metaphysis of each segment and about 1 centimeter on either side of the fracture line. At least two and preferably three fixation pins are placed in each bone segment. The pins are secured to a connecting rod creating a unilateral, uniplanar frame (Figure 62-6). To apply a type Ib frame, an additional unilateral frame is placed on the cranial lateral surface of the tibia to create a unilateral, biplanar frame (Figure 62-7). Type Ib frames may be connected with articulating rods. A type II frame is applied to the tibia by inserting transfixation pins through the metaphyses and securing them to the connecting rods. Fixation pins are then placed about a centimeter on either side of the fracture. These pins can be unilateral, secured only to the medial connecting bar, or transfixation pins which are secured to both connecting bars. Additional pins are placed when there is adequate bone[13] (Figure 62-8). This frame is a bilateral, uniplanar construct. Rarely, a type III frame is applied by adding a unilateral frame to the cranial surface of the tibia forming a bilateral, biplanar frame.

Treatment of Tibial Diaphyseal Fractures with Bone Plates and Screws

Bone plates and screws may be used to stabilize both single and comminuted tibial diaphyseal fractures. Single transverse or short oblique fractures should be anatomically reduced and stabilized using the bone plate as a compression plate (Figure 62-9). Long oblique fractures should be anatomically reduced and compressed with lag screws. The reconstructed bone is then protected with a bone plate used as a neutralization plate (Figure 62-10). A comminuted nonreducible fracture should be realigned and bridged with a bone plate functioning as a bridging plate (Figure 62-11A). The plate may be combined with an IM pin when stabilizing comminuted nonreducible fractures to reduce strain on the plate and extend fatigue life of the fixation (Figure 62-11B).[14,15]

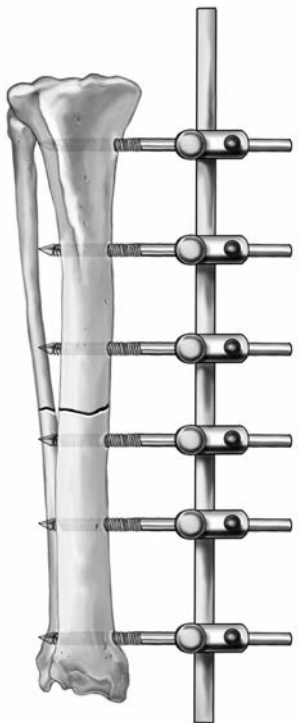


Figure 62-6. A type Ia external fixator is applied to the cranial medial surface of the tibia. Optimally, three pins are positioned above the fracture and three fixation pins positioned below the fracture.

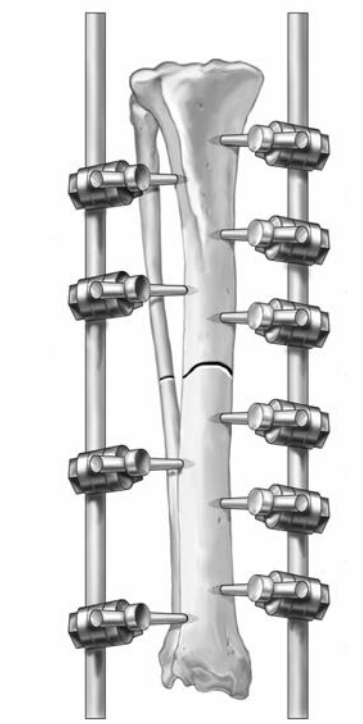


Figure 62-7. A type Ib external fixator is constructed by combining two type Ia frames. The first frame is applied to the cranial medial surface of the tibia and the second frame applied to the cranial lateral surface of the tibia.

A cranial medial approach to the shaft of the tibia is used to expose the fracture site and the medial surface of the bone for plating.[16] When treating comminuted nonreducible fractures, an open but don't disturb the fragments technique should be used to expose the proximal and distal bone segments with minimal disturbance of the fracture hematoma and bone fragments.[7] Cranial caudal radiographs of the contralateral intact tibia are useful to serve as a template for plate contouring. The tibia has an S shaped curve which must be reproduced when contouring the plate to avoid a valgus deformity of the limb postoperatively.

General Postoperative Treatment of Tibial Diaphyseal Fractures

Postoperative treatment starts with radiographs made of the tibia to document fracture reduction or appropriate limb alignment, and implant placement. Radiographs of comminuted fractures treated by realigning the limb should be evaluated closely to determine that the proximal and distal joint surfaces are parallel to each other and the joints are not rotated in relationship to each other. Mal-aligned limbs with varus or valgus deformity which are treated with external fixators may be corrected postoperatively by loosening the distal fixation clamps and realigning the limb. Mal-aligned limbs treated with plates cannot be corrected without a second surgical procedure. The surgeon must make the decision about severity of the mal-alignment and act appropriately.

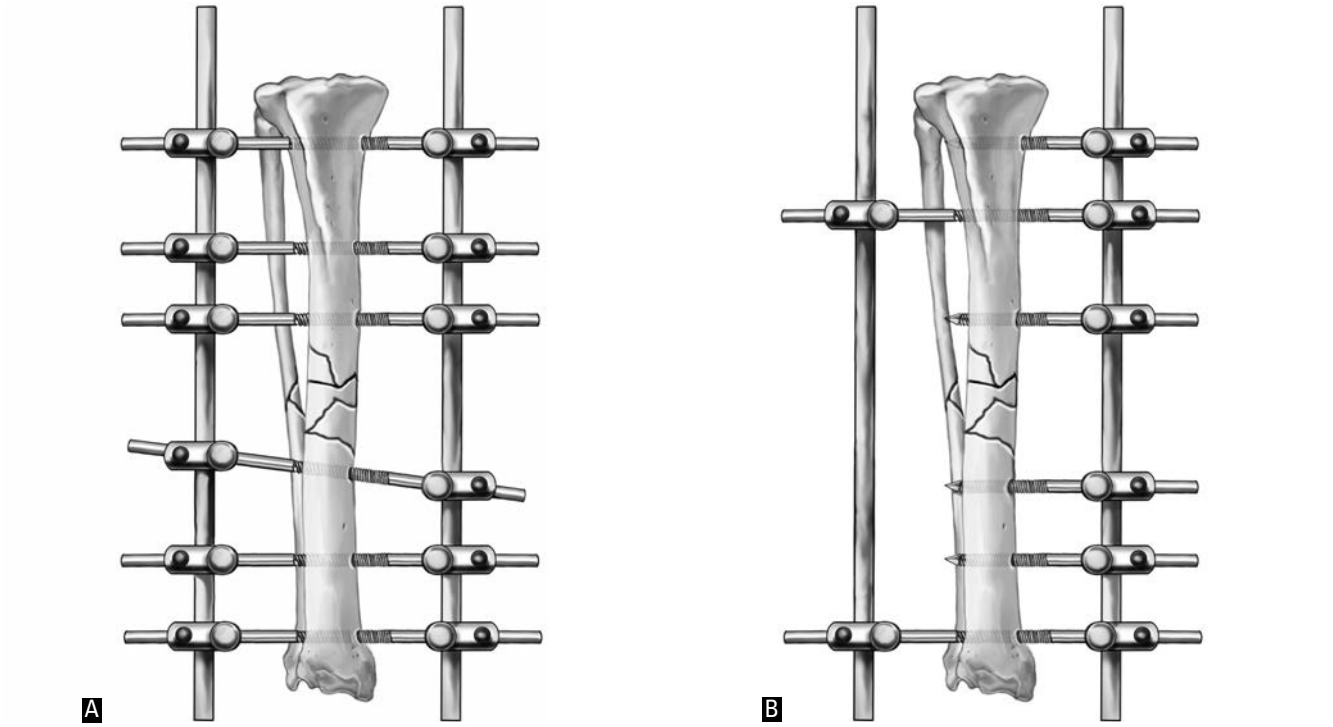


Figure 62-8. A type II external fixator may be applied to the tibia with minimal morbidity. The frame may be filled out with bilaterally secured fixation pins (maximal type II frame) **A.** or unilaterally secured fixation pins (minimal type II frame) **B.**

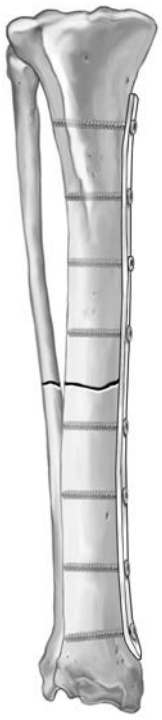


Figure 62-9. Single transverse or short oblique fractures may be anatomically reduced and stabilized using the bone plate as a compression plate.

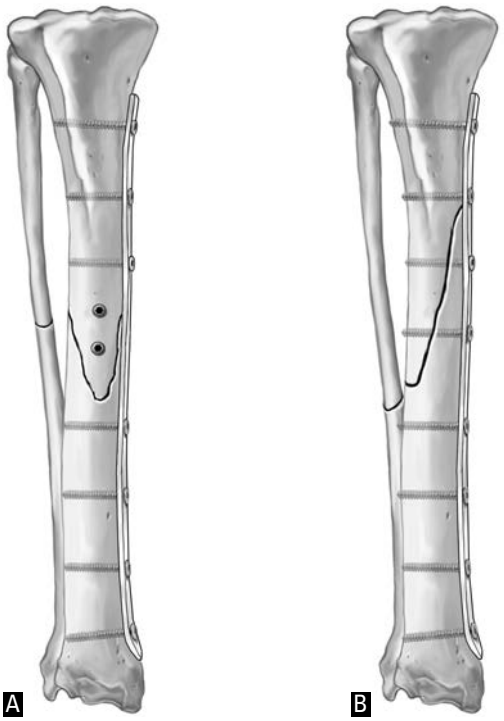


Figure 62-10. Long oblique fractures should be anatomically reduced and compressed with lag screws. Depending on the orientation of the fracture, the lag screws may be inserted outside of the plate **A.** or through the neutralization plate **B.**

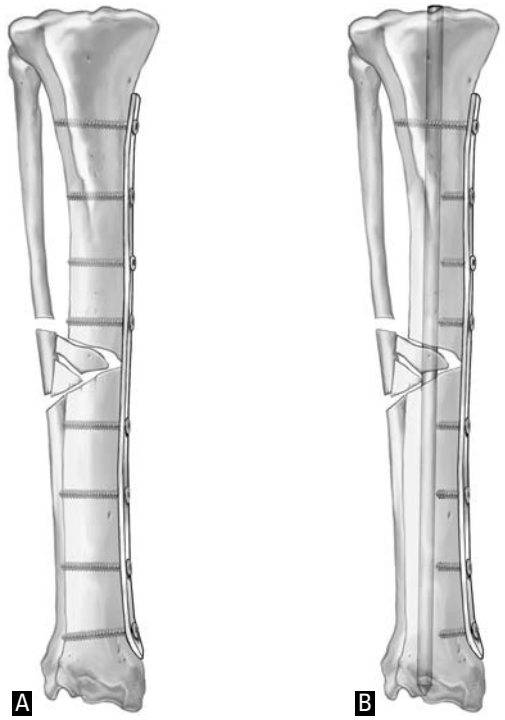


Figure 62-11. Comminuted nonreducible fracture may be realigned and bridged with a bone plate functioning as a bridging plate. **A.** Alternatively, the plate may be combined with an IM pin **B.**

General postoperative management instructions given to clients consist of recommending close confinement of the patient with activity limited to leash walking until there is radiographic evidence of bone bridging the fracture. Radiographic re-evaluations should be made at 6 week intervals.

Animals treated with internal fixation do not require special management of the limb. Animals treated with external fixators require extensive aftercare. Postoperatively, gauze sponges should be packed around the fixation pins and secured with a bandage, which also incorporates the paw, to limit postoperative swelling. External fixator management includes daily pin care and pin packing as needed. Additionally, the external fixator can be destabilized as dictated by the radiographic evidence of bone healing by removing one unilateral frame from a type Ib fixator: removing selected fixation pins from a type Ia or type II fixator; removing the lateral connecting rod of the type II fixator, or downsizing the connecting rods in a frame.

In immature animals, fracture bridging is generally observed by 6 weeks, with additional remodeling occurring in 12 weeks. Mature animals generally are healed in 12 to 18 weeks (depending on fracture configuration and signalment of the animal).

External fixators are removed when there is evidence of bone bridging the fracture site on both radiographic views. Intramedullary pins are generally removed after bone healing because of the morbidity associated with the pin end irritating the insertion site. Interlocking nails, orthopedic wire and lag screws are left in situ unless they are associated with a clinical problem. Plate removal may be necessary after the fracture heals if soft tissues irritation or cold sensitivity occurs.

Distal Physeal Fractures

The most common physeal fractures of the distal tibia are Salter Harris type I and II fractures. If the fracture is nondisplaced, treatment with cast application is generally sufficient. If the fracture is displaced, then a cranial approach to the distal tibia is made to allow anatomic reduction of the fracture.[17] Crossed Kirschner wires or small intramedullary pins are driven from the medial malleolus across the physis, into the tibial metaphyses, seating in the lateral cortex; and from the medial aspect of the distal tibial metaphysis, across the fracture into the epiphysis avoiding the articular surface. Alternatively, the second wire may be driven from the fibular malleolus into the tibia (Figure 62-12).[17]

Postoperative radiographs must be evaluated for accuracy of reduction and implant placement. Generally, a lateral splint is applied for 2 to 3 weeks to support internal fixation. Postoperatively, the patient should be confined to a small area with activity limited to leash walking. Follow up radiographs may be made at 3 and 6 weeks after treatment. Physeal fractures generally heal rapidly, within 3 to 4 weeks. If a cast is used, it should be removed as early as possible. Physical therapy may be necessary to restore range of motion to the hock. Premature closure of the physis usually occurs because of the trauma inflicted on the growing cells during the initial injury. Owners of very immature animals should be warned of the potential for growth deformities. Implant removal may be required if soft tissue irritation occurs.



Figure 62-12. Fractures of the distal tibial physis may be stabilized with crossed Kirschner wires or small intramedullary pins.

References

1. Johnson JA, Austin C, Breur GJ: Incidence of canine appendicular musculoskeletal disorders in 16 veterinary teaching hospitals from 1980 through 1989. *Vet Comp Orthop Traumatol* 7:56, 1994.

2. Johnson AL: Fundamentals of orthopedic surgery and fracture management, decision making in fracture management, in Fossum TW (ed) *Small Animal Surgery,* 4th edition St. Louis, Mosby 2013, p 1055.

3. Johnson AL: Fundamentals of orthopedic surgery and fracture management, perioperative patient management in Fossum TW (ed) *Small Animal Surgery,* 4th edition St. Louis, Mosby 2013, p 1044.

4. Johnson KA and Piermattei DL: *Surgical Approaches to the Bones and Joints of the Dog and Cat,* 4th edition, Philadelphia, WB Saunders Co, 2004, p 366.

5. Johnson AL, Dunning D. *Atlas of Orthopedic Surgical Procedures in the Dog and Cat.* St. Louis, Elsevier Saunders, 2005, p 196.

6. Johnson AL. Current concepts in fracture reduction. *Vet Comp Orthop Traumato*l 16:59, 2003.

7. Aron DN, Palmer RH, Johnson AL: Biologic strategies and a balanced concept for repair of highly comminuted long bone fractures, *Compend Cont Educ Pract Vet* 17:35, 1995.

8. Johnson AL, Johnson K, Houlton J, et al: *AO-ASIF Small Animal Preoperative Planning Guide:* Synthes (USA); 1999.

9. Johnson AL, Fracture planning website, University of Illinois http://vetmed.illinois.edu/fractureplanning/ January 2014

10. Johnson AL: Fundamentals of orthopedic surgery and fracture management, perioperative patient management in Fossum TW (ed) *Small Animal Surgery,* 4th edition St. Louis, Mosby 2013, p 1201.

11. Johnson AL, Dunning D. Atlas of Orthopedic Surgical Procedures in the Dog and Cat. St. Louis, Elsevier Saunders, 2005, p 202.

12. Dueland RT, Johnson KA, Roe SC, et al: Interlocking nail treatment of diaphyseal long bone fractures in dogs, J Am Vet Med Assoc 214:59, 1999.

13. Johnson AL, Dunning D. Atlas of Orthopedic Surgical Procedures in the Dog and Cat. St. Louis, Elsevier Saunders, 2005, p 206.

14. Johnson AL, Dunning D. Atlas of Orthopedic Surgical Procedures in the Dog and Cat. St. Louis, Elsevier Saunders, 2005, p 204.

15. Schwarz G: Fractures of the tibia. *In* Johnson AL, Houlton JEF, Vaninni R.(editors) AO principles of fracture management in the dog and cat, New York, Thieme for AO Publishing, 2005, p 310 .

16. Johnson KA and Piermattei DL: Surgical Approaches to the Bones and Joints of the Dog and Cat, 4th edition, Philadelphia, WB Saunders Co, 2004, p 370.

17. Johnson AL, Dunning D. Atlas of Orthopedic Surgical Procedures in the Dog and Cat. St. Louis, Elsevier Saunders, 2005, p 198.

Surgical Treatment of Malleolar Fractures

Brian Beale

Fractures of the medial or lateral malleolus of the tibia result in instability of the tarsus because of disruption of the origin of the collateral ligament complex. Subluxation or dislocation may occur if instability is severe. Occasionally, both the medial and lateral malleoli are fractured concurrently. The fractures may be simple and closed, or they may involve loss of bone and soft tissue in cases of shear wounds. External coaptation is usually inadequate because accurate anatomic reduction and rigid stabilization are necessary to decrease the chance of developing degenerative joint disease. Most fractures are best repaired using open reduction and internal fixation. Bone screws and pins and tension bands are the most common implants used to stabilize these fractures (Figure 62-13).

Pin and tension band fixation provides good stability and anatomic reduction in most cases. An approach to the fractured malleolus is performed by incising skin and subcutaneous tissues directly over the fragment. A periosteal elevator is used to expose the distal aspect of the tibia or fibula and the fracture site. The fracture site is cleaned of hematoma and fibrinous debris, to allow better visualization of the articular surface and the edges of the fracture fragments. The fracture is reduced anatomically; this is extremely important because of the intra-articular nature of the fracture. Bone-reduction forceps can be used to provide temporary stability. Two pins are driven in normograde fashion sequentially through the fractured malleolar fragment perpendicularly across the fracture site into the main fragment, with care taken to avoid the articular surface of the tibiotarsal joint. In small fragments, a single pin may be used. The pin size varies, depending on the size of patient and the size of malleolar fragment. Most cats and small dogs can accommodate 0.035- or 0.045-inch Kirschner wires, whereas medium-size and large dogs may accommodate 0.062-inch Kirschner wires or 5/64-inch pins. The tension band wire used is 20 or 22 gauge in cats and small dogs and 16 or 18 gauge in medium and large breed dogs. A hole, large enough to pass the selected wire, is drilled from cranial to caudal in the main fragment approximately 1 cm proximal to the fracture line. A small loop is created in the wire to permit tightening of the wire on the opposite side of the knot formed by twisting the ends of the wire. The wire is passed through the hole and around the Kirschner wires in figure-of-eight fashion.

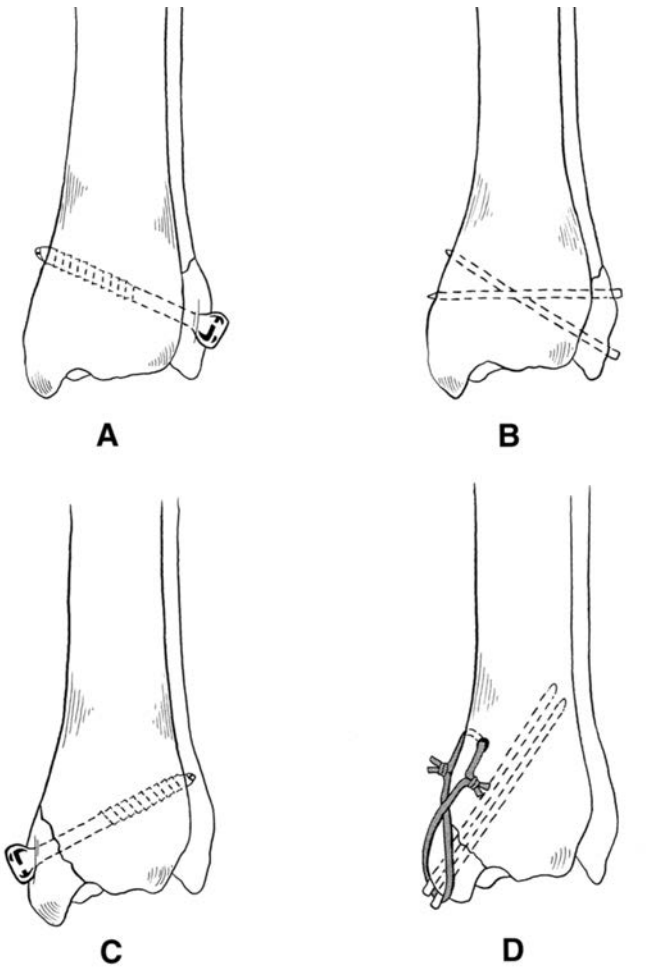


Figure 62-13. Repair of malleolar fractures. **A.** Lateral malleolar fracture stabilized with a partially threaded cancellous screw. **B.** Lateral malleolar fracture stabilized with two divergent Kirschner wires. **C.** Medial malleolar fracture stabilized with a partially threaded cancellous screw. **D.** Medial malleolar fracture stabilized with pins and tension band.

The wire is tightened by simultaneously twisting the loop and ends of the wire while applying moderate traction. This forms a knot on each side of the loop that allows greater and more even wire tension after tightening. The knots should be centered if possible. The wires are tightened onto the surface of the bone, they are cut leaving a minimum of three twists, and they are bent over if irritation of the soft tissues is likely.

Lag screw fixation of the medial malleolus provides excellent stability if the distal fragment is large enough to accommodate a screw. Lag screw fixation of the medial malleolus may be preferred to pin and tension band fixation, especially if the fracture involves a large articular segment. Lag screw fixation of the lateral malleolus usually requires its attachment to the tibia, rather than to the fibula, because of the thin distal fibial diaphysis. The screws should be placed in lag fashion, by either using partially threaded cancellous screws or overdrilling the near cortex when using cortical screws. The size of screw (1.5 to 4.5 mm) selected depends on the size of the fragment size and the patient. One or two screws can be placed; placement of two screws may help to prevent rotation of the fragment. The fracture can be reduced and temporarily stabilized with bone-reduction forceps. The appropriate thread hole and gliding hole (if using a cortical screw) are drilled perpendicularly across the fracture line, with care taken to avoid the articular surface of the tibiotarsal joint. Alternatively, a hole can be pre-drilled in the small fragment to allow more precise centering. The fragment is reduced and temporarily stabilized. The far hole is drilled. After drilling, the hole is measured and tapped, and the screw is inserted and tightened.

External coaptation is recommended for 4 weeks after internal stabilization. A lateral fiberglass splint is inexpensive and easily applied. The splint is applied while placing the tarsus at a functional angle. The bandage is changed if it becomes soiled or wet. After 4 weeks, the splint is removed, and physical therapy is performed several times daily until range of motion is improved. Exercise should be limited to leash walks only for 2 months postoperatively or until radiographic healing is evident. Running and jumping should be prevented. Implant removal is not necessary unless the implant migrates or loosens.

Prosthetic Ligament Repair for Severe Tarsocrural Joint Instability

Dennis N. Aron

Functional Anatomy[1]

Many luxations, subluxations, and shear injuries directly involve the tarsocrural joint. The major ligaments providing stability on the medial side of the joint are the long medial ligaments and tibiotalar short component ligament (Figure 62-14A). The major ligaments providing stability on the lateral side of the joint are the long lateral ligament and the calcaneofibular short component ligament (Figure 62-14B). The components of the medial and lateral ligaments complement each other in maintaining the talus in the mortise provided by the tibia and fibula. Certain parts of the ligament complexes are tighter in extension (long lateral and long medial ligaments) or flexion (calcaneofibular and tibiotalar short component ligaments).

The tibiotalar and calcaneofibular short component ligaments of the medial and lateral sides, respectively, are especially important for maintaining stability when the hock is flexed and should be accorded primary attention with any reconstruction procedure. It is possible that these short ligaments are stressed when the hock is flexed and subjected to concussive forces encountered in jumping or running, thus, needing to be particularly strong to prevent excessive ligament deformation or failure. The joint capsule and malleoli also contribute to joint stability.

The gross anatomy of the medial and lateral collateral ligament complexes is similar (See Figure 62-14). The components cross at the tarsocrural joint space, providing the greatest amount of ligament and an advantageous spatial arrangement directly over the joint.

Mechanism and Diagnosis of Injury

Based on personal experience and published reports protective stenting (augmentation) or prosthetic replacement for severe ligamentous disruption of the tarsocrural joint is indicated.[2] The shear injury produces especially severe disruption and instability of the joint. With this injury, not only are the supporting ligaments lacking, but the support to the respective side of the joint mortise provided by the malleolus and joint capsule are missing. The closed dislocation of the tarsocrural joint also can result in severe ligamentous disruption and joint instability. Most closed injuries cannot be adequately repaired by primary suturing of the joint capsule and collateral ligaments owing to the severity of the tissue damage.

Tarsocrural luxation results from different combinations of injuries including fractures of both malleoli, fracture of one malleolus and damage to the contralateral ligament complex, fracture of the fibula and damage to the medial ligament complex. Uncommonly, damage to both the lateral and medial collateral ligament complexes can occur with no fractures. Tarsocrural subluxation usually results from complete rupture or avulsion of either the lateral or medial collateral ligament complex. In medial ruptures, the paw tilts abnormally toward the lateral direction with a lateral (valgus) applied force. In lateral ruptures, the tilt is in a medial direction with a medial (varus) applied force. Occasionally, there is primary damage to only the long or short components of the medial or lateral ligament complexes. Less joint laxity makes these subluxation injuries more difficult to diagnose. In these situations determine joint laxity by placing lateral and medial tilt forces on the hock at different joint angles. Laxity in extension but not flexion suggests major damage to the long medial ligament, or long lateral ligament; laxity in only flexion suggests that most damage is isolated to the tibiotalar or calcaneofibular short components. Make a dorsoplantar (stress) radiograph while applying lateral and medial tilt forces on the hock. Take the stress radiograph at the tarsocrural joint angle that produces the subluxation. For subtle subluxations, compare

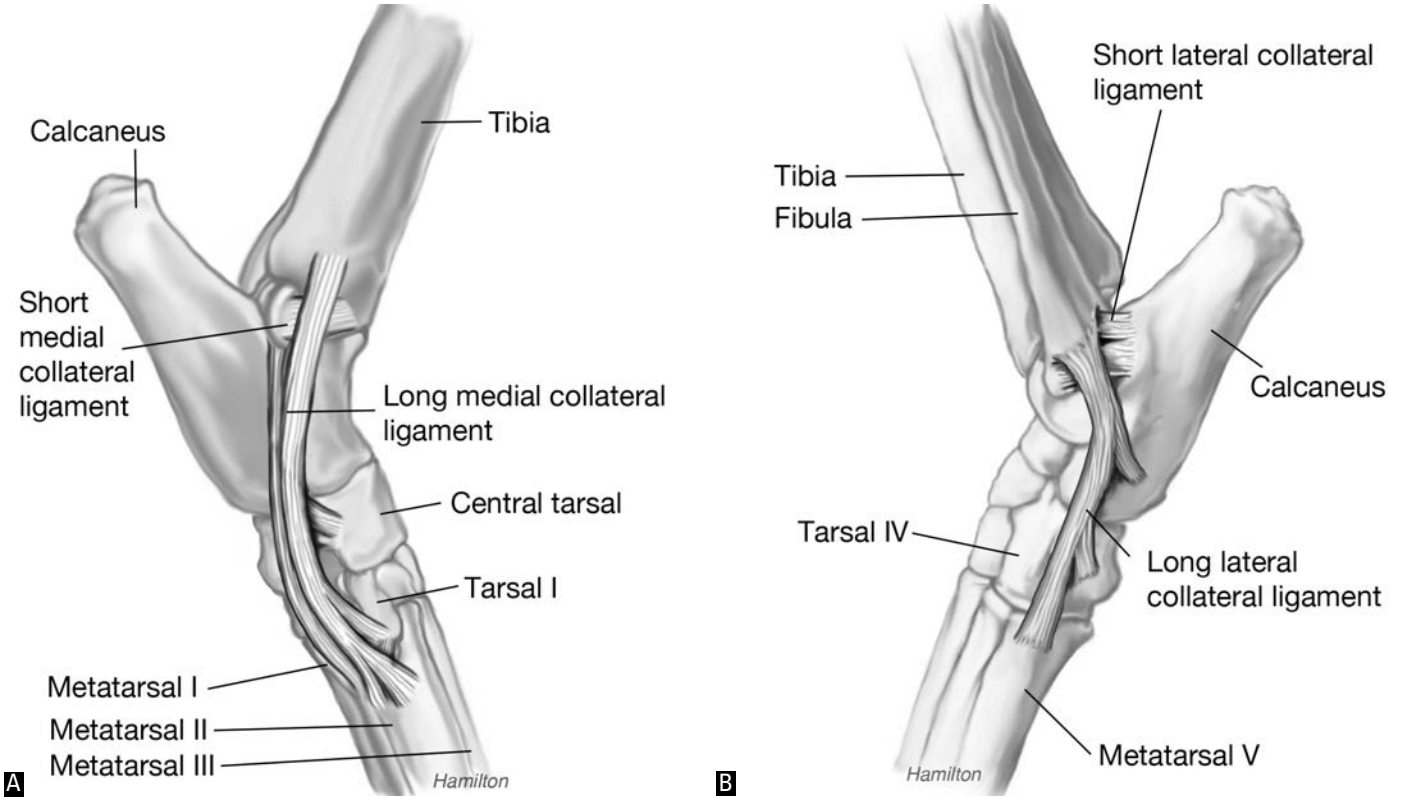


Figure 62-14. A. Medial tarsocrural ligamentous anatomy. **B.** Lateral tarsocrural ligamentous anatomy.

this radiograph with a similar radiograph of the contralateral (normal) hock. Routine dorsoplantar and lateral radiographic views are always needed to check for concomitant tarsal injuries. Stress radiographs are useful to confirm the diagnosis in less straightforward situations but are not always necessary.

Surgical Technique

The double-ligament method closely reproduces the components of the intact medial and lateral collateral ligament complexes, thus, allowing nearly normal joint stability to be maintained throughout a functional range of motion. The double-ligament method provides the surgeon consistent locations for application of the stenting or prosthetic sutures. Further, these locations closely mimic the origins and insertions for the medial and lateral tarsocrural collateral ligament complexes. It has been shown that the stability of both the medial and lateral tarsocrural joint is dependent upon the interaction of the components of the respective collateral ligament complexes. The double-ligament method closely reproduces components of the medial and lateral collateral ligament complexes. This similarity to normal ligament components allows nearly normal joint stability to be maintained throughout a functional range of motion when using the double-ligament method.[1] Similar to the components of the normal collateral ligaments, the stenting or prosthetic sutures becomes taut and lax upon flexion and extension Because of this, wire is not advocated as a useful material with the double-ligament method. Monofilament polybutester[i] (preferred) or braided polyester[ii] sutures are successful with the double-ligament method, seemingly due to the retention of elasticity upon cyclic loading.

Clinically, the double-ligament method gives results superior to conservative management with splints or nonanatomic single-ligament replacement methods. The prognosis is good for long-term function with most closed luxation and subluxation injuries, depending on timely repair (within five to seven days of injury) and absence of articular damage.

Surgical Technique - Closed Injury

Clip the injured limb from the level of the proximal femur, extending distally to include the paw. Include the paw in the sterile field to allow direct manipulation. Place the patient in lateral recumbency, with the injured limb up for lateral replacement or down for medial replacement, and prepare the limb for aseptic surgery. Expose the injury through a curved skin incision centered over the medial or lateral malleolus. Begin from the distal one-fourth of the tibia and continue to the proximal metatarsal bones. Locate the medial or lateral collateral ligament complex along the same line by incising the subcutaneous tissue and deep fascia. Inspect the components of the ligament complexes for damage. To help assess the damage, stress the ligament components with a varus or valgus tilt in both flexion and extension. It is unlikely that there will be a totally isolated injury to only one component of the ligament complex. The ligaments can appear intact but may have lost considerable function owing to internal derangement of the collagen fibers. Usually, the ligament components are too badly damaged to allow primary suturing of the torn ends or reattachment to bone. Replace irreparable ligaments with prosthetic sutures and protect repaired ligaments with stenting sutures. Replace or protect the medial or lateral ligament complexes with figure-eight heavy sutures fastened to the bone directly, with bone anchors,[iii-vi] or with bone

[i]Novafil*, Syneture™, Norwalk, CT 06856
[ii]Tevdek®, Polydek®, Deknatel™, Fall River, MA 02720

[iii]BoneBiter™ Suture Anchor System, Innovative Animal Products, Rochester, MN 55901
[iv]FlexiTwist Suture Anchor, Innovative Animal Products, Rochester, MN 55901

screws. (It is preferred to secure the sutures to the bone directly or with bone anchors as bone screws are too bulky, which can irritate overlying tissue.) Drill bone tunnels in the malleolus in locations similar to the origins of the components of the ligament complex (Figure 62-15). Bone tunnels serve as anchors for the suture prostheses. Secure the suture prosthesis that mimics the lateral or medial short components to tags of the torn ligament at the insertion site. Use a locking loop suture pattern to grip the torn ligament. A bone anchor may be needed to fix the prosthesis to the insertion site (Figure 62-15). Secure the suture prosthesis that mimics the lateral or medial long components to a drill hole in the tubercle of the distal talus or distal calcaneus (Figure 62-15). A bone anchor may be used to fix the prosthesis (Figure 62-15). For each ligament stenting or replacement use one or two (for large patients) strands of #0-2 braided polyester or monofilament polybutester (preferred) sutures for prosthetic replacement or protection. Set the sutures in a figure-eight pattern. Do not use wire, absorbable sutures, or sutures with a high degree of plasticity. Do not use monofilament polypropylene for sutures as it tends to stretch permanently (high plasticity) and is better suited for primary repair of torn ligaments. Do not use monofilament nylon (fishing leeder) as it is very stiff and tends to function like wire. Tie the long and short suture prostheses. Tie the short prosthesis with the tarsocrural joint held in approximately 90° flexion for dogs and 70° for cats. Tie the long suture prosthesis with the joint in a functional standing angle of 135° for dogs (varies with breed) and 120° for cats. After the sutures are tied, tighten the bone anchors against the bone.

Expose and provide stenting or ligament replacement to the luxation injury through separate surgical incisions on the medial and lateral sides of the joint. Fix a malleolar fracture with a tension band technique and replace or protect the contralateral ligaments. To manage luxations due to fracture of the fibula and damage to the contralateral ligament complex replace or protect the medial ligaments and stabilize the fibula to the tibia with K-wires or bone screws.

Shear Injury

Shear injuries usually occur when an animal is trapped by a moving vehicle, resulting in shearing by the road surface of supporting ligaments, bone, joint capsule, and malleolus. The medial side of the joint is injured more commonly than the lateral side of the joint. Perform wound management and ligament replacement when the bone and cartilage damage is isolated primarily to the malleolus. Severe soft tissue damage makes stabilization difficult and prolongs healing. Although a successful ligament replacement gives better results than a tarsocrural joint arthrodesis, consider joint arthrodesis if there is extensive bone and cartilage damage.

Technique – Shear Injury

Before debridement and ligament replacement, cover the shear wound with a temporary sterile dressing and apply a temporary splint to prevent further damage to the unstable joint. Exteriorized material will contaminate deeper recesses if replacement into the wound is attempted before formal debridement. Therefore, do

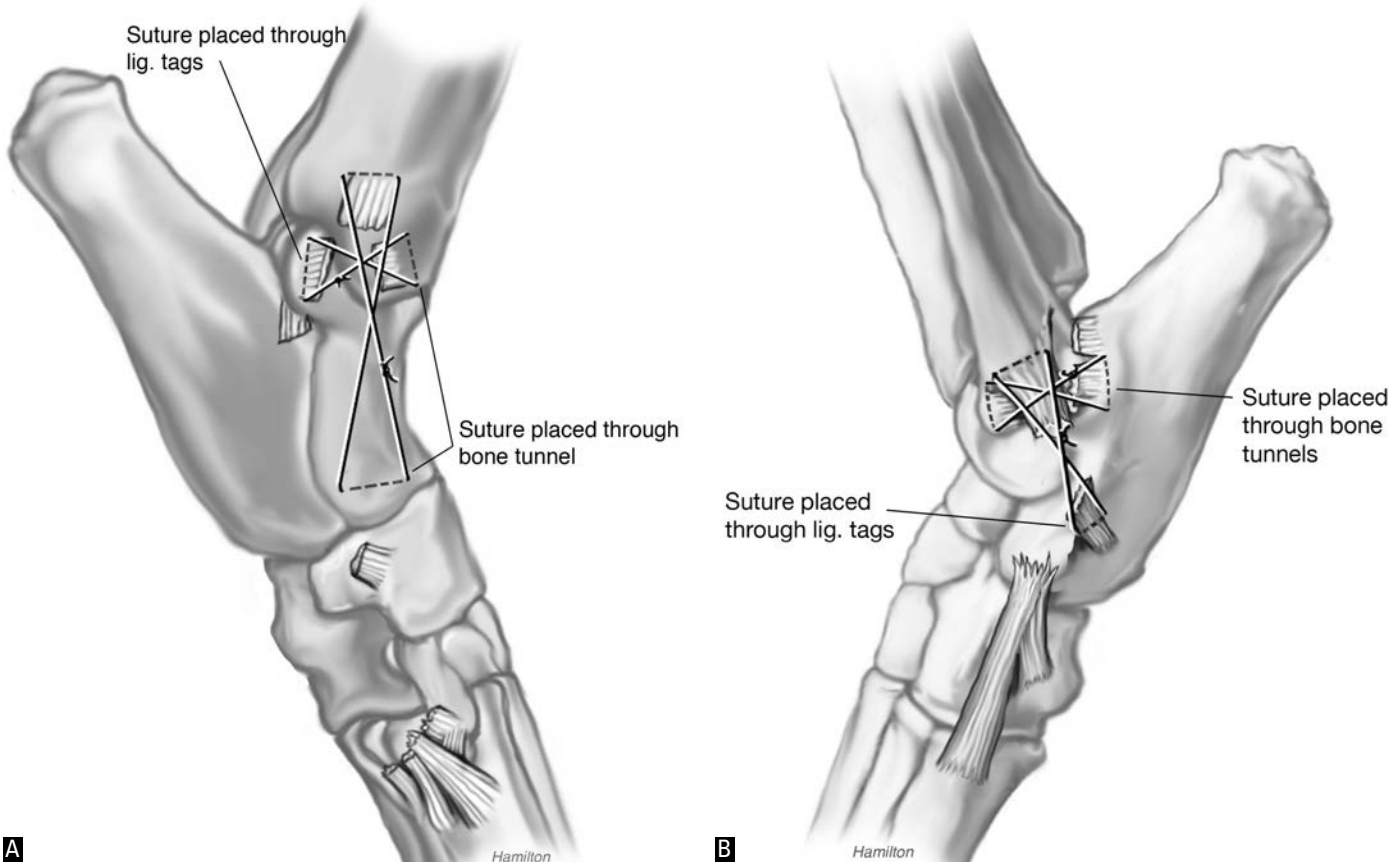


Figure 62-15. A. Stent suture reinforcement of medial ligament injury. **B.** Prosthetic suture replacement of lateral ligament injury. Affix sutures to tags of the ligament. Alternatively, secure the suture to bone tunnels or to bone anchors.

[v]Bone Anchor, SECUROS, Charlton, MA 01507
[vi]Suture Anchor, IMEX™ Veterinary Inc., Longview, TX 75604

not push or "stuff" extruded soft tissue, bone, or cartilage back into the wound. Do not soak the wound. Perform debridement as soon as the animal is a stable candidate for surgery, ideally within 6 hours from the time of injury for moderate wounds, and within or less than 1 to 2 hours for severe wounds. Ligament replacement and wound closure can be delayed but do not delay wound debridement.

Anesthetize the animal and remove the temporary splint. Keeping the wound covered, clip the limb, and cleanse with an appropriate antiseptic. Remove the dressing and thoroughly irrigate the wound with copious amounts of a pre-warmed balanced electrolyte solution. After moving the animal to the operating area, perform a final surgical scrub and drape the limb. Debride the wound of all visible necrotic tissue and debris. Be careful to avoid damage to articular surfaces. During the debridement process, lavage continuously with copious amounts (1 L or more) of a balanced electrolyte solution such as lactated Ringer's, using a moderate amount of pressure, through a 30 to 60 ml syringe and 18 or 19 gauge needle or catheter. Fluid pressure on the tissues should approximate 7 psi. Perform ligament replacement at this time or delay for repeat wound debridement or orthopedic referral. If delaying replacement cover the wound with an absorbent dressing to keep the wound moist and stabilize the joint with a rigid coaptation splint such as a fiberglass slab incorporated into a padded wrap. Change the dressing once a day or more frequently if there is fluid striking through the bandage. Repeat wound debridement if necrotic tissue is left in the wound after the first procedure. Continue this process of serial debridement until only viable tissue is present in the wound.

The prosthetic ligament replacement technique for the shear injury usually requires three bone anchors (preferred) or three bone screws and figure-eight heavy sutures. Bone anchors are required for the shear injury because some bone is usually sheared off, thus, making it difficult to create bone tunnels as with the closed injury. Place the anchors as close as possible to the origin and insertion of the components of the ligament complex (Figure 62-16). Position the origin anchor in the distal tibia for the medial ligament or the distal fibula and tibia for the lateral ligament. Direct this anchor slightly proximal to avoid penetrating joint cartilage and to obtain maximum bony purchase. Position the insertion anchor for the medial tibiotalar short ligament in the proximoplantar quadrant of the medial trochlear facies of the talus. Direct this anchor slightly distal to avoid the trochlear sulcus of the talus. Position the anchor corresponding to the insertion of the medial long ligament through the tubercle at the plantar base of the talus. Direct this anchor slightly proximodorsally. Position the anchor corresponding to the insertion of the calcaneofibular short ligament proximoplantar to the base of the lateral articular facies of the tuber calcis. Position the insertion anchor for the long ligament through the tubercle at the dorsal extent of the base of the calcaneus. Direct this anchor slightly proximoplantar. Using one or two (for large patients) strands of #0-5 polyester sutures or monofilament polybutester sutures as prosthetic replacements, place suture(s) from the origin anchor and the short insertion anchor, and separate suture(s) from the origin anchor to long insertion anchor. Set the sutures in a figure-eight pattern (See Figure 62-16). Tie taut the tibiotalar or calcaneofibular short suture prosthesis with the tarsocrural joint held in approximately 90° flexion for dogs and 70° for cats. Tie

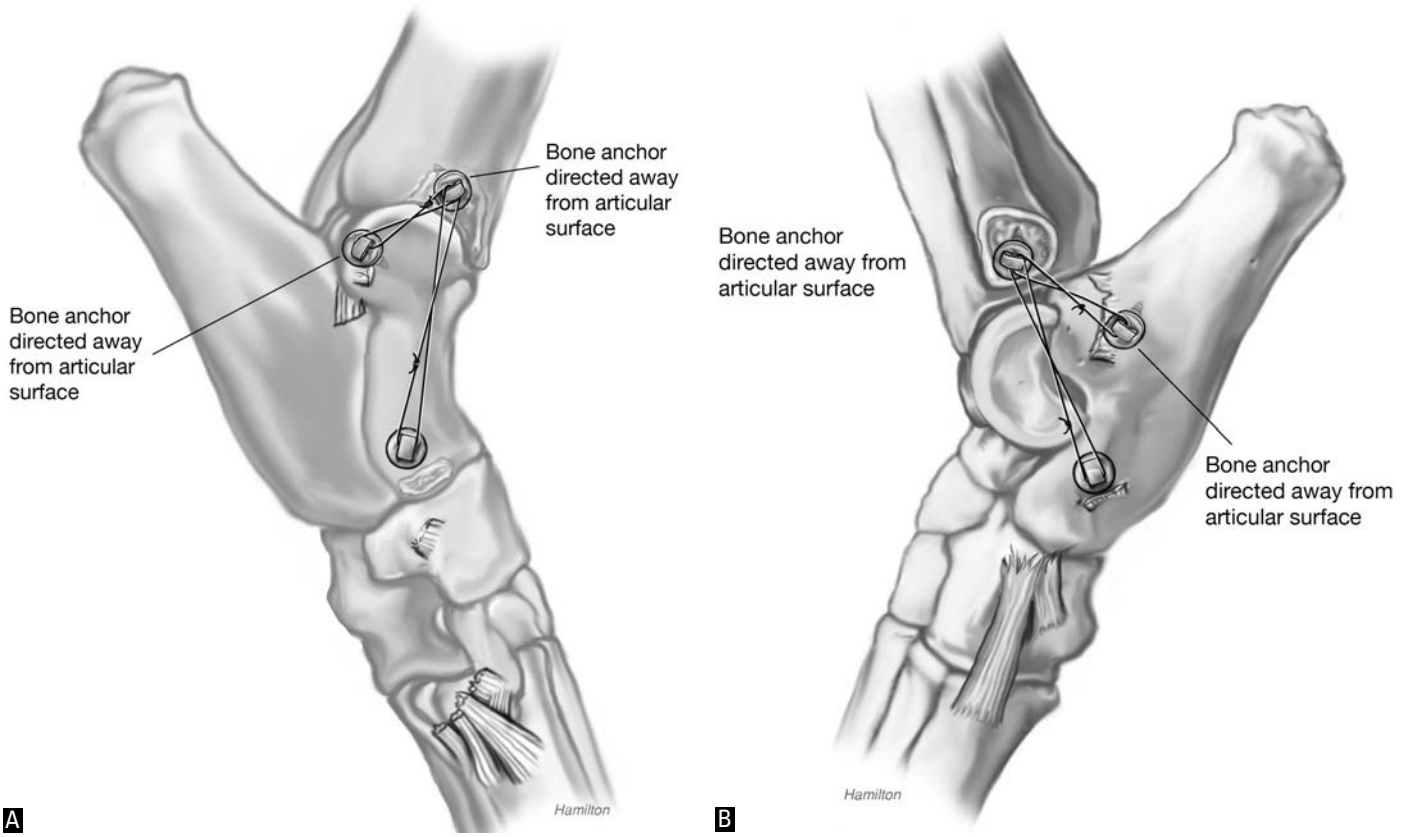


Figure 62-16. A. Prosthetic suture replacement of medial ligament shear injury. **B.** Prosthetic suture replacement of lateral ligament shear injury.

taut the medial long or lateral long suture prosthesis with the tarsocrural joint in a functional standing angle of 135° for dogs (varies for some breeds) and 120° for cats. Tighten the anchors against the bone. Never perform primary soft tissue closure over a shear injury. If possible, allow second intention healing; alternatively, perform delayed closure or apply a skin graft after all surfaces of the wound and prosthetic sutures are covered with healthy granulation tissue.

Postoperative Care

The postoperative rehabilitation is crucial to achieving a consistently high long-term result with these tarsocrural injuries. For both the closed and shear injuries the rehab is similar in that there are three phases: progressive decrease of inflammation and increase of tissue proliferation, gain of muscle strength, and reintroduction of normal activity. A vital point is that all during rehab and beyond, inflammation must not be exacerbated. Whenever activity exacerbates inflammation the rehab activity must be reduced until the inflammation is once again diminished and more healing and strength is attained.

To facilitate clearing the inflammation and promote rapid healing, the first phase of rehab depends on early and strong controlled weight-bearing to stimulate positive physiology of the limb. However, allowing too much tissue strain to occur will be detrimental by adding to the inflammation and risking implant breakdown and tissue damage. During this phase, strain is controlled through coaptation splints (mobilization aids). Immediately after surgery apply a below the knee firm coaptation splint that allows slight strain. This can be done several ways such as with a fiberglass slab or aluminum rod incorporated into a padded wrap. This type of splint will allow periodic bandage changes for the shear wound. Concurrently, perform progressive controlled walking and encourage the animal to bear strong weight. The weight-bearing is as strong as possible but controlled to limit the exacerbation of inflammation as indicated by subtle to gross worsening of weight-bearing. Avoid using a transarticular external skeletal fixator (ESF) during this phase of rehab as this rigid form of immobilization does not allow positive physiology to the limb and is very detrimental to the joint. However, if an ESF must be used it should only be maintained for two weeks or less. Remove the firm coaptation after two to six weeks (shorter time period for closed injury and rapid healing situations and longer for shear injury). Next, place the limb in a mobilization aid that allows progressive strain for three to eight weeks. This is accomplished by using a below the knee four to ten layer soft cast.[vii] The amount of tissue strain produced (moderate to high) can be greatly altered by the number of layers in the soft cast.[3] If the shear wound has not completely been covered by healthy epithelial tissue a "window" can be easily cut into the soft cast. During use of the supple soft cast mobilization aid, perform controlled low impact mobilization by allowing increasingly longer walks and by progressively unwrapping layers from the splint to increase tissue strain as healing advances and muscles gain strength. Once the soft cast is completely removed, initially back down the walking time but continue progressive controlled mobilization by, once again, slowly increasing the animal's walking activity over a four to eight week period. Controlled muscle building techniques (underwater treadmill, exercise ball, etc) are valuable during this stage of rehabilitation. When a high level of muscle strength has been regained, slowly and progressively bring the animal back to normal activity. As all during rehab, if the animal shows signs of increased lameness or pain, progress more slowly with controlled mobilization in a manner that does not create lameness or discomfort.

Prognosis

The prognosis is good for long-term pain-free function if there is no damage to the articular surfaces other than the malleolus and if surgery is timely. Careful rehabilitation through progressive controlled mobilization is critical to success.

Suggested Readings

Aron DN: Luxation, subluxation, and shearing injuries of the tarsal joint. In Birchard SJ, Sherding RG, eds.: Saunders Manual of Small Animal Practice. 2nd ed. Philadelphia: W. B. Saunders, 2000, p 1168.

Piermattei DL, Flo GL: Brinker, Piermattei, and Flo's Handbook of Small Animal Orthopedics and Fracture Repair. 3rd ed. Philadelphia: W.B. Saunders, 1997, p 610.

References

1. Aron DN, Purinton PT: Collateral ligaments of the tarsocrural joint. An anatomic and functional study. Vet Surg 14:173, 1985.

2. Aron DN: Prosthetic ligament replacement for severe tarsocrural joint instability. Am Anim Hosp Assoc 23:41, 1987.

3. Rytz U, Aron DN, Foutz L, Thompson SA: Mechanical evaluation of soft cast (scotchcast, 3m) and conventional rigid and semirigid coaptation methods. Vet Comp Orthop Traumatol 9:14, 1996.

Repair of Fractures of the Tarsus

William G. Marshall and Jon F. Dee

Introduction

Fractures of the tarsus, in the authors' experience, occur with greatest incidence in the racing greyhound population, but are also encountered in other working breeds, in pet dogs, and in the cat. Clinical presentation varies depending upon the particular bone or bones involved. Diagnosis and accurate characterization of tarsal fractures can be challenging because the radiographic appearance of the region is complex, with superimposition of the bones. Standard orthogonal studies often must be supplemented by oblique and stressed views. Computed tomography could be considered the modality of choice for detailed imaging of the tarsus[1] (Figure 62-17), though financial considerations often preclude its' use. Successful surgical repair of tarsal fractures demands a comprehensive knowledge and understanding of the normal regional anatomy (Figure 62-18).

Repair of the Talus

Fractures of the medial or lateral trochlear ridge are intra-articular and therefore anatomical reduction and rigid stabilization are imperative. A dorsomedial or dorsolateral approach may be

[vii]Scotchcast™ Soft Cast Casting Tape, 3M™, St. Paul, MN 55144

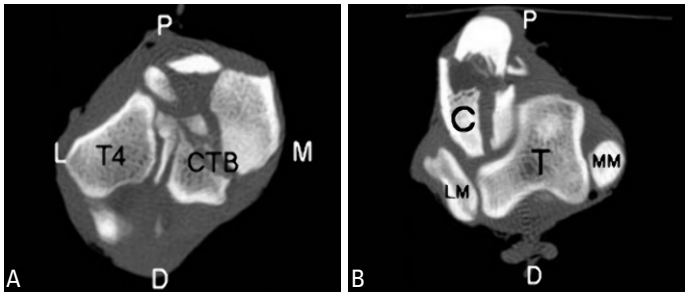


Figure 62-17. Computed tomographic images of comminuted central tarsal bone **A.** and calcaneal **B.** fractures in a racing greyhound. *D* = dorsal, *P* = plantar, *CTB* = central tarsal bone, *T4* = fourth tarsal bone, *C* = calcaneus, *T* = talus, *MM* = medial malleolus, *LM* = lateral malleolus.



Figure 62-18. Dorsoplantar **A.** and mediolateral **B.** radiographs of a normal canine tarsus. *C* = calcaneus, *T* = talus, *CTB* = central tarsal bone, *T4* = fourth tarsal bone, *T3* = third tarsal bone, *T2* = second tarsal bone, *T1* = first tarsal bone.

used if the fracture is restricted to the dorsal part of the trochlea. More proximal fractures can be approached by osteotomy of the relevant malleolus. Accessing the talus by osteotomy of the medial malleolus should be avoided wherever possible however, as significant morbidity in the form of degenerative joint disease is associated with this approach. When a lateral malleolar osteotomy is performed, it is wise to pre-drill the screw holes that will be required for reconstruction of this articular surface. The fracture is reduced with small bone forceps or digital pressure, and fixation achieved through the use of Kirschner wires. Multiple 0.035 or 0.045-inch Kirschner wires driven perpendicular to the fracture line are the fixation method of choice. Alternatively, small (2.0 or 1.5 mm) lag screws can be used. All implants must be countersunk below the articular surface. A lateral malleolar osteotomy is repaired with positional screws as previously alluded to (Figure 62-19), or with a pin and tension band wire. Where osteotomy of the medial malleolus must be performed it is repaired using pin and tension band fixation. In one case where the condylar fragment was too large to simply remove, and too small for internal fixation, a transarticular external fixator was applied which achieved indirect repair and a good functional result (Figure 62-20).

Fractures of the neck of the talus are approached from the medial aspect. There is often a concurrent luxation of the distal segment

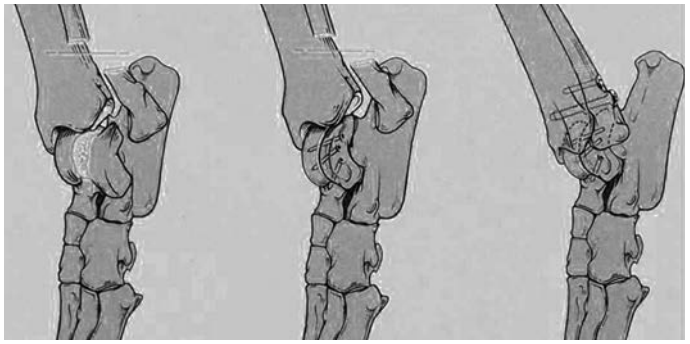


Figure 62-19. Illustration of a fracture of the lateral trochlear ridge of the talus. The fracture has been accessed via a lateral malleolar osteotomy and repaired using countersunk Kirschner wires. The lateral malleolus is reconstructed using positional screws. The screw holes should be drilled before performing the osteotomy. (Reproduced from Dee JF. Fractures of the tarsus. *In:* Johnson AL, Houlton JEF, Vannini R eds. AO Principles of Fracture Management in the Dog and Cat. Switzerland: AO publishing, 2005).

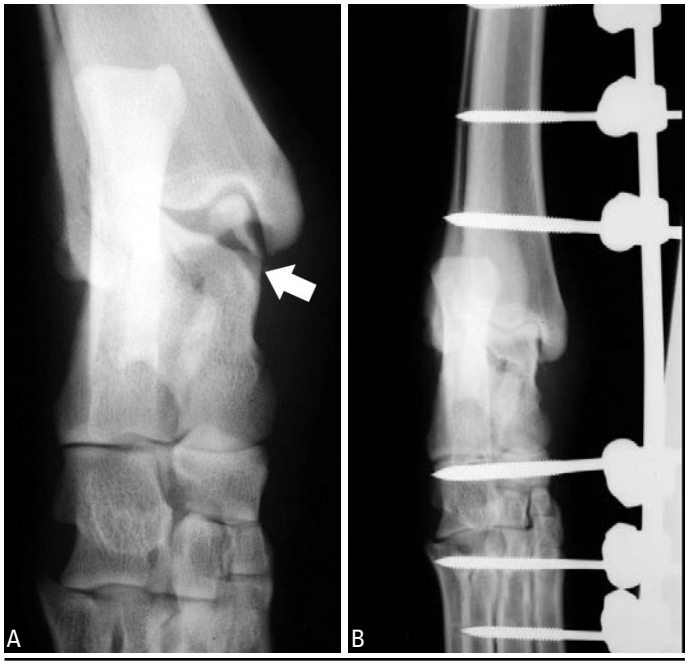


Figure 62-20. Preoperative **A.** and postoperative **B.** dorsoplantar radiographs of a fracture of the medial trochlear ridge of the talus *(arrow)* repaired indirectly by application of a transarticular external fixator.

at the talocentral articulation. Reduction may be facilitated by flexing the tarsus and simultaneously applying pressure to the lateral surface to open the medial aspect of the joint. A Vulsellum forceps can be used to temporarily stabilize the fragments. Talar neck fractures are repaired by Kirschner wire or lag screw fixation. If the fracture has sufficient obliquity, a screw or wire may be directed from the distomedial aspect of the distal fragment into the lateral trochlear ridge. In the case of more transverse fractures, the distal segment is stabilized by directing a lag or positional screw from its dorsomedial aspect in a plantarolateral direction into the body of the calcaneus.

Fractures of the head of the talus are accessed by a medial or dorsomedial approach. They may be extra or intra-articular. An extra-articular, transverse fracture of the head is stabilized

with crossed Kirschner wires or a modified T-plate. Reduction is maintained by the use of forceps or digital pressure – holding the joint in extension may enhance stability. A wire is driven from the plantaromedial aspect of the distal fragment into the dorsolateral aspect of the talar trochlea. The second wire is driven from the plantaromedial aspect of the trochlea into the dorsolateral aspect of the distal fragment. In larger dogs, it is possible to repair this fracture by use of a modified (three hole) T-plate placed on the dorsal aspect of the head and neck. The racing greyhound with a severe (grade IV or V) fracture of the central tarsal bone may, on occasion, suffer a concurrent dorsal or medial slab fracture of the talar head. These are best repaired by the use of a single countersunk lag screw.

Any repair of the talus should be supported by a lateral splint for four to six weeks postoperatively. After removal of the splint, physical therapy should be encouraged to preserve range of motion. Exercise must be restricted to short leash walks for two months postoperatively. Provided there is radiographic evidence of healing, a gradual return to normal activity can then be permitted.

In the case of a severe, comminuted, articular fracture of the talus, a pantarsal arthrodesis should be considered over any attempt to reconstruct the fragments.

The talus is the most frequently fractured tarsal bone in the cat.[2] These fractures can be managed using techniques described for the dog, though internal fixation of the feline talus is a challenging prospect. Small avulsed fragments of the medial or lateral trochlear ridge may be removed to restore joint function, albeit with inevitable progression of degenerative joint disease. Larger fragments are repaired with countersunk Kirschner wires. Fractures of the neck (Figure 62-21) may be repaired with a lag screw or a solitary Kirschner wire (Figure 62-22) but these methods are technically demanding. A more conservative approach is worth considering, because excellent results have followed closed reduction of feline talar neck fractures and application of a transarticular fixator.[3] Transarticular external fixation is a good means of protecting the repair of any feline tarsal injury as this species is often intolerant of bandages and splints. A tarsal injury particular to the cat is luxation of the talus with rupture of the short ligaments of the talocalcaneal and talocalcaneocentral joints (Figure 62-23). The luxation is often accompanied by a distal fibular fracture and avulsion of a fragment from the lateral trochlear ridge. The fibular component is repaired using positional screws (Figure 62-24) or an intramedullary pin and tension band wire. To help prevent reluxation the talus may be fixed by a positional screw to the calcaneus.



Figure 62-21. Dorsoplantar **A.** and mediolateral **B.** radiographs of a talar neck fracture in a cat.



Figure 62-22. Dorsoplantar **A.** and mediolateral **B.** radiographs of the talar neck fracture shown in Figure 62-21, repaired with a single Kirschner wire driven from distomedial to proximolateral.



Figure 62-23. Mediolateral radiograph of a feline tarsus. The talus has luxated cranially *(arrow)* and the distal fibula has fractured *(arrowhead)*. The short ligaments of the talocalcaneal and talocalcaneocentral joints have ruptured.

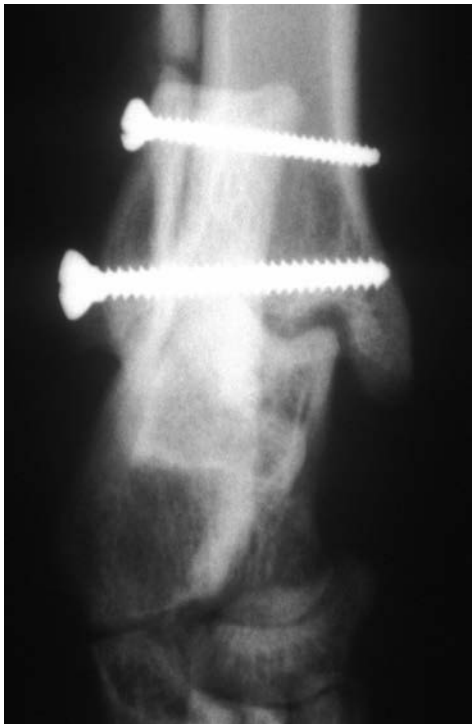


Figure 62-24. Dorsoplantar radiograph of a talar luxation and fibular fracture in a cat that has been repaired by open reduction of the talus and positional screw fixation of the fibula.

Repair of the Calcaneus

Fractures of the calcaneus have a multitude of configurations but all are accessed via a lateroplantar approach. The author prefers to position the patient in sternal recumbency as this negates some of the forces of the extensor mechanism, facilitating fragment reduction.

An avulsion of the medial or lateral insertion of the superficial digital flexor tendon from the tuber calcanei can be managed in two ways depending upon the size of the bone fragment. Small fragments are removed and the insertion of the tendon reconstructed. Larger fragments may be reattached using lag screws. Avulsion of the entire tuber calcanei is usually seen in skeletally immature animals and is repaired using Kirschner wires or a small Steinmann pin, driven from proximal to distal, seated in the base of the calcaneus. Pin fixation is combined with a figure-of-eight tension band wire. In immature animals the implants are removed once the fracture has healed. The pin and tension band method of fixation may be applied to many calcaneal fractures with minor variations in seating of the pin and placement of the wire. Taking a simple oblique midshaft fracture as an example, pin and wire fixation is carried out as follows. The calcaneus is a very dense bone and therefore a hole, slightly smaller than the pin to be used, is drilled from proximal to distal in the proximal fragment. A hole for the wire is drilled through the distoplantar aspect of the base from lateral to medial and a single-loop wire passed, with the loop on the lateral side. Vulsellum forceps are applied to the tuber calcanei and base of the calcaneus to reduce the fragments and the pin is now seated in the base. The wire is wrapped around the proximal end of the pin to form a figure eight and is tightened; the pin is bent over and cut with the proximal end orientated to point dorsally. Some surgeons use two pins, though this has no proven advantage (Figure 62-25). The implants will lie under the superficial digital flexor and may cause some irritation though the clinical significance of this is unknown. If the surgeon prefers to interfere with the superficial digital flexor as little as possible, the wire may be passed through a transosseous tunnel drilled proximally (from lateral to medial), and the pin countersunk (Figure 62-26).

In more distal fractures that approach the base, the pin should be seated in the fourth tarsal bone (T4). The wire may be passed through T4 in the region of the plantar process. The pin and figure-of-eight wire method is also applicable to comminuted

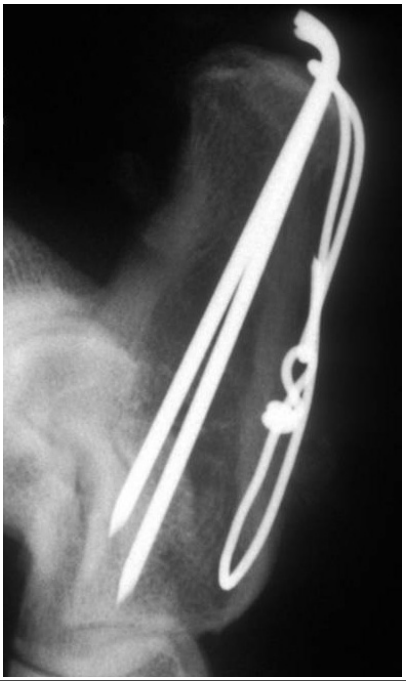


Figure 62-25. Mediolateral radiograph of a calcaneal fracture that has been repaired using two Steinmann pins and a figure-of-eight tension band wire.



Figure 62-26. Dorsoplantar **A.** and mediolateral **B.** radiographs of a calcaneal fracture in a skeletally immature dog, repaired with a countersunk Steinmann pin and a tension band wire. Proximally, the wire has been passed through a transosseous tunnel.

fractures; this may be supplemented by the use of lag screws or cerclage wire to reconstruct the calcaneal shaft. In one case a tension band wire alone was successfully combined with lag screw reconstruction (Figure 62-27). Application of a neutralization or buttress plate to the lateral aspect of the calcaneus has been advocated in comminuted fractures, with or without a supplemental figure-of-eight wire. The authors would suggest that a pin and figure-of-eight wire can be applied to virtually all comminuted calcaneal fractures, with a decreased surgical time and inventory when compared with plate fixation. Fractures with a plantarodistal component benefit from the addition of a "reverse" pin and tension band, with the pin orientated from plantarodistal to dorsoproximal and the wire passed through the calcaneal shaft. Small plantarodistal chip fractures representing an avulsion of the origin of the middle plantar ligament may not be amenable to reconstruction. Such cases are best managed by arthrodesis of the calcaneoquartal joint space. This procedure again utilizes pin and tension band fixation with the pin seated in T4 and the tension band passing through the same bone in the region of the plantar process.

Lateral sagittal fractures of the base and shaft of the calcaneus are repaired using multiple lag screws placed from lateral to medial (Figure 62-28). Dorsomedial slab fractures involving the base and sustentaculum tali are a challenge to diagnose radiographically. Repair is similarly challenging: lag screws have been used in a few instances but often external coaptation must be resorted to.

Post-operatively, simple fractures of the tuber calcanei or shaft do not require external coaptation. Comminuted fractures should be supported by a lateral splint for around 6 weeks. Exercise must be restricted to short leash walks for two months postoperatively, followed by a gradual return to normal activity provided there is radiographic evidence of healing.



Figure 62-27. Mediolateral radiographs of a racing greyhound's tarsus showing a type 4 central tarsal bone fracture and a comminuted calcaneal fracture **A.** In the postoperative view **B.** lag screws have been used to reconstruct both bones, with a tension band wire protecting the repair of the calcaneus.

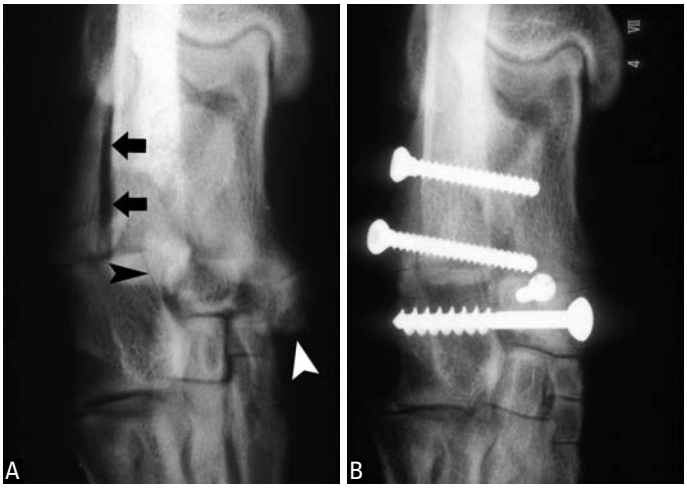


Figure 62-28. Dorsoplantar radiograph **A.** of a lateral sagittal fracture of the calcaneus *(black arrows)*, a compression fracture of the fourth tarsal bone *(black arrowhead)* and a type 4 fracture of the central tarsal bone *(white arrowhead)* in a racing greyhound. Lag screw repair is illustrated **B.** (Reproduced from Dee JF, Dee LG, Eaton-Wells RD. Injuries of high performance dogs. *In:* Whittick WG, ed. Canine Orthopedics. 2nd ed. Philadelphia: Lea and Febiger, 1990).

Repair of the Central Tarsal Bone

Stress fracture of the central tarsal bone (CTB) occurs in the racing greyhound.[4] Five types of CTB fracture have been described in this breed based on radiographic and intra-operative appearance[5] (Table 62-1). A fracture-luxation of the CTB occurs sporadically in all breeds;[6] the fracture occurs at the plantar process which remains attached to the plantar ligaments. The rest of the bone is displaced dorsomedially.

Table 62-1. Classification of Central Tarsal Bone Fractures in the Racing Greyhound.

Fracture Type	Fracture Configuration
I	Non-displaced dorsal slab fracture
II	Displaced dorsal slab fracture
III	Large displaced medial fragment
IV	Dorsal and medial slab fractures
V	Highly comminuted fracture

Repair of type 4 CTB fractures in the greyhound proceeds as follows,[7] and is illustrated in Figure 62-29. With the patient positioned in dorsal recumbency and the tarsus immobilized parallel to the table surface, the CTB is approached on its dorsomedial aspect. The 5 cm skin incision runs between the dorsal branches of the medial and lateral saphenous veins. The CTB is found, by blunt dissection, just distal to the oblique tendon of the tibialis cranialis muscle (Figure 62-29A). The tendon of the long digital extensor is retracted laterally, and those of the tibialis cranialis and extensor digitorum brevis retracted medially to expose the fracture fragments. The fracture is reduced through hyperextension and eversion of the hock, and reduction is maintained with Vulsellum and/or pointed reduction forceps (Figure 62-29B). The medial fragment is repaired first. A 4.0 mm partially threaded cancellous screw is driven mediolateral,

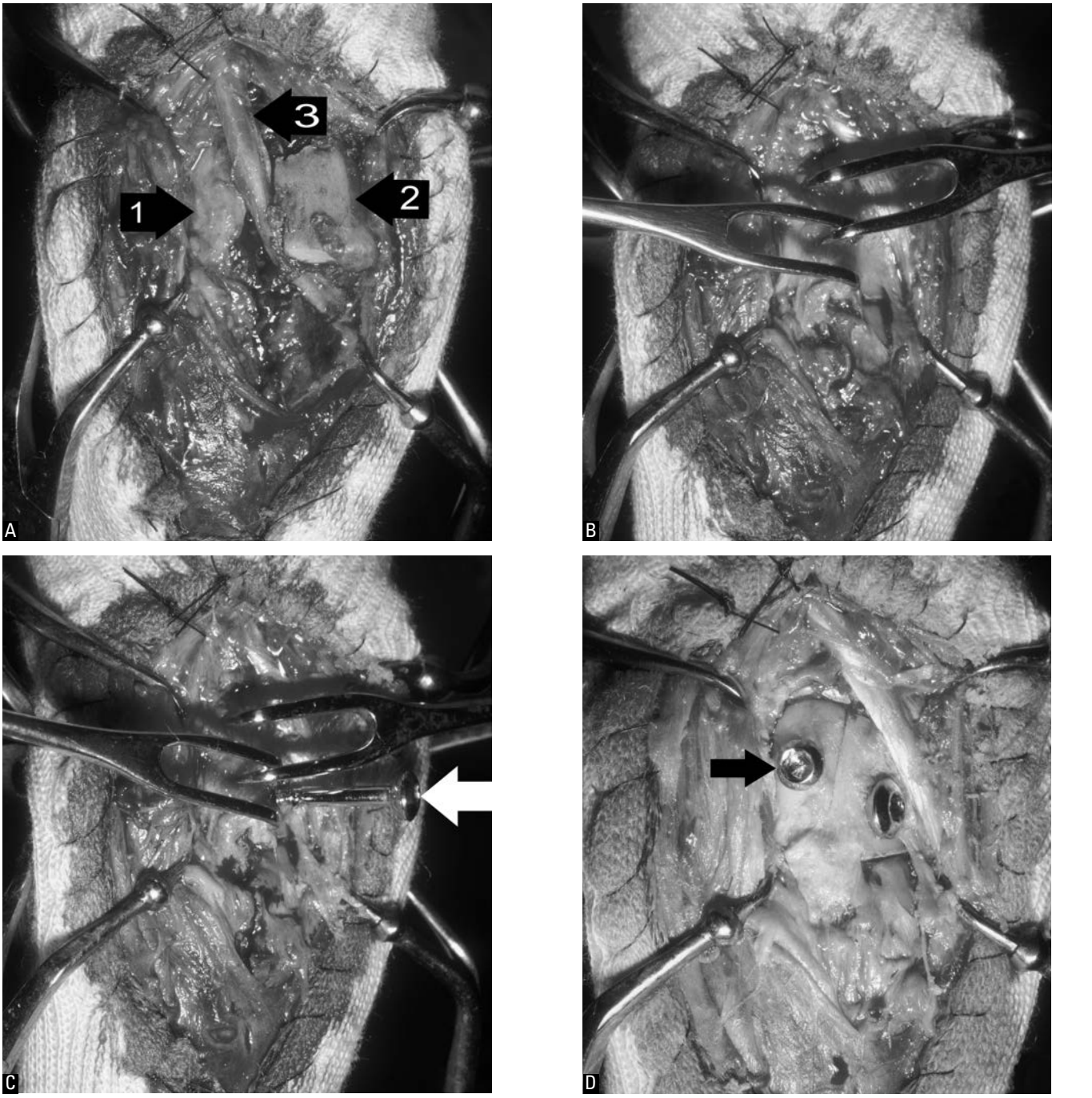


Figure 62-29. Intraoperative photographs of a type 4 central tarsal bone repair. **A.** Dorsal *(1)* and medial *(2)* fragments are identified. The tendon of the tibialis cranialis passed obliquely between the fragments *(3)*. **B.** The tendon has been retracted medially and the fragments reduced using Vulsellum forceps. **C.** A 4.0 mm partially threaded cancellous screw is applied in lag fashion to secure the medial fragment *(arrow)*. **D.** The dorsal fragment is secured with a lagged 2.7 mm cortical screw *(arrow)*. (Reproduced from Boudrieau RJ, Dee JF, Dee LG. Treatment of central tarsal bone fractures in the racing greyhound. *J Am Vet Med Assoc* 184:1492, 1984).

from a point just proximal to the origin of the oblique intertarsal ligament that joins the CTB to the third tarsal bone (T3), and the threads are engaged in the body of T4 (Figure 62-29C). This screw is placed in lag fashion and countersunk. The dorsal slab component is then repaired. A 2.0 or 2.7 mm screw is driven perpendicular and just proximal to the mediolateral screw to seat in the plantar process of the CTB. The screw is lagged and countersunk (Figure 62-29D). Figure 62-30 illustrates optimal lag screw positioning in repair of type 4 fractures. Repair of fracture types I and II is achieved as described for repair of the dorsal component of a type 4 fracture (Figure 62-30). Type III fractures are best managed as if they were type IV because it is possible that a dorsal fragment exists, but is non-displaced, and therefore not visible radiographically. This recommendation has been borne out by experience.[7] The poor prognosis for return to racing that accompanies the type V fracture means that many are treated by external coaptation alone, resulting in a permanent varus deformity though a basically functional limb. Repair may be attempted in a number of ways. If the dorsal and medial fragments are large enough, repair can proceed as for

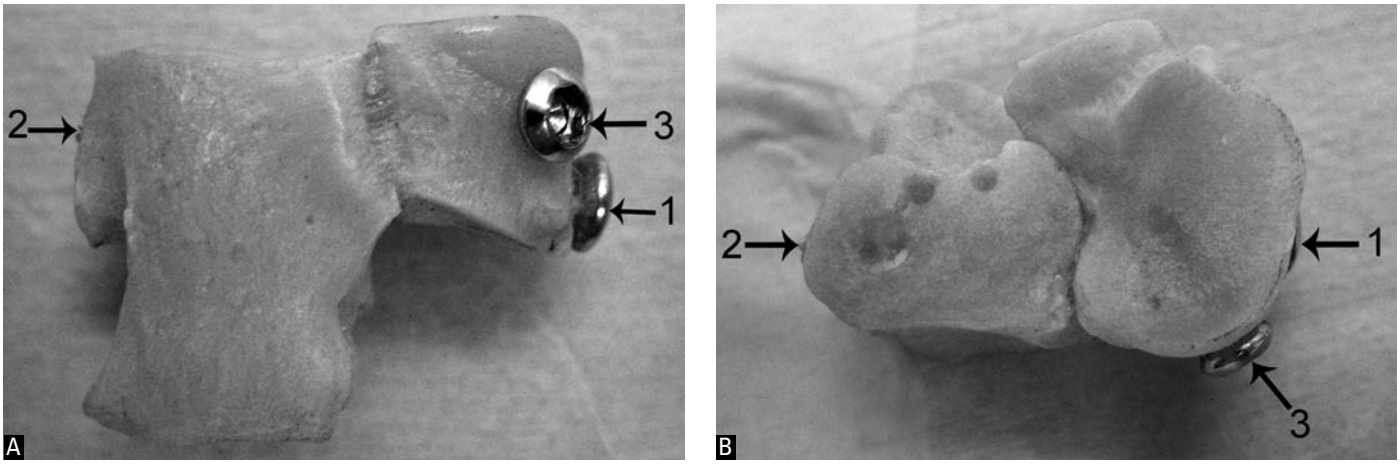


Figure 62-30. The dorsal **A.** and proximal **B.** aspects articulated fourth and central tarsal bones demonstrating optimal lag screw positioning for repair of a type 4 central tarsal bone fracture. *1* = mediolateral screw head, *2* = mediolateral screw threads exiting the trans cortex of T4, *3* = head of dorsoplantar screw. Note the orientation of the dorsoplantar screw required to seat in the plantar process of the central tarsal bone.

type IV fractures though the reconstruction will not be perfect. Alternatively, a buttress plate can be placed on the dorsal aspect of the tarsus from talar neck to T3 and the central tarsal space filled with bone graft. Central tarsal prosthesis or allograft could also be considered. As the level of experience increases and instrumentation improves, a number of type V CTB fractures have been successfully reconstructed by placing up to five lag screws in this bone. One such racing greyhound has returned to win. The most rational course of action for management of type V fractures will depend upon the proficiency of the surgeon, the patients' ability on the track, and the owners' expectations. Repair of the CTB fracture-luxation in non-greyhound breeds is accomplished by directing a lag screw mediolaterally to seat in T46. A threaded Kirschner wire has been used in place of a screw in small toy breeds.

In the author's experience approximately two thirds of fractured CTB's have associated secondary fractures, with fractures of the calcaneus, T4, and avulsion fracture of the lateral aspect of the base of the fifth metatarsal being the most common[5] (See Figures 62-17, 62-27, 62-28, 62-29 62-33, and 62-35). It is important to actively look for secondary fractures when evaluating fractures of the CTB as they have implications for prognosis as well as for management.

Postoperatively, a lateral splint is applied and maintained for six to eight weeks while restricting activity to leash walks. Radiographic evidence of healing is assessed around one month post-operatively. A gradual increase in activity leads into training and finally racing. Overall, prognosis for return to function may be good. In one study, 71 (88%) of 81 greyhounds with a central tarsal fracture that was treated by internal fixation returned to racing.[7]

Repair of the Fourth Tarsal Bone

Fracture of this bone may be considered rare in the general pet population (Figure 62-32). However, around 40% of type IV and V CTB fractures in the racing greyhound are accompanied by a



Figure 62-31. Mediolateral radiographs showing a dorsal slab fracture of the central tarsal bone in a racing greyhound **A.** *(arrow)* and 2.7 mm lag screw fixation **B.** (Reproduced from Dee JF, Dee LG, Eaton-Wells RD. Injuries of high performance dogs. *In:* Whittick WG, ed. Canine Orthopedics. 2nd ed. Philadelphia: Lea and Febiger, 1990).

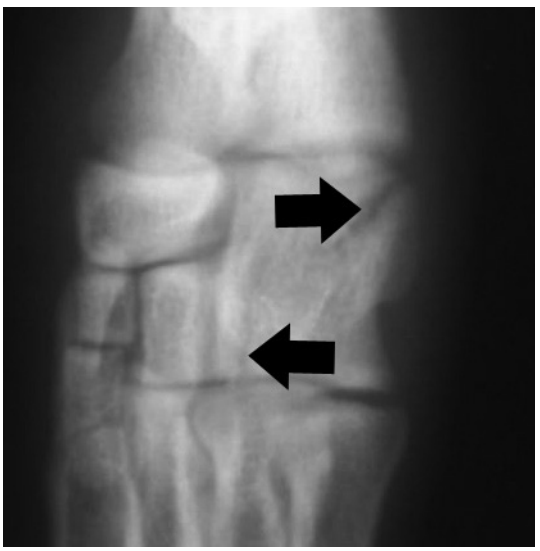


Figure 62-32. Dorsoplantar radiograph showing a rare isolated fracture of the fourth tarsal bone in a Doberman *(arrows)*. This fracture was treated by external coaptation and healed uneventfully.

compression fracture of T4[5]. Repair of these fractures is almost always achieved indirectly through repair of the CTB which restores hock length and axial alignment. If required, a second mediolateral screw can be placed through the second and third tarsal bones and seated in T4 to provide additional stability (Figure 62-33).

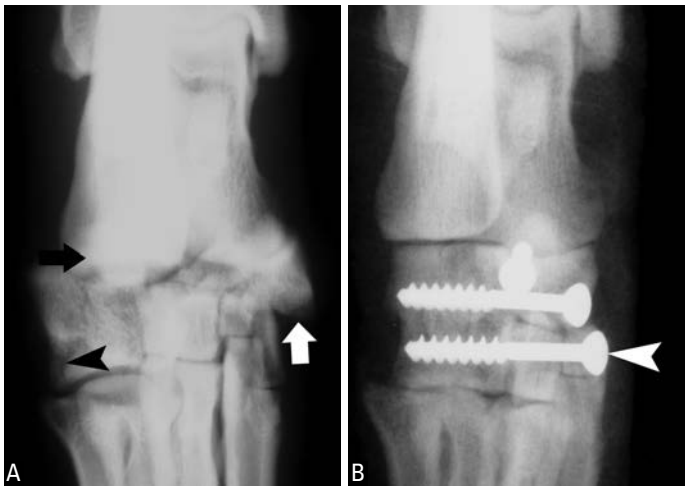


Figure 62-33. A. Dorsoplantar radiographs showing a highly comminuted central tarsal bone fracture with a large medial fragment *(white arrow)* combined with a fracture of the fourth tarsal bone in a racing greyhound. The fourth tarsal bone has been compressed by the calcaneus *(black arrow)*, and the fracture extends through the distal surface of the bone *(black arrowhead)*. In **B.** the central tarsal bone has been repaired by lag screw fixation. A second 4.0 mm lag screw directed through the second and third tarsal bones to seat in the fourth provides additional stability *(white arrowhead)*. (Reproduced from Dee JF, Dee LG, Eaton-Wells RD. Injuries of high performance dogs. *In:* Whittick WG, ed. Canine Orthopedics. 2nd ed. Philadelphia: Lea and Febiger, 1990).

Repair of the Third Tarsal Bone

Dorsal slab fracture of T3 occurs in the racing greyhound (Figure 62-34) though it would be considered uncommon compared with fracture of the CTB. Based on experience, these fractures should be managed by internal fixation where a return to racing is desired. The approach to T3 is a distal extension of the approach to the CTB. Location of T3 is simplified by first identifying the second tarsal bone (T2) and tarsometatarsal joint space. Reduction is achieved by application of Vulsellum forceps. A 2.0 or 2.7 mm cortical screw is driven in a dorsoplantar direction, perpendicular to the fracture line, and seated in the plantar process. The screw is lagged and countersunk. Post-operative management is the same as for CTB fractures.

Repair of the Second Tarsal Bone

Fractures of this bone can be considered extremely rare. When they do occur, repair is by lag screw fixation (Figure 62-35) illustrates a T2 fracture in conjunction with a number of other tarsal injuries in a racing greyhound, and 2.0 mm lag screw repair. Somewhat more common is subluxation of T2, which may accompany fracture of T3 (Figure 62-36) or tarsometatarsal subluxation. To repair a T2 subluxation, the bone is approached on its' medial aspect and a positional or lag screw driven from medial to lateral, seating in T3 and T4.

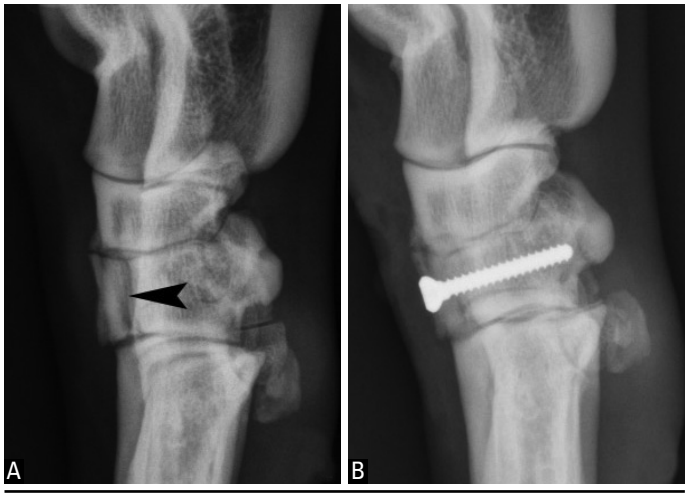


Figure 62-34. Mediolateral radiographs of the tarsus of a racing greyhound with a dorsal slab fracture of the third tarsal bone *(***A.** *black arrowhead)* and the method of repair using a 2.7 mm lag screw **B.**

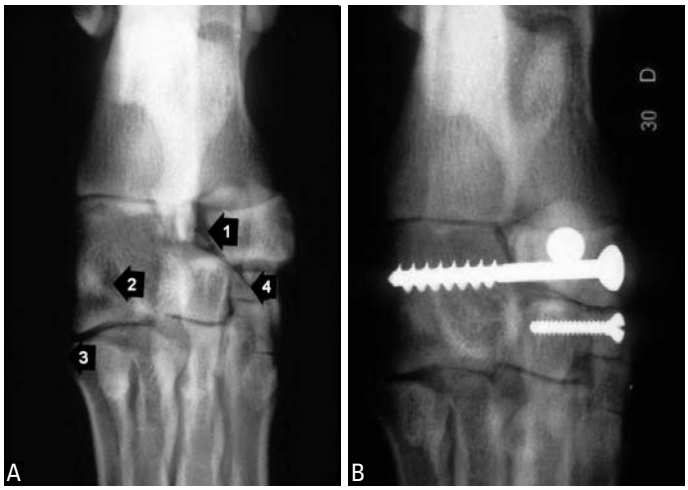


Figure 62-35. Dorsoplantar radiograph **A.** demonstrating a central tarsal bone fracture *(1)*, fracture of the fourth tarsal bone *(2)*, avulsion of the lateral aspect of the base of metatarsal five *(3)*, and an oblique fracture of the second tarsal bone *(2)* in a racing greyhound. A post-operative view **B.** shows lag screw fixation of the central and second tarsal bones; the other injuries are managed indirectly. (Reproduced from Dee JF, Dee LG, Eaton-Wells RD. Injuries of high performance dogs. *In:* Whittick WG, ed. Canine Orthopedics. 2nd ed. Philadelphia: Lea and Febiger, 1990).

Post-operative management will depend upon the nature of any concurrent tarsal injury but in general, external coaptation for six to eight weeks is appropriate.

Repair of the First Tarsal Bone

Transverse fracture of the first tarsal bone (T1) has recently been reported in conjunction with tarsometatarsal subluxation in a small breed dog.[8] It is hypothesized that fracture of this bone represents an avulsion of the long component of the medial collateral ligament from its insertion on T1. Since then, another case with an almost identical injury has been recognized by the authors. Stress radiography was used to accurately characterize the injury (Figure 62-37). Both dogs were successfully treated by external coaptation of the affected limb, for six weeks, in a lateral

splint. The T1 fractures went on to heal (Figure 62-38), stability was restored to the joint, and the dogs were sound two months after the initial injury. A greater number of T1 fractures need to be documented and managed before strong recommendations can be made regarding this injury.

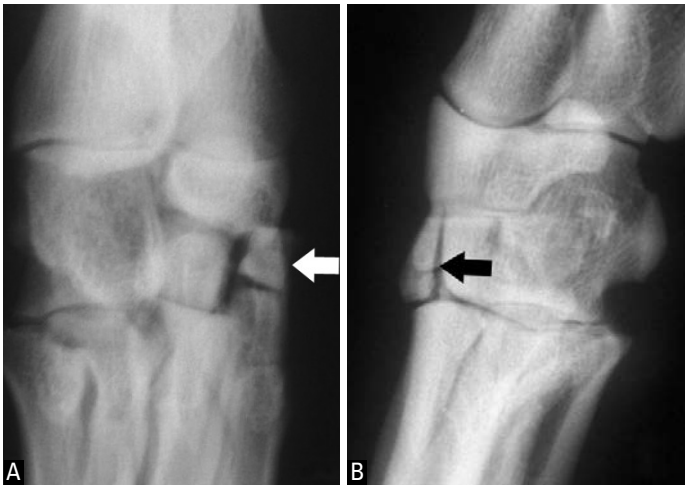


Figure 62-36. Dorsoplantar **A.** and mediolateral **B.** radiographs demonstrating a subluxation of the second tarsal bone *(white arrow)* with a concurrent dorsal slab fracture of the third tarsal bone *(black arrow)*. (Reproduced from Dee JF, Dee LG, Eaton-Wells RD. Injuries of high performance dogs. *In:* Whittick WG, ed. Canine Orthopedics. 2nd ed. Philadelphia: Lea and Febiger, 1990).



Figure 62-37. Dorsoplantar radiographs of the tarsus of a terrier-type mixed breed dog. In **A.** fracture of the first tarsal bone can be seen *(white arrow)*, with widening of the tarsometatarsal joint space *(black arrows)*. In **B.** force has been applied in the direction of the *arrowhead*, showing the full extent of the injury.



Figure 62-38. Dorsoplantar radiograph of the tarsus of a dog that sustained a first tarsal bone fracture and tarsometatarsal subluxation five months previously. External coaptation was the method of treatment. The first tarsal bone is highlighted by the *white arrowheads*.

References

1. Gielen I, De Rycke L, van Bree H, Simoens P: Computed tomography of the tarsal joint in clinically normal dogs. *Am J Vet Res* 62:1911, 2001.

2. Matis, U. Complex fractures of the tarsus – cats. *In:* Lecture abstracts: advanced techniques in small animal fracture management course. Arbeitsgemeinshaft für Osteosynthesefragen. Columbus, Ohio, 2007.

3. McCartney WT, Carmichael S. Talar neck fractures in five cats. *J Small Anim Pract* 41:204, 2000.

4. Muir P, Johnson KA, Ruaux-Mason CP. In vivo matrix microdamage in a naturally occurring canine fatigue fracture. *Bone* 25: 571, 1999.

5. Boudrieau RJ, Dee JF, Dee LG. Central tarsal bone fractures in the racing greyhound: a review of 114 cases. *J Am Vet Med Assoc* 184:1486, 1984.

6. Piermattei DL, Flo GL, DeCamp CE. Fracture-luxation of central tarsal bone. *In:* Piermattei, DL, Flo GL, DeCamp CE, eds. Brinker, Piermattei and Flo's handbook of small animal orthopedics and fracture repair. 4th ed. St Louis: Elsevier Inc, 2006 p698.

7. Boudrieau RJ, Dee JF, Dee LG. Treatment of central tarsal bone fractures in the racing greyhound. *J Am Vet Med Assoc* 184:1492, 1984.

8. Marshall WG, Dee JF, Spencer CP. What is your diagnosis? Tarsometatarsal subluxation. *J Am Vet Med Assoc.* 2007 Dec 15;231(12):1809-10.

Suggested Readings

Beale B. Surgical treatment of talus fractures. *In:* Bojrab MJ, Ellison GW, Slocum B, eds. Current techniques in small animal surgery. 4th ed. Baltimore: Williams and Wilkins, 1998 p1264.

Dee JF, Dee LG, Eaton-Wells RD. Injuries of high performance dogs. *In:* Whittick WG, ed. Canine Orthopedics. 2nd ed. Philadelphia: Lea and Febiger, 1990 p519.

Dee JF. Tarsal injuries. *In:* Bloomberg MS, Dee JF, Taylor RA, eds. Canine Sports Medicine and Surgery. Philadelphia: WB Saunders Co, 1998 p120.

Evans HE: Millers' anatomy of the dog. 3rd ed. Philadelphia: WB Saunders Co, 1993.

Piermattei DL, Johnson KA: An atlas of surgical approaches to the bones and joints of the dog and cat. 4th ed. Philadelphia: Elsevier, 2004.

Surgical Treatment of Osteochondritis Dissecans of the Hock

Brian Beale

Lesions associated with osteochondritis dissecans (OCD) of the hock occur on the medial or lateral trochlear ridge of the talus. The lesions may be characterized as small, cartilage flaps or large, osteochondral fragments. Early diagnosis and prompt surgical removal of these fragments are recommended, before the onset of significant degenerative joint disease (DJD). Several approaches have been described to gain access to the flaps. Severance of either collateral ligament allows subluxation of the joint and excellent visualization of the trochlear ridges; however, this approach should be avoided because of the probability of causing iatrogenic joint instability, predisposing the dog to greater DJD. Osteotomy of the medial or lateral malleolus also gives excellent surgical exposure; however, this approach can also be associated with increased morbidity. Medial malleolar osteotomy is technically demanding and requires iatrogenic formation of an articular fracture of the distal tibia. Precise reduction and rigid stabilization is necessary to prevent DJD. Lateral malleolar osteotomy is preferred, but precise reduction and rigid stabilization are necessary to prevent joint instability or nonunion of the osteotomy site. The preferred approaches are the dorsolateral and plantarolateral approaches to the lateral trochlear ridge and the dorsomedial and plantaromedial approaches to the medial trochlear ridge. Accurate radiographic assessment of the location of the OCD lesion is necessary to select the appropriate surgical approach. Most OCD lesions can be accessed through a single approach; however, a combination of the dorsal and plantar approaches is necessary to gain access to some large lesions or lesions located on the midportion of the trochlear ridges. A combined approach to the medial trochlear ridge allows access to all but approximately 5% of the ridge (the midportion). A combined approach to the lateral trochlear ridge allows access to the entire ridge. The advantage of using the combined approaches is the preservation of the collateral ligaments without the need for a technically demanding, time-consuming osteotomy. If these approaches fail to provide sufficient surgical exposure, a malleolar osteotomy can then be performed. Because of the low morbidity associated with these procedures, bilateral lesions can be operated on at the same time.

All four approaches are performed by making a curvilinear skin incision centered over the appropriate region of the trochlear ridge. Subcutaneous tissues are incised and are retracted. Certain anatomic structures should be avoided during each approach. The dorsolateral approach requires lateral retraction of the tendons of the extensor digitorum longus, tibialis cranialis, and extensor hallucis longus muscles, the dorsal branch of the lateral saphenous vein, and the superficial peroneal nerve (Figure 62-39). This approach also requires plantar retraction of the tendons of the peroneus longus, extensor digitorum lateralis, and peroneus brevis muscles. In the plantarolateral approach, the tendons of the peroneus brevis, extensor digitorum lateralis, and peroneus longus muscles must be avoided dorsally (Figure 62-40). The plantar branch of the lateral saphenous vein and branch of the

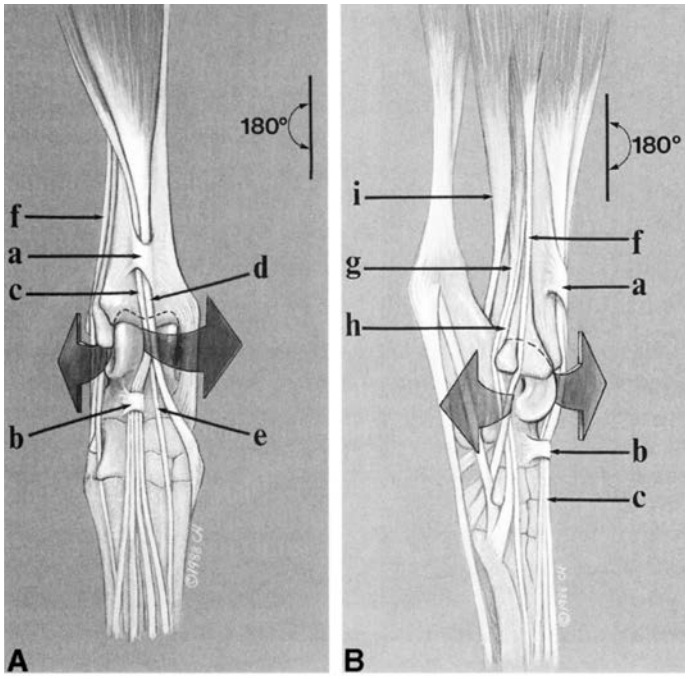


Figure 62-39. Dorsolateral approach to the hock. **A.** Dorsal view of the lateral trochlear ridge showing medial retraction of the tendons of the extensor digitorum longus, extensor hallucis longus, and tibialis cranialis muscles. **B.** Lateral view of the lateral trochlear ridge showing plantar retraction of the tendons of the peroneus longus, extensor digitorum lateralis, and peroneus brevis muscles. The lateral collateral ligament (not shown) is preserved, *a,* proximal extensor retinaculum; *b,* distal extensor retinaculum; *c,* extensor digitorum longus muscle; *d,* tibialis cranialis muscle; *e,* extensor hallucis longus muscle; *f,* peroneus longus muscle; *g,* peroneus brevis muscle; *h,* extensor digitorum lateralis muscle; *i,* flexor hallucis longus muscle.

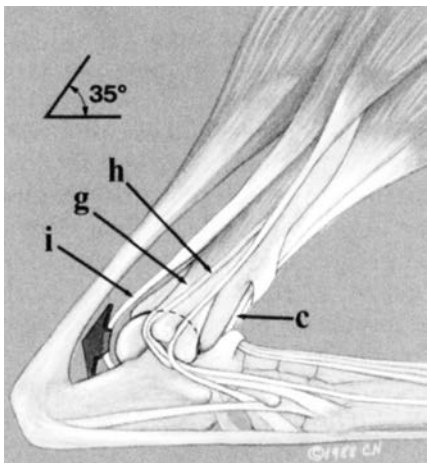


Figure 62-40. Plantarolateral approach to the hock. Flexion of the hock to 35° results in passive dorsal movement of the tendons of the peroneus brevis, extensor digitorum lateralis, and peroneus longus muscles. The tendon of the flexor hallucis longus muscle is retracted medially, resulting in exposure of the lateral trochlear ridge. The lateral collateral ligament (not shown) is preserved, *c,* extensor digitorum longus muscle; *g,* peroneus brevis muscle; *h,* extensor digitorum lateralis muscle; *i,* flexor hallucis longus muscle.

caudal cutaneous sural nerve are retracted in a plantar direction, and the flexor hallucis longus tendon is retracted medially. The dorsomedial approach requires lateral retraction of the tibialis cranialis tendon, saphenous nerve, cranial tibial artery and vein, and dorsal branches of the saphenous artery and vein (Figure 62-41). In the plantaromedial approach, the tendon of the flexor digitorum longus muscle and the distal attachment of the tibialis caudalis tendon are retracted dorsally, and the flexor hallucis longus tendon, tibial nerve, and medial saphenous vein and artery are retracted laterally (Figure 62-42). The collateral ligament complex is preserved in all four approaches. The joint capsule is incised longitudinally, directly over the palpable trochlear ridge, and is retracted. Extension and flexion of the joint allow access to the trochlear ridge for removal of the OCD fragment. Removal is usually simple using a Freer elevator or similar instrument. If present, synovial attachments to the fragment are sharply incised. Reattachment of the fragment with Kirschner wires or lag screws is not recommended because of the typical remodeling of the fragment present at the time of surgery, the technical difficulty of the procedure, and the possibility of implant failure. Gentle curettage of the subchondral lesion can be performed to remove loose debris and undermined edges at the periphery of the lesion. Fibrocartilaginous repair tissue within the defect should be left undisturbed. Forage (drilling of several small holes into the subchondral bone) of the defect to encourage vascular ingrowth has been proposed, but its efficacy is unknown. The joint capsule and subcutaneous tissues are closed in two layers using synthetic absorbable suture. The skin is closed using synthetic nonabsorbable suture. A soft, padded bandage is recommended for 7 to 10 days. Exercise should be restricted to leash walks only for 6 weeks.

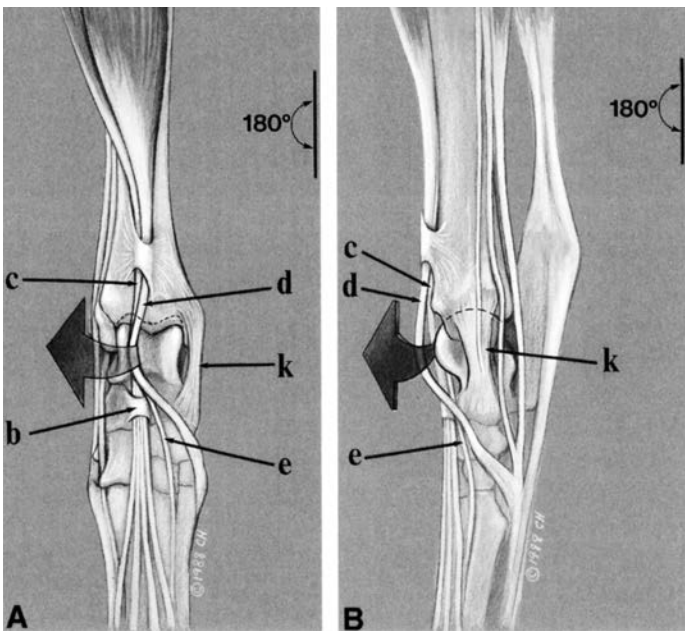


Figure 62-41. Dorsomedial approach to the hock. **A.** Dorsal view of the medial trochlear ridge showing lateral retraction of the tendons of the extensor digitorum longus, extensor hallucis longus, and tibialis cranialis muscles. **B.** Medial view of the medial trochlear ridge showing dorsolateral retraction of the tendons of the tibialis cranialis, extensor hallucis longus, and extensor digitorum longus muscles. The medial collateral ligament is preserved, *b,* distal extensor retinaculum; *c,* extensor digitorum longus muscle; *d,* tibialis cranialis muscle; *e,* extensor hallucis longus muscle; *k,* long part of the medial collateral ligament.

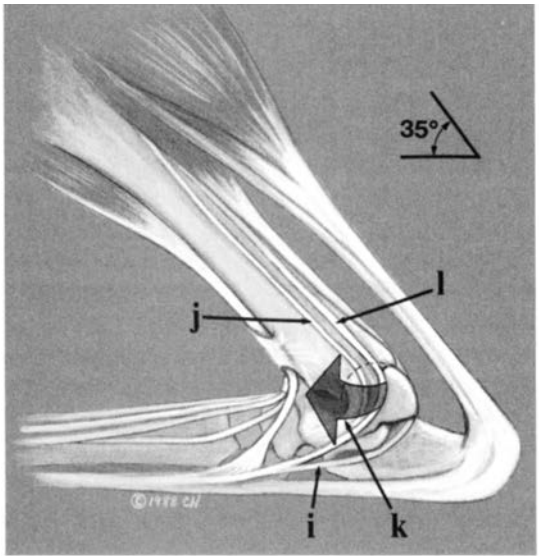


Figure 62-42. Plantaromedial approach to the hock. The tendons of the flexor digitorum longus and tibialis caudalis are retracted dorsally resulting in exposure of the medial trochlear ridge. The tendon of the flexor hallucis longus muscle and the medial collateral ligament are avoided. *l,* flexor hallucis longus muscle; *j,* tibialis caudalis muscle; *k,* long part of the medial collateral ligament; *i,* flexor digitorum longus muscle.

Tibiotarsal Arthrodesis and other Tarsal Arthrodesis Procedures

Arnold S. Lesser

Introduction

When performing arthrodesis of the tibiotarsal joint, as in pancarpal arthrodesis, it is recommended to include the fusion of the intertarsal and tarsometatarsal joints. Fusion of the tibiotarsal joint alone creates added stress to these secondary joints. Tibiotarsal arthrodesis has a better prognosis then elbow or stifle arthrodesis for a successful return to function. Dogs and cats can tolerate the loss of motion in the hock and carpus better then a mid limb joint (elbow and stifle). However, arthrodesis is never simple because the surgeon is trying to overcome motion in areas where the body is constructed to maintain motion. Although the lever arm is shorter for the hock than for the stifle or elbow, the angle of the arthrodesis is more acute than for the carpus. A stiff, straight structure is hard to bend but once it is bent, and the more acute the angle, the easier it is to bend. The same is true for a plate-bone composite structure, thus the straighter or more oblique the angle of a joint being fused the more stable it is. Even the plate alone is weaker when bent at more acute angles. The normal standing angle of the hock is 130 to 150°, but if the arthrodesis angle is straighter it will be more stable and more likely to succeed. When the plate is placed on the cranial aspect of the joint, which is most commonly described, it is on the compression side which adds to the instability. Other positions for the plate have been described but are problematic for pantarsal arthrodesis. A plate is now available for placement on the medial aspect of the joint at a fixed angle of 135 degrees to overcome this weakness.

Indications

The tibiotarsal joint is subject to trauma and degenerative disease just as in any other joint. When these conditions lead to chronic pain and dysfunction, arthrodesis is indicated.

Any fracture or luxation where the articular surface cannot be reestablished or is permanently damaged, such as a gunshot or infected nonunion, arthrodesis is indicated. Shearing injuries to the medial aspect of the tibiotarsal joint with ligamentous and bone loss are frequently seen. This occurs when the leg is dragged on the ground. Most of these injuries heal by second intention and the scar tissue or screws (bone anchors) and stainless steel orthopedic wire are enough to provide stability. But, if the bone loss is excessive then arthrodesis is an alternative.

OCD of the talus is probably the most common reason for arthrodesis of the tibiotarsal joint. Even after the osteochondral fragment is removed any improvement tends to be temporary with degenerative joint disease progressing to chronic lameness. When conservative therapy is no longer effective, arthrodesis is indicated. Rheumatoid or polyarthritis also commonly affects the tibiotarsal joint and, as in the carpus, arthrodesis is beneficial for individual joints. But the disease tends to affect multiple joints. Septic arthritis or secondary degenerative arthritis can be severe enough to warrant arthrodesis.

A unique indication for a talocrural fusion is in sciatic nerve paralysis. A muscle transfer of the vastus lateralis to the long digital extensor tendon requires fusion of the tibiotarsal joint providing mechanical advantage to dorsiflex the paw when walking. The fusion helps position the paw and removes a point of motion along the path of the transferred tendon.

A failed repair of the calcanean (Achilles) tendon can be salvaged with a tarsocrural or pantarsal arthrodesis. The rupture of the plantar ligament however, can be repaired with fusion of the proximal intertarsal joint alone. This is a very common injury especially in collies and shetland sheep dogs, but all breeds can be affected. These dogs present with hyperextension of the hock with the tubercalcus more parallel to the tibia then normal. This varies from the complete luxation of the intertarsal joint where the talocentral joint is also unstable. With luxations of the individual joints, such as the intertarsal and tarsometatarsal joints, fusion of the involved joints alone is sufficient. The extent and location of the soft tissue injuries may differ and dictate the repair. This will be discussed later.

Procedure

In all cases the cartilage must be removed from the adjacent surfaces. The articular surfaces of the talocrural joint can be approached by cutting either of the collateral ligaments or by an osteotomy of the medial maleolus or fibula and incising the joint capsule. For the tibiotarsal joint either the cartilage itself can be removed with a power bur or a curette leaving the original saddle shape of the distal tibia and tallus intact. Alternatively, two flat surfaces can be developed with a saw or bur (Figure 62-43). In either case, autogenous cancellous bone should be packed between the surfaces to fill in the gaps. If a significant amount of bone is removed to create flat planes then this will act to effectively shorten the leg and to compensate for this the joint should be fused at a straighter angle which is also more stable. The angle of the cuts will determine the final angle of the arthrodesis. The normal standing angle in dogs is between 130 and 150°, but there are significant differences between individuals and breeds such that measurement of the normal standing angle of the contrlateral limb is the best method for determination of the desired angle. The normal standing angle of this joint in cats is usually 115 to 125°. The cartilage of the intertarsal and tarso- metatrsal joints is removed in a routine manner with a curette or bur.

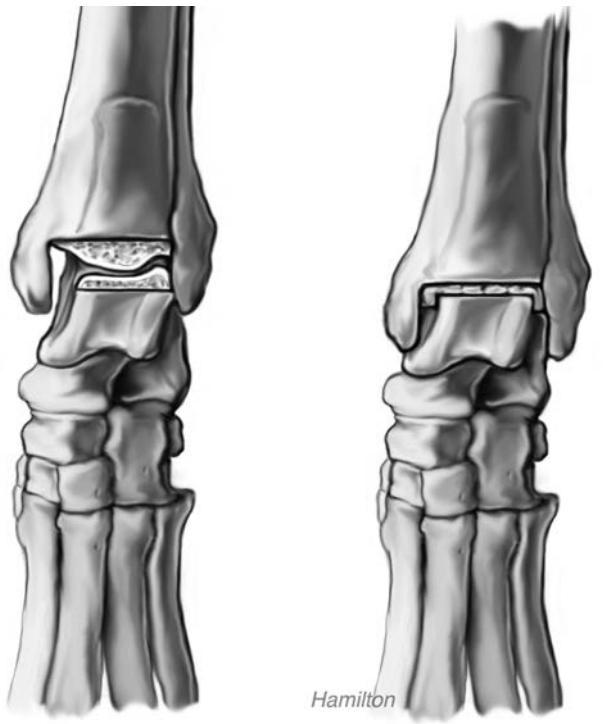


Figure 62-43. When the articular cartilage is being removed, it is advantageous to shape the opposing surfaces to produce the most stable configuration possible as well as locking in the desired angle. Two congruent rectangular surfaces can be shaped and augmented with cancellous bone.

In small dogs or cats the tibiotarsal joint can be fused with compression screws. One screw is generally placed from the sustentaculum tali into the medullary canal of the tibia, and another screw is placed from the tibia calcaneus into the tibia to hold the position of the joint and oppose flexion (Figure 62-44). Once the medulary canal is wider than the thread of the screw, then multiple screws must engage the cortex of the tibia, the talus and fibular tarsal bone. They can either be passed from proximal to distal or vise versa (Figure 62-45). Either orthopedic wire or another screw should go from the calcaneus to the tibia to resist flexion and protect the other screws from bending forces. A Kirschner wire can be used to hold the joint temporarily while the holes for the screws are drilled. The problem with this technique is that only the tibiotarsal joint is fused and although it can be successful (especially when muscle transfer is done for sciatic nerve paralysis) there are some dogs that will develop problems in the other tarsal joints. A study by Gorse and co-workers found better function with pantarsal arthrodesis than for talocrural arthrodesis alone. External coaptation with a

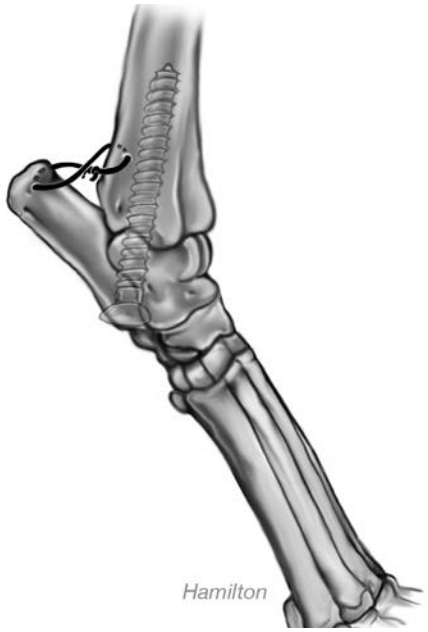


Figure 62-44. A screw can be placed from the calcaneus through the talus up into the medullary canal of the tibia. Once the medullary canal becomes wider than the screw, this placement is no longer viable. A figure-eight wire or screw is placed from the tuber calcei to the tibia to resist flexion.

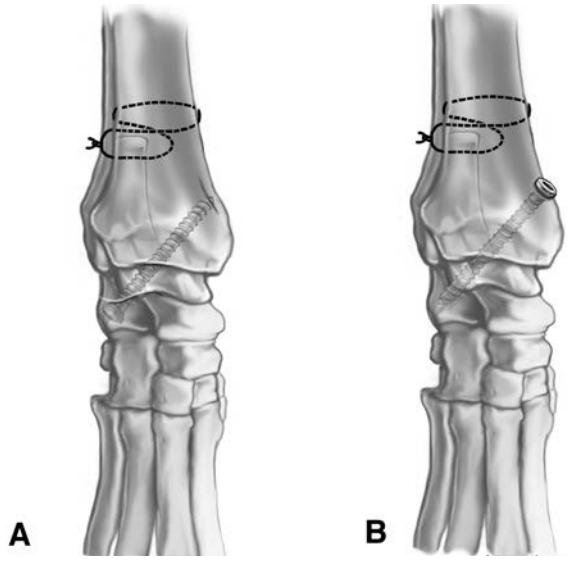


Figure 62-45. The screw can also be placed from the calcaneus to emerge from the medial malleolus **A.** or the opposite **B.** from proximal to distal. A wire or screw should be added from the tuber calcei to the tibia.

splint or cast should be maintained until there are radiographic signs of healing with all screw fixations.

Preferred methods for stabilization of a pantarsal arthrodesis are bone plate fixation or external skeletal fixation (ESF). The most common placement of the plate is along the cranial aspect of the tibia, tarsus and metatarsal bones (Figure 62-46). This is, however, the compression side of the construct and not ideal. A straight plate can be placed caudolaterally, but a new tarsal arthrodesis plate (Jorgensan labs) is available with a built-in angle of 135° which can be placed medially (Figure 62-47). The 3.5mm plate has 2.7mm holes distally for the metatarsal bones and the 2.7mm plate has 2.0 mm holes distally. For medial placement of a plate, the medial maleolus may need to be shaved. Regardless of the aspect of plate placement, three to four screws should be applied to the tibia; one to three screws should be applied to the talus, calcaneus and central tarsal bones; and three screws should be applied to the metatarsal bone. In a cranial plating, one of the screws should be placed across the arthrodesis under compression, and either a screw or wire should immobilize the calcaneus to resist bending. Motion between the calcaneus and talus post arthrodesis can cause lameness. The plate should engage either the 3rd or the 4th metatarsal bone. A separate screw can be used to compress the arthrodesis and grab the calcaneus when the plate is applied medially. Even with plate fixation, some form of splinting should be considered until radiographic signs of healing are evident (usually 2 to 3 months). Since we are not worried about joint stiffness, as would be the case in fracture fixation, extra support is warranted, especially in large active dogs. The complications of soft tissue irritation has to be weighed against this added support. Therefor a ESF can be used for additional support instead of coaptation.

External fixation is also well adapted as primary repair for pantarsal arthrodesis, especially in shearing injuries or open, contaminated, comminuted fractures (Figure 62-48). A type II construct is needed for rigid fixation but a modified type II, using full pins only in the most proximal and distal position or positions, and using half pins in between is technically easier without sacrificing too much stability. Fixation pins with a positive thread profile or Duraface pins should be used. These should be applied using pre-drilling technique and slow speed power insertion. If the older Kirschner Ehmer or newer Securos clamps are used, the stainless steel connecting bars are contoured to the desired angle. A reinforcing bar applied from proximal to distal bilaterally will triangulate the construct and strengthen it. With the SK system, titanium or carbon fiber composite connecting rods are generally used and these cannot

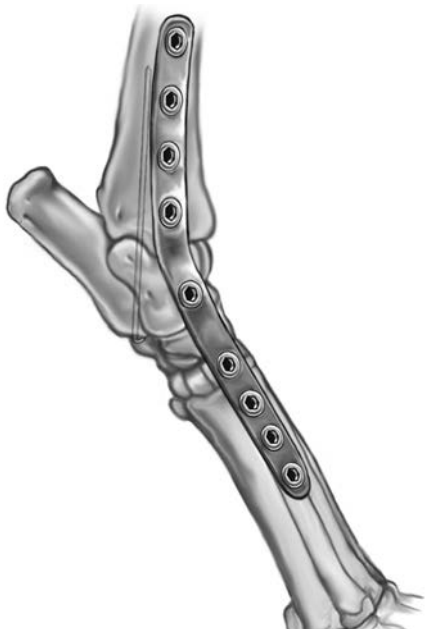


Figure 62-46. A plate can be placed on the cranial aspect of the tibia and tarsus including the third or fourth metatarsal bone. Plates are now available with smaller holes for the metatarsal bones.



Figure 62-47. A plate is available to be placed on the medial aspect of the joint. This does limit the angle of arthrodesis to 135 degrees but removes the plate from the compression side of the fixation. The medial malleolus can be shaved down to accommodate the plate if necessary.

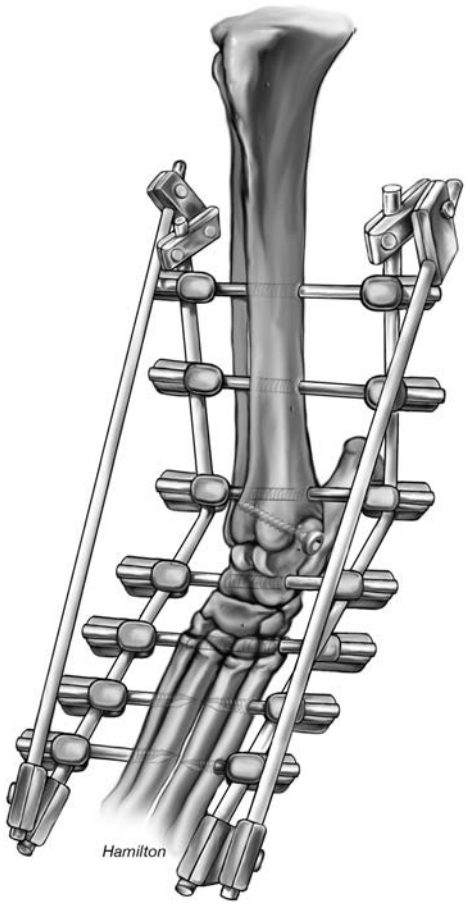


Figure 62-48. A type II external skeletal fixator is well adapted for use in fusing the hock. Compression should be applied across the arthrodesis and the connecting bars can be contoured or linked. Triangulating articulations can be added for bending resistance.

be contoured. Instead, modified SK connecting clamps can be used to create an adjustable articulation to create the desired angle between two connecting rods (Figure 62-49). The metatarsal bones form an arch and it is rarely possible to get a full-pin through all four. It is better to aim for the 2nd and 5th, or the 3rd and 4th metatarsal bones. Half-pins are a simpler way of securing the metatarsal bones. Compression should be placed across the arthrodesis site so ideally a full-pin should be placed in the talus and at least one of the pins in the tibia. Two to three pins should be placed in the tibia. The greater the number of fixation pins used, the less stress there will be on any individual pin and the less chance of pin loosening. As long as the frame is rigid and all the joints are spanned with compression across the arthrodesis site, the surgeon has some leeway in regard to pin placement sites. A third bar can be triangulated, spanning the cranial aspect of the frame for added strength. Ring fixators or hybrids also work well in this joint.

When an injury involves just the intertarsal or tarsometatarsal joints, only the affected joints need to be fused. When the plantar ligament ruptures causing hyperextension of the hock, the cartilage is removed between the fourth tarsal bone and the calcaneus, and a Steinmann pin is placed through the calcaneus, fourth tarsal bone and into the 3rd or 4th metatarsal bone. Cancellous bone is placed in the gap and a 20 or 18 gauge tension band wire is placed from a hole drilled in the calcaneus to a hole in the 4th tarsal or metatarsal bone (Figure 62-50). This bone is very dense and pre-drilling the hole for the pin facilitates pin placement. The proximal end of the pin is either countersunk or bent over but still can cause irritation. A laterally applied plate is a quick and very stable alternative. When there is a complete luxation of the proximal intertarsal joint, bone plate fixation is preferable (Figure 62-51).

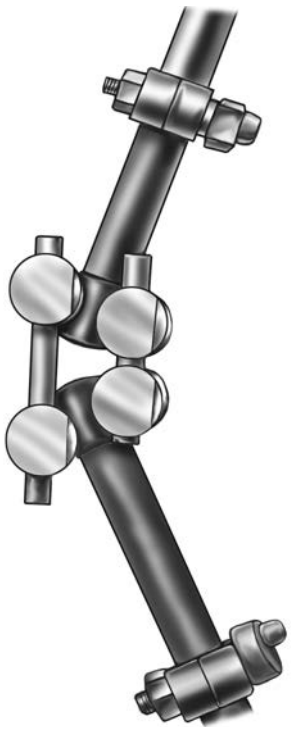


Figure 62-49. If SK clamps with titanium or carbon fiber bars are used a modified clamp can be used to span the joint.



Figure 62-50. Rupture of the plantar ligament can be treated with an intermedullary pin and tension band wire. The wire can be placed through a hole in the tuber calcei or around the proximal end of the pin before it crosses to enter a hole in the taral or metatarsal bone.

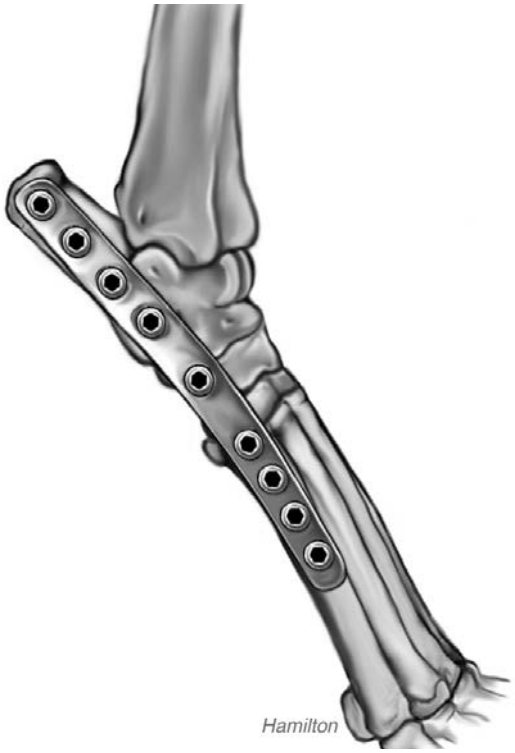


Figure 62-51. For unstable distal tarsal ot tarso-metatarsal luxations a laterally placed plate provides good fixation with little soft tissue irritation and is a good alternative to a pin and tension band.

With luxations or fracture-luxations of the intertarsal and tarsometatarsal joints, stress radiographs are helpful to accurately define the injured structures. Often combinations of pins, wires and screws can be used to stabilize these injuries. If the intertarsal luxation involves only the dorsal ligaments, weight bearing stabilizes the injury and coaptation alone will often suffice. If the instability is in one plane only, then screws and figure eight wire will stabilize the injury, but if two planes are involved, as in tarsometatarsal fracture luxations, cross pins and wire will be necessary for stability. It is always best to remove the cartilage and graft these partial fusions, but if the luxations involve only capsular and ligamentous disruption, it may not be necessary to remove the cartilage especially in smaller patients. Coaptation during healing is also a good idea due to the large weight bearing stresses encountered post operatively. The pins and wire can be removed once healing has occurred, usually in 8 to 12 weeks.

Suggested Readings

Gorse MJ, Early TD, Aron DN: Tarsocrural arthrodesis: Long term functional results. *J Am Anim Hosp Assoc* 27:231, 1991.

Section O

Orthopedic Bandaging and Splinting Techniques

Chapter 63

Commonly Used Bandages and Slings

Application of a Robert Jones Bandage

David W. Knapp

The materials necessary to apply a Robert Jones bandage include one to three 1 -lb rolls of absorbent cotton, 1- or 2-inch white adhesive tape, several rolls of 3- or 4-inch stretch gauze, one to three rolls of 3- or 4-inch elastic tape or self-adherent stretch tape, and a nonadherent dressing when indicated.

Application is begun by placing adhesive tape stirrups medially and laterally from the carpal or tarsal area distally (Figure 63-1A). Dog-earing each end or placing a tongue depressor between the tape ends aids in separating the stirrups later. Placement of a nonadherent dressing on any open wound or surgical incision is done at this time.

The next portion of the bandage is the application of the cotton. One begins distally and wraps proxi-mally, high into the axillary or inguinal regions (Figure 63-1B). The ends of digits 3 and 4 should be left exposed, and the cotton should be wrapped with enough tension to make the bandage tight, but not tense enough to cause the cotton to tear. The final bandage should convert an irregularly shaped leg into a uniform-diameter or stovepipe configuration, thereby allowing the bandage to apply even pressure over the entire length of the leg (Figure 63-1C).

After application of the cotton, even pressure is accomplished by wrapping from distal to proximal with 3- or 4-inch stretch gauze (Figure 63-1D). Each wrap should overlap the previous by about 50% its width, avoiding any formation of ridges and valleys, indications of uneven pressure. When wrapping the stretch gauze, one should apply enough tension to compress or reduce the size of the bandage adequately. In most cases, the final diameter of the bandage after the stretch gauze is applied is 40 to 50% of the original diameter.

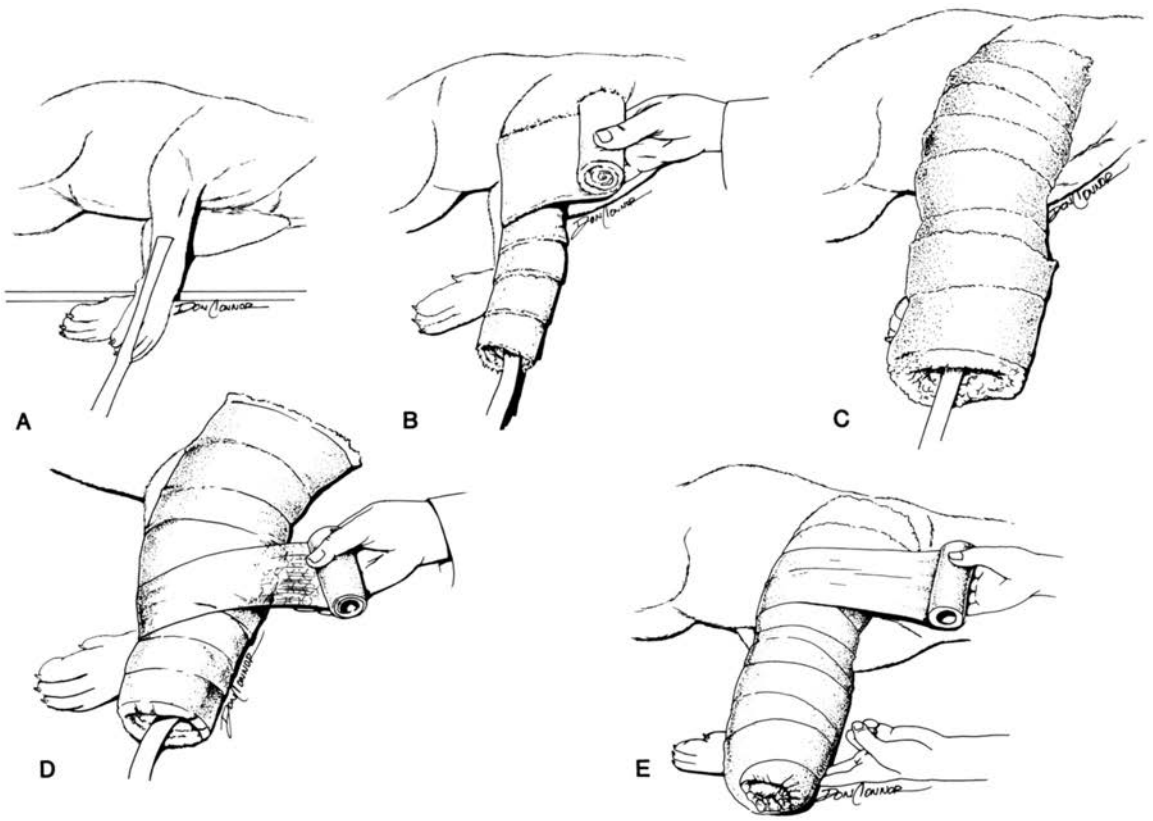


Figure 63-1. Application of a Robert Jones bandage. **A.** Placement of stirrups on medial and lateral aspects of paw. **B.** Wrapping with rolled cotton starting at distal end. **C.** Cotton padding in place. **D.** Application of stretch gauze, compressing cotton. **E.** Application of elastic tape or self-adherent stretch tape after stirrups are folded up, leaving only digits 3 and 4 exposed.

To complete the bandage, the tape stirrups are separated and are placed along the appropriate medial and lateral sides. Using either elastic tape or self-adherent stretch tape, the final layer is started, again distally, wrapping proximally and continuing to overlap each layer by 50% while taking care to maintain even compression. When this layer is completed, only the distal ends of digits 3 and 4 should be exposed (Figure 63-1E). If the toes are not visible, adequate amounts of the surrounding cotton should be removed to allow exposure of the digits.

The goal of the Robert Jones bandage is to provide immobilization while maintaining even compression over the length of the limb. Compression can be evaluated by tapping over the length of the bandage; a properly applied bandage sounds like a ripe watermelon when it is thumped. To obtain even compression may require several applications of the stretch gauze, beginning each wrap distally and continuing proximally to either the axillary or inguinal region. In smaller dogs and cats, cotton cast padding may be substituted for the roll cotton, thereby achieving a more uniform fit to the leg. A more uniform fit may also be accomplished by removing the paper insert in the cotton roll, tearing the roll in half, and wrapping with 6-inch widths rather than 12-inch widths of cotton strips. All layers of the bandage are wrapped in a lateral-to-medial rotation to allow for a neutral to slightly internally rotated position of the limb.

Postbandaging care should include keeping the bandage clean and dry and observing the exposed digits for swelling or coolness to the touch. If problems are noted, the bandage may have been improperly applied and should be removed and the leg reevaluated. If no signs of problems are evident, the Robert Jones bandage may be left in place for up to 3 weeks.

Ehmer Sling (Figure-of-Eight Sling)

Paul W. Dean

The Ehmer or figure of eight sling is a non weight bearing sling for the pelvic limb. A properly applied Ehmer sling maintains the leg in a flexed position with the coxofemoral joint abducted and inwardly rotated.

Indications

The Ehmer sling is used primarily to maintain the coxofemoral joint in a stable position following closed reduction of craniodorsal coxofemoral luxation. Maintenance of the coxofemoral joint in an inwardly rotated and abducted position provides for maximal coverage of the head of the femur by the acetabulum while periarticular fibrosis stabilizes the coxofemoral joint. Use of an Ehmer sling may also be beneficial in maintaining stability of the hip joint in the immediate post operative period following certain surgical procedures such as repair of fractures of the femoral head and neck, acetabular fractures, and to provide stability following open reduction of coxofemoral joint luxations.

Application Technique

The only material necessary to apply an Ehmer sling is a roll of porous, adhesive tape. I prefer to use 2" porous tape (Curity®, Kendal Healthcare Products Company, Mansfield, MA 02048) rather than elastic adhesive tape (Elastikon, Johnson and Johnson, Somerville, NJ 08876), as the elastic type tape is more prone to create a constriction if not applied loosely. Regardless of the type of tape material used, it is advisable to first unroll, or strip off, a length of tape then re-wrap it loosely so that when the tape is applied, there is less of a tendency to tape too tightly around the foot or thigh.

To begin placement of an Ehmer sling, the tape is first anchored to the metatarsal region of the foot by wrapping the tape loosely around the metatarsals. The tape is begun on the dorsal metatarsus, proceeds to the lateral and then plantar aspect of the metatarsus. The limb is then flexed, taking care not to hyperflex the hock joint, and the tape is continued up the medial aspect of the tibia, medial to the stifle joint and medially over the thigh muscles (Figure 63-2). The tape should not be passed up the medial aspect of the tibia, caudal to the stifle joint and over the lateral side of the thigh muscles as this predisposes the tape to slipping off the cranial thigh muscles (Figure 63-3). After the tape is passed up the medial aspect of the thigh muscles, it is brought over the cranial thigh muscles to the lateral side of the thigh and continues distally caudal to the stifle joint, medial to the distal tibia and hock, and passes under the plantar aspect of the metatarsals from medial to lateral (Figures 63-4 and 63-5).



Figure 63-2. Tape placed loosely around lateral metatarsus and brought up the medial side of the leg adhesive surface of tape facing skin.



Figure 63-3. Incorrect placement of tape predisposes the sling to slippage off the cranial aspect of the stifle.



Figure 63-4. Tape is continued from medial to lateral over the cranial quadriceps muscles to pass caudal to the stifle.

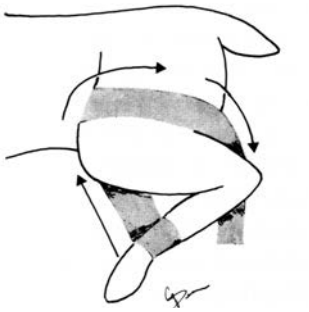


Figure 63-5. Tape continued from lateral aspect to pass medial to the hock and metatarsus and is then brought around the plantar surface of the metatarsus to the lateral side.

Two or three wraps of tape are continued in a manner similar to that previously described. Properly applied, the toes should point slightly inward, the hock joint should be rotated outward and the stifle and coxofemoral joint should be rotated internally. To provide maximal coverage of the femoral head by the acetabulum, abduction of the limb is provided by passing a length of tape from the plantar metatarsal region, over the lateral aspect of the flexed limb and around the abdomen where it is attached to a pre placed bellyband (Figure 63-6). Care should be taken to stay cranial to the prepuce with the bellyband in male dogs. If using an Ehmer sling to stabilize a ventral coxofemoral luxation, the limb is not abducted as this will predispose to re-luxation.

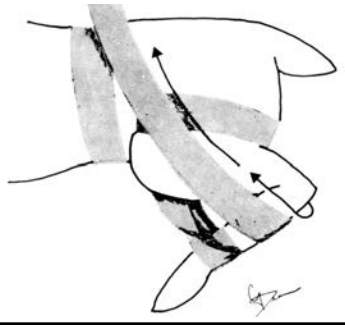


Figure 63-6. After completion of two to three wraps of the tape as previously described, the tape is brought up the lateral side of the leg and attached to the pre placed bellyband in order to maintain abduction of the hip joint.

Aftercare and Potential Complications

A properly applied Ehmer sling is well tolerated by most dogs. The sling should be left in place for 2 to 3 weeks following closed reduction of coxofemoral luxations and following open reduction of coxofemoral luxations using the trans acetabular pinning technique.[1] Immobilization of joints beyond 4 weeks should be avoided as potentially irreversible changes such as capsular and pericapsular contracture, proliferation of intracapsular connective tissue, and major cartilage alterations may occur.[2] Owners should be instructed to check the sling daily for slippage and to observe the toes daily for potential swelling. Should swelling of the toes be observed, the owner should be instructed to return the animal immediately to have the sling removed and re applied correctly.

The primary complication from a properly applied Ehmer sling is skin irritation from the tape. This is most noticeable over the cranial aspect of the thigh musculature, and will resolve with conservative management once the sling is removed. Occasionally, a short course of antibiotic therapy is used. In male dogs, the bellyband may produce irritation cranial to the prepuce or cause preputial swelling if it slips caudally; it should be monitored and adjusted as needed.

References

1. Tomlinson JL. Reduction of coxofemoral luxations. *In* Bojrab MJ (ed), Current Techniques in Small Animal Surgery (4th ed). Philadelphia 1998; Lea & Febiger, pp 1180-1182.

2. Herron AJ. Fracture disease. *In* Bojrab MJ (ed), Pathophysiology in Small Animal Surgery (2nd ed). Philadelphia 1981; Lea & Febiger, pp 697-699.

90°-90° Flexion Splint for Femoral Fractures

Dennis N. Aron

Introduction

Compromised stifle joint function is a frustrating complication of surgery on fractures of the femur. This process develops most readily when the limb is carried or is splinted in extension. This may be a result of tension created in the quadriceps muscle group after fracture reduction or splinting. The resulting abnormal gait and decreased weight-bearing of the limb can induce disuse osteoporosis, muscle atrophy, and articular changes. Periarticular connective tissue contracture and abnormal joint motion lead to irreversible degenerative joint disease of the stifle. In addition to these changes, growth disturbances such as hip subluxation and bone hypoplasia may develop when quadriceps contracture affects immature animals. A review of femoral fracture cases supports the type of circumstance considered to be high risk for development of stifle joint stiffness.[1] These "at risk" fractures are those that involve the immature patient and/or those with considerable bone comminution and soft tissue damage. When these situations exist and involve the distal third of the femur the risk is quite high. In addition, risk is high when multiple trauma results

in involvement of other bones and joints in the same limb and/or other limb(s) in conjunction with the femoral fracture.

Various treatment modalities have been used for correction of this problem. For the most part these treatments have been active and passive physical therapy modalities and surgical manipulations. The goals of these treatments are restoration of stifle joint and limb function, but significant clinical improvement is unpredictable and costly. Especially common for these types of cases is to attempt manual passive flexion and extension of the stifle after the development of stiffness. It has been suggested in a research study in rabbits that passive therapy only prevents stiffness if it is conducted continuously for more than 16 hours a day for three weeks. Further, it was noted that to do passive therapy for less time per day would actually produce more stiffness.[2]

Because of the great difficulty in treating stifle stiffness once it has occurred it is important to use techniques that contribute to prevention of stiffness. Undoubtedly, providing a stable osteosynthesis will encourage early weight-bearing and contribute to prevention of joint stiffness. However, even situations with stable fracture repair can develop joint stiffness.[1] This has been of clinical importance in humans; as a result, the Association for the Study of the Problems of Internal Fixation has recommended that all fractures of the middle and distal femur be held for the first five postoperative days with the knee positioned in 90 degrees of flexion.[3] A similar technique (90-90 flexion splint) has been evaluated in the dog and cat and appears to be a strong deterrent to the development of stifle stiffness with these types of cases.[1]

The 90-90 flexion splint needs to be applied in the immediate postoperative period to be effective and is not generally helpful if applied after development of stifle joint stiffness.[1] The amount of time the splint should be used for prophylaxis is empirical. However, to avoid the risk of developing stiffness in flexion the joint should not be held by the prophylactic splint for more than seven days. The splint is usually used for three to five days. Gravity may play an important role in allowing the good extension noted after only a day or two following removal of the flexion splint.

Technique

(Figure 63-7)

The only material necessary for application of the 90-90 flexion splint is a roll of elastic tape.[i] One can use a small amount of gauze under the tape to cover an incision. Using too much padding of any type will tend to lead to slippage of the splint. Apply the 90-90 flexion splint in a similar fashion to an Ehmer sling. However, unlike the Ehmer sling place both stifle and hock joints in approximately 90° of flexion, not maximal flexion. While holding the hock and stifle 90° begin by applying adhesive tape loosely around the metatarsal area. Direct the tape up the medial aspect of the tibia. Pass the tape to the medial side of the thigh then around the cranial femur onto the lateral thigh and return to the starting point. Repeat this two or three times attempting to place the tape high in the inguinal region at the top to prevent it from slipping off the cranial aspect of the thigh. Last, place tape strips perpendicular to the already applied tape to encircle the tibia from cranial to caudal to squeeze the tape and further prevent it from slipping. There is no effort, however, to maintain hip abduction as is recommended for the Ehmer sling. A properly applied 90-90 splint is well tolerated by most dogs and cats. Monitor the splint for areas of irritation and especially the toes for swelling. If the toes or distal limb starts to swell, the splint must be removed immediately. Irritation of the skin in the groin region may occur. This is usually minor and is managed conservatively following splint removal.



Figure 63-7. Photograph of a 90-90 flexion splint placed on a young dog with a comminuted distal femoral fracture stabilized with an IM pin - external skeletal fixator tie-in technique.

Suggested Readings

Aron DN, Crowe DT: The 90-90 flexion split for prevention of stifle joint stiffness with femoral fracture repairs. Am Anim Hosp Assoc 23:447, 1987.

References

1. Aron DN, Crowe DT: The 90-90 flexion split for prevention of stifle joint stiffness with femoral fracture repairs. Am Anim Hosp Assoc 23:447, 1987.

2. Gebhard JS, Kabo JM, Meals RA: Passive motion: the dose effects on joint stiffness, muscle mass, bone density, and regional swelling. A study in an experimental model following intra-articular injury. J Bone Joint Surg Am 75:1636, 1993.

3. Muller ME, Allgower M, Schneider R, Willenegger H: Manual of internal fixation: Techniques recommended by the A-O-groups. 2nd ed. Berlin: Springer-Verlag, 1979, 246.

[i]Elastikon™ Johnson & Johnson, New Brunswick, NJ 08933

Chapter 64

Commonly Used Splinting and Casting Techniques

Splinting Techniques

Douglas N. Lange and Kenneth E. Bartels

External fixation by coaptation implies the use of casts, splints, or bandages to provide immobilization of an injured limb. These devices approximate the shape of the limb to which they are applied, and they provide stable fixation of bone fragments without the need for surgical implants at the fracture site.

External fixation for orthopedic injuries in veterinary medicine offers distinct advantages over open reduction and internal fixation. In most instances, tissue and vascular trauma is reduced, the risk of infection is decreased, and the cost of application can be much lower than that of surgery.[1] Careful case selection is required to achieve successful treatment of fractures with external coaptation. In general, these devices are best used in young patients (less than 1 year of age) that tend to heal rapidly with transverse or incomplete fractures distal to the elbow or stifle. External coaptation best neutralizes bending forces on fractures away from joints, rather than near joints, and requires stabilization of the joint above and the joint below the fracture.[2] Therefore, coaptation does have disadvantages resulting from long-term limb immobilization that can cause severe disuse atrophy and possible "fracture disease." The use of a below-the-knee cast bracing (Sarmiento-type) system has been advocated; if properly used for certain tibial fractures, this type of system may reduce problems associated with total immobilization of the hind limb.[3,4] If a coaptation device is incorrectly applied, loosens, or becomes wet, skin necrosis and even gangrene can result. Certain cases of multiple or severely comminuted fractures are best managed by internal fixation techniques, because precise anatomic reduction and adequate neutralization of forces acting on the fractures cannot be achieved with external coaptation.

Indications

Coaptation splints are commonly used for immobilization of simple transverse fractures of the radius, ulna, fibula, metacarpals, metatarsals, and phalanges. They can also be useful for immobilization of certain joints, such as the stifle, after traumatic injuries or surgical stabilization.[2,5] With most fractures, however, use of both internal fixation and external coaptation combines the disadvantages of both and, in general, should be avoided whenever possible.[1]

Temporary coaptation devices usually are indicated in the acutely traumatized animal for prevention of edema, relief of pain, reduction of subsequent damage to soft tissue, wound protection from further contamination, prevention of development of closed fractures into open fractures, and fracture stabilization. Robert Jones bandages, coaptation splints of various materials, Schroeder-Thomas splints, tape hobbles, Ehmer slings, Velpeau slings, and nonweightbearing slings have been described for temporary immobilization as well as for definitive immobilization of certain orthopedic injuries.

The choice of coaptation device depends on each individual case and circumstance. The coaptation device may serve as a temporary splint for traumatic injuries while waiting for definitive internal fixation, as a primary treatment of certain fractures, or as an adjunct to internal fixation or ligament repair.[1,2] Cost is another important aspect that must be considered as well as the availability of materials required for different coaptation devices.

General Application Guidelines

A few general guidelines are relevant to application of all types of coaptation splints and casts. Depending on the animal's physical condition and the severity of the orthopedic problem, application of coaptation splints or casts is best performed with the patient sedated or under general anesthesia. When the patient's physical status precludes the use of chemical restraint, traction and excessive manipulation of the limb must be kept to a minimum.

Use of Stirrups

Application of adhesive tape on the cranial and caudal surfaces of the foot to form "stirrups" is usually necessary so the limb can be attached to the splint or cast securely (Figure 64-1A). In some instances, one should fix the strips of adhesive tape medially and laterally on the limb; this has been recommended for application of a full-encircling cast.[6] When lateral and medial stirrups are used, they must be incorporated into the lateral and medial sides of the cast, respectively, to avoid excessive pressure and possible skin necrosis over the outer distal metatarsal or metacarpal epiphyseal areas.[7] Encircling bands of tape should never be used on an animal's foot because they can cause irreparable vascular damage and skin necrosis.

If problems are encountered in attaching the tape to the foot, the skin can be dried with alcohol to increase the holding capacity on the foot. Some veterinarians spiral a piece of adhesive tape around the cranial and caudal tape pieces to increase fixation of stirrups to the skin.[8] Two to three overlapping layers of elastic gauze (Kling or Sof-Kling, Johnson & Johnson Medical, Inc., Arlington, TX) applied snugly and evenly over the stirrups has also been used without problems to prevent the tape stirrups from slipping (Figure 64-1B). Good judgment must be used during application of these gauze layers to prevent vascular compromise. Tape application over the carpal pad can cause mild irritation to this structure at the time of tape removal, but it is usually not severe.

A technique described specifically for cats uses longitudinal "anchor" strips of adhesive tape applied medially and laterally on the leg, with the tape ends extending proximal and distal to the bandage or splint. The exposed ends of the tape anchor strips are reflected back on the bandage and then are covered with a second layer of bandaging material, which locks the anchor strips on the bandage.[9]

Use of Padding

The padding layer of the bandage provides protection, absorbency, and minimal support to the limb, depending on the thickness of the padding layer. The use of padding before cast or splint application may ensure patient comfort, but when used inappropriately or in excess, it may actually decrease a device's ability to provide adequate immobilization. Excessive padding, hair, and soft tissue structures increase the distance between the rigid part of the coaptation device and the rigid part of the limb (bone), and this can decrease the stiffness and effectiveness of the cast or splint. Therefore, long hair should be clipped, but not shaved, before bandage placement, and adequate cast padding should be applied to provide comfort and to prevent skin irritation. Hohn has stated that properly applied cast padding actually enhances fracture fixation by compensating for slight tissue shrinkage after cast application.[6]

One or two layers of orthopedic stockinette often are adequate; in some cases, incorporation of hair with the encircling plaster during the cast application may provide enough padding to prevent chafing and pressure sores as well as slippage. Removal of a plaster cast in which hair is securely incorporated can be difficult, however. Although some veterinarians apply small pieces of cotton between the toes before cast or splint application, an excess of padding can lead to additional vascular compromise.

Cast padding is applied, beginning at the toes, by overlapping half of the roll's width as it is unrolled; it should be wrapped snugly but not tightly (See Figure 64-1B). Cast padding applied in this manner provides two layers of padding, which is normally adequate. Pressure points over humeral or femoral condyles, olecranon, tuber calcis, or carpal pad may be padded with an extra piece or two of padding, although Swaim and colleagues noted that applying full-length cast padding provided the best form of protection from dermal pressure injury.[10]

Limb Positioning

During application of any coaptation–in particular plaster, fiberglass, and thermolabile plastic casts–for immobilization of a front or rear leg, the limb should be placed in a functional position while the material is still moldable. The rear leg should be kept in a normal position with the hock slightly flexed. When the casting material is conformed to the shape of the front leg, the carpus should be placed in slight flexion (15°) and deviated medially by 15° (Figure 64-2). This positioning helps to prevent a valgus deformity, which otherwise could occur during manipulation because of the normal laxity of the radial carpal joint or as a result of eccentric growth of the radius and ulna in the immature patient. External rotation of the metacarpus should be avoided, and the foot should be kept in a neutral position.[4,11] The old adage expressed by some experienced clinicians, "crooked leg in, straight leg out; straight leg in, crooked leg out," succinctly summarizes the preceding guidelines concerning proper limb position during cast application.

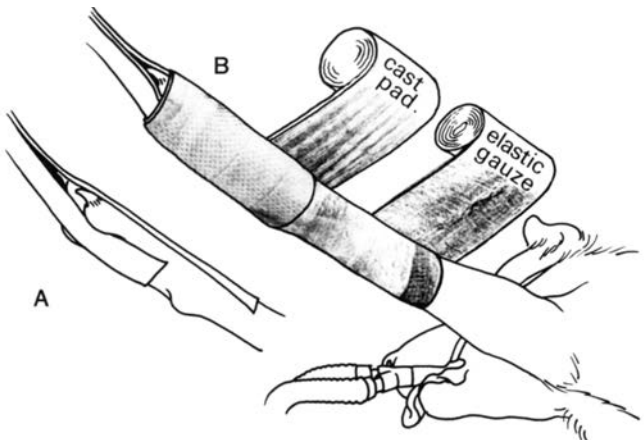


Figure 64-1. A. Application of adhesive tape stirrups on the cranial and caudal surfaces of the foot. **B.** Application of elastic gauze over the adhesive tape stirrups followed by overlapping layers of cast padding.

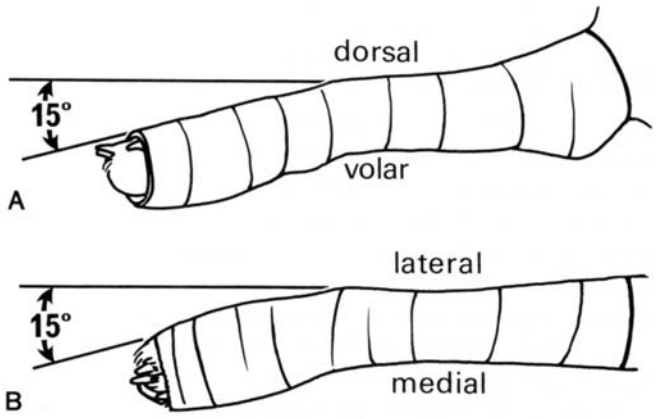


Figure 64-2. Proper positioning of the front leg for application of a fully encircling cast. The carpus is flexed slightly and is deviated medially.

Coaptation Splints

Coaptation splints consisting of various rigid materials are used to approximate the shape of the limb to which they may be applied. In general, they should not be used for immobilization of the humerus or femur. Pre-made commercial splints consisting of plastic or aluminum are known as Mason metasplints or spoon splints. They are applied over padding on the caudal aspect of the limb. Because the limb is curved and the splint is straight, adequate padding is necessary to avoid soft tissue problems, but it may result in poor immobilization. Molded splints of plaster, water-activated fiberglass, or thermolabile plastic can be fitted to the limb almost perfectly. For this reason, they seem to be tolerated better by the patient and cause fewer soft tissue problems during long-term use than Mason metasplints.

Preformed Splints

Indications

Metasplints for the front or rear leg are primarily indicated for fractures of the distal radius and ulna, fracture-dislocations of the carpus or tarsus, and fractures of the metacarpal or metatarsal bones or phalanges. Stabilization of proximal radial or ulnar fractures usually is not adequate with these devices. Generally, the elbow joint cannot easily be immobilized without using a spica configuration over the shoulder.

Application Technique

Adhesive tape stirrups are applied on the cranial and caudal aspects of the paw, with the cranial tape extending beyond the paw 2 to 3 inches farther than the caudal tape. The tape ends are then pressed together. A piece of precut cotton is applied to the back of the paw and antebrachium, or the leg is wrapped with at least two layers of cast padding, even if the splint is foam padded. The splint is snugly secured to the limb with elastic gauze by wrapping the leg with firm conforming pressure beginning at the toes and extending proximally up the limb. The stirrups are reflected up the caudal aspect of the splint and are secured with tape or another layer of elastic gauze (Figure 64-3A). The "gauze-covered" splint is covered with adhesive tape, elastic tape (Elastikon, Johnson & Johnson, Medical, Inc.), or conforming elasticized tape (Vetwrap bandaging tape, Animal Care Products/ 3M, St. Paul, MN) (Figure 64-3B). If the splint extends only to the elbow joint, a V-shaped section can be cut from the cranial aspect of the bandage material just below the joint to prevent pressure necrosis in that area (Figure 64-3C).

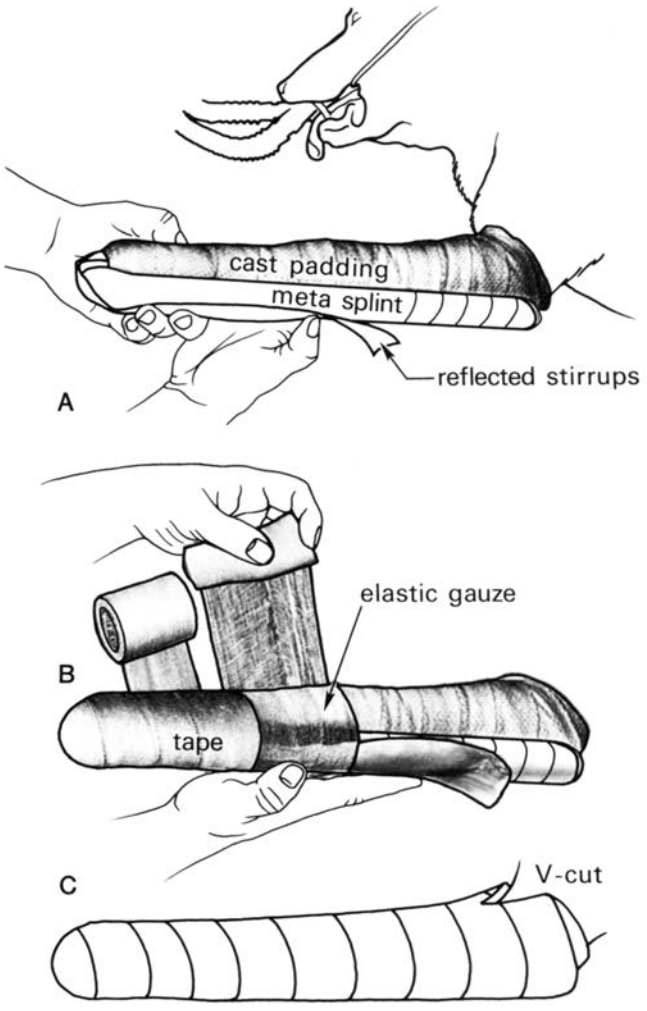


Figure 64-3. Application of aforeleg Mason metasplint. **A.** Stirrups are reflected proximally and are secured to caudal aspect of metasplint. **B.** Metasplint is secured to the limb with overlapping layers of elastic gauze followed by application of adhesive or elastic tape. **C.** A V-shaped section is cut from the cranial aspect of bandage material at the elbow joint to prevent pressure necrosis.

Some clinicians apply metasplints by an alternative method that does not involve use of tape stirrups. With this method, slippage of the splint is prevented by wrapping tape proximally around the elbow to prevent flexion (Figure 64-4). The toes are left exposed, so circulation can be assessed.

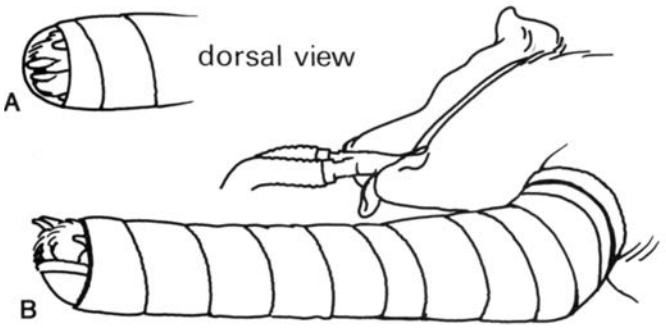


Figure 64-4. A. and **B.** Application of a foreleg Mason metasplint without the use of adhesive tape stirrups.

Molded Lateral Splints

Indications

A molded splint applied laterally on either the forelimb or the rear leg can provide immobilization of the elbow joint or stifle, respectively. It can also stabilize less severe fractures of the radius, ulna, tibia, and fibula. This type of coaptation can be particularly helpful in providing protection from bending forces after internal fixation or joint stabilization. The casting material can be extended over the shoulder or hip as a modified spica to provide partial joint immobilization.

Application Technique

Adhesive tape stirrups may not be necessary for application of this type of splint, especially if it extends proximally to include the shoulder or hip. The patient is placed in lateral recumbency with the injured limb positioned uppermost. The limb is padded with two layers of cast padding beginning at the toes and ending at the axilla or inguinal area.

If the shoulder or hip is to be immobilized through the use of a modified spica splint, the layers of padding should encircle the chest wall or pelvis, respectively. For splint application on the front leg, the padding creates a figure-of-eight pattern around the thorax and the affected limb, but the padding and the next layer of conforming gauze are carried behind the opposite axilla (Figure 64-5A). For a hip spica, the cast padding and conforming gauze applied to the affected leg and the opposite limb create a figure-of-eight pattern and can incorporate the proximal half of the opposite leg. When this configuration is used, the resulting coaptation device is called a "one-and-a-half leg" spica.[4] Care must be taken when applying a hip spica on a male dog so the prepuce is not included in the bandage. Spica splints are also restrictive, and some animals may not be able to stand without assistance.

Cast materials that can be molded to form a lateral splint are plaster, water-activated fiberglass, thermola-bile plastic,

or yucca board. Rolls of plaster, water-activated fiberglass materials, or thermolabile plastic can be cut to proper length or shape before application on the lateral aspect of the limb after activation. Elastic gauze is used to conform the softened splint material to the limb and to attach the splint to the shoulder and chest wall or the hip and thigh area. The gauze-covered splint is then bandaged with elastic tape applied in a pattern similar to that of the gauze (Figure 64-5B and 64-6).

Conformable materials used for molded lateral splints should be applied according to the manufacturer's directions and as each individual case dictates. A splint thickness of four to five layers of fiberglass or plaster casting material is usually adequate for the small animal patient. Prepackaged fiberglass splints are commercially available (Ortho-Glass Splinting System, Parker Medical Associates, Charlotte, NC) as well as unitized plaster splints (Specialist J-Splint plaster roll immobilizer, Johnson & Johnson Orthopaedics, Rayn-ham, MA). These products consist of multiple layers (8 to 15) of casting tape enclosed in a stockinette, which is packaged in a roll and can be cut to any length. Sheets of fabric impregnated with a thermolabile plastic (Orthoplast Splint Johnson & Johnson Orthopaedics) can be shaped according to a paper pattern of the affected limb and then softened in hot water (170°F) before application. Rolls of casting material composed of loosely knitted fabric impregnated with thermolabile plastic (Hexalite, Kirschner All Orthopedic Appliances, Marlow, OK) can be cut into splints as described earlier. The rigidity of this material requires that a flve-to six-layer splint be used to immobilize a limb adequately. To provide as much strength as possible, splint width of each coaptation material should be approximately one-third to one-half the outside circumference of the affected limb. In other words, the splint configuration is similar to a full-encircling cast cut in half in a cranial-to-caudal direction, with the lateral half of the cast used as the coaptation device.

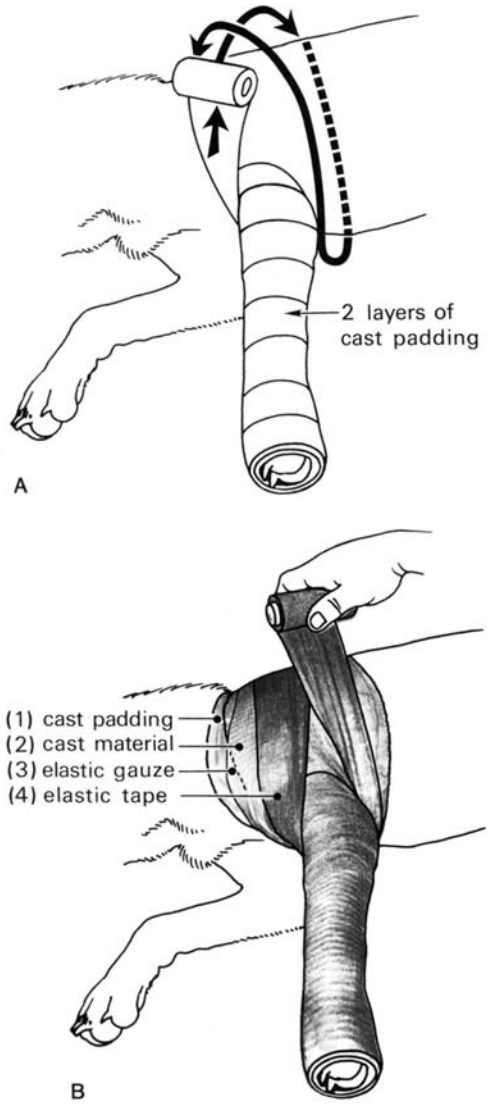


Figure 64-5. Application of a molded foreleg lateral splint. **A.** Cast padding encircles the affected limb and thorax. **B.** Molded conformable material is secured to limb with elastic gauze and elastic tape.

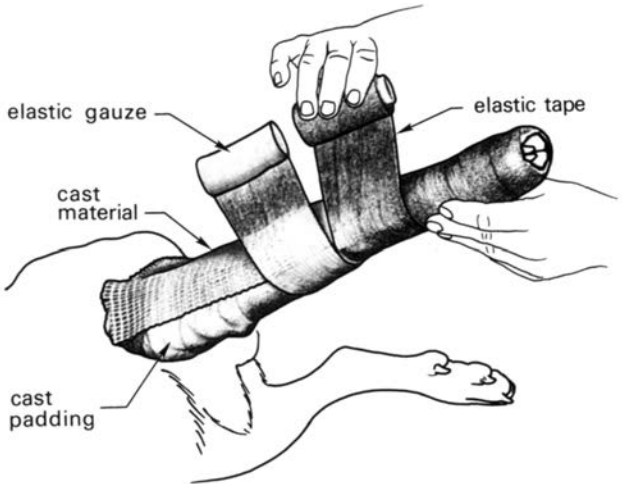


Figure 64-6. Application of a molded lateral splint to the rear leg.

Schroeder-Thomas Splints

Probably the most misused and misunderstood coaptation device today is the Schroeder-Thomas splint. When correctly applied, this splint can be an excellent means for immobilizing joints postoperatively surgery and for immobilizing certain fractures. This traction device can provide accurate and continued fixation of bone fragments by counteracting muscle forces and immobilizing parts of the skeleton. Under certain circumstances, skeletal traction can be provided when transfixation pins located in the areas of the femoral or humeral condyles are incorporated into the splint so traction from the splint on the distal end of the affected limb controls the distal fracture fragment.

Indications and Possible Complications

The use of Schroeder-Thomas splints may be indicated for some fractures of the radius, ulna, and tibia; avulsion fractures of the tibial tuberosity and distal malleolar fractures are exceptions. These splints have been used for fractures of the distal humerus (distal one-third), although not for condylar fractures, which require precise reduction of the joint surface to avoid degenerative joint disease. Nonarticular fractures of the distal femur (distal one-third) are considered by some clinicians to be amenable to reduction and immobilization with a Schroeder-Thomas splint, although supracondylar or condylar fractures must receive superb postreduction care because immobilization can

be difficult to maintain. The splint has been used for temporary immobilization of the stifle and elbow joints postsurgically.

Although a Schroeder-Thomas splint can be used successfully for more orthopedic conditions than are mentioned here, its inappropriate use can have disastrous consequences.

Application to a fracture of the proximal humerus or femur is definitely contraindicated because the ring of the splint must support and rest on the proximal fracture fragment. If the splint is used for proximal femoral and humeral fractures, the ring rests in the fracture site and acts as a fulcrum point, whereas the limb serves as the lever resulting in movement at the fracture site. In these circumstances, fracture disease (nonunion, quadriceps tiedown, joint stiffness) results. The splint often loosens with time because of the dynamic nature of its application. Circulatory problems causing tissue necrosis can develop as a result of loosening, swelling of the limb, or improper application. Pressure necrosis under the ring of the splint, edema of the scrotum, severe limb edema, and strangulation of the foot can occur.

Application Technique

Schroeder-Thomas splints should be custom-made for every individual case. Obviously, splint rods can be reused if they are the appropriate length for an individual patient. Because this type of splint is a dynamic traction device, it requires careful attention by the owner and periodic adjustment by the clinician. A Schroeder-Thomas splint is constructed of aluminum rods (1/8-, 3/16-, or 3/8-inch diameter) available in 6-foot lengths or 12-foot coils. For small dogs or cats, regular coat-hanger wire has been used. An average-size dog (30 to 40 lb) requires the 3/8-inch diameter aluminum rod. Commercially available plastic or wooden "ring" blocks usually are used to form the elliptic ring at the proximal end of the splint. Adhesive tape and combine roll or elastic gauze are used for application of the stirrups and the traction slings, respectively. A vise is helpful in shaping the rod, and bolt cutters or a hacksaw are necessary for cutting the rod. The shape of the splint is modified in relation to the specific leg injured, the bone that is fractured, or the joint that is involved. Traction application also varies according to the fracture, so the fragments can be separated and aligned (Figure 64-7).

The first step in construction of a Schroeder-Thomas splint is the formation of the upper ring at the proximal end of the splint. For the rear leg, the diameter of the ring is determined by measuring the distance between the cranial aspect of the wing of the ilium and the caudal point of the ischium; for the foreleg, the ring diameter can be determined by measuring the length of the scapular spine.[4] The bottom of the ring should be flattened to conform to the animal's axillary area or thigh. The bottom of the ring must bend medial to the vertical bars at a 45° angle at the middle of the ring. The ring can be bent, or the vertical bars can be bent to accommodate this angle. The lower half of the ring should be padded; however, excessive padding may cause irritation and circulatory problems and should be avoided. Applying tape to the ring with the adhesive side facing outward and then wrapping the lower half of the ring with thin strips of cotton or cast padding work well. The tape with the adhesive side inward is applied over the cotton loosely so the padding is soft and conforms to the inguinal or axillary region.

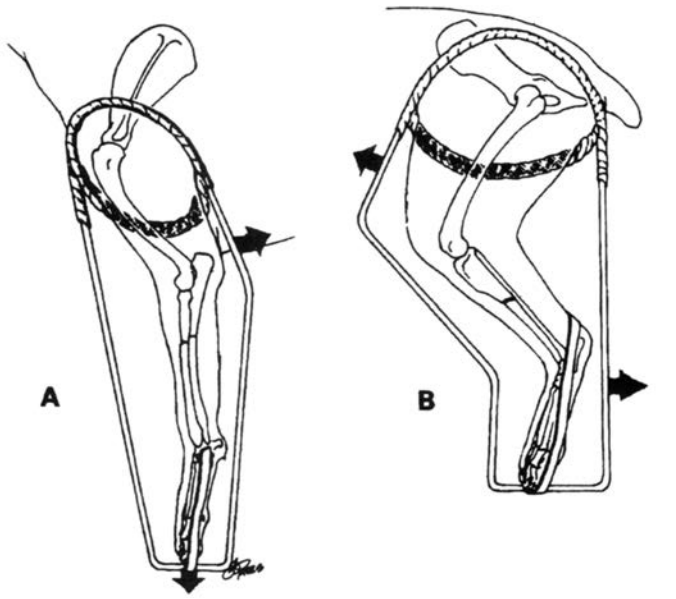


Figure 64-7. Configurations of a foreleg and hind leg Schroeder-Thomas splint and traction application for radioulnar fractures **A.** and tibial fractures **B.** (From Tobias TA. Slings, padded bandages, splinted bandages, and casts. In: Olmstead ML, ed. Small animal orthopedics. St. Louis: CV Mosby, 1995:108.

The vertical bars of the splint are sometimes left straight to accommodate certain fractures. However, each case should be considered on an individual basis and the splint configuration varied accordingly. For the rear leg, the front bar is bent to conform to the normal angulation of the stifle and hock; the rear bar is left straight. The angles of the front bar are varied according to the injury (See Figure 64-7). For the fore-limb, both bars are bent to conform to the angulation of the elbow. Although various configurations for humeral and radioulnar fractures have been described,[4,8,12] the configuration illustrated in Figure 64-7A has been used successfully and seems to be well tolerated by most animals.

The vertical bars are bent and connected with adhesive tape at the bottom of the splint. The length of the splint is determined by gently extending the limb so the end of the splint coincides with the end of the toes. The limb should not be stretched taut in a Schroeder-Thomas splint. The middle of the horizontal bar formed by connecting the vertical bars can be bent into an inverse-V shape so the adhesive tape stirrups fastened there will not be worn away by walking. A separate piece of aluminum rod can also be added to the bottom of the splint to protect the tape. The width of the distal end of the splint should be approximately three times the width of the paw. The finished splint should be completely wrapped as smoothly as possible with adhesive tape for cosmetic purposes. More important, this procedure prevents slippage of traction slings. The completed splint is applied to the leg carefully, with the ring snugly placed in the axillary or inguinal area. The splint is secured initially to the distal end of the foot by means of an adhesive tape stirrup. For additional support, a spiral of tape ("barber pole") can be applied over the foot to help

secure the vertical stirrups. Wrapping tape circumferentially around the foot usually causes swelling and should be avoided. Cotton can be used to pad between the toes. The adhesive tape stirrups should not be used to apply traction.

Traction is applied by means of the combine roll or wide elastic gauze used to secure the leg to the vertical bars of the splint. Both products, but especially the elastic gauze, must be used with caution, because the application of excessive tension can cause necrosis or edema. Positioning of the traction slings depends on the nature of the fracture. For fractures of the tibia, the traction slings are placed around the hock joint first and then in the femoral area to provide traction on the tibia (See Figure 64-7B). For distal femoral fractures, the first traction sling is applied around the hock joint, and then one is applied around the proximal tibia to provide traction on the femur. Traction slings should be applied in such a manner that they provide adequate medial support to both the tibia and femur and avoid a valgus deformity of the limb.[4] For fractures of the front leg, a traction sling is first applied at the level of the elbow, pulling the humerus caudally. The second sling is applied at the level of the carpus, pulling it cranially, which increases the traction on the radius, ulna, or humerus. As Figure 64-7A illustrates, tension can be applied caudally on the radius and ulna; a support sling placed in the area of the distal humerus maintains even pressure on the limb and reduces motion.

The entire Schroeder-Thomas splint can be covered with orthopedic stockinette to protect the device.

Postapplication Care

Excellent client and professional care is essential in maintaining a Schroeder-Thomas splint after application. The limb must be kept dry and clean, and the animal must be confined. Scheduled rechecks should be performed on a weekly basis, and clients must be diligent in evaluating the device for loosening, irritation, or swelling of the limb. If mild edema does occur, the animal must be monitored carefully for the next 24 to 48 hours; the splint may have to be adjusted or removed if this swelling persists or becomes more severe. Clients must be informed that reevaluation of the device whenever one suspects a problem is essential for proper splint management.

Tape Hobbles

Tape hobbles have been advocated as a method of protecting an injured limb and preventing additional trauma. This device can limit rotational stress on the limb and can aid in preventing stresses to proximal humeral or femoral fractures. It can also prevent excessive adduction or abduction of limbs with scapular or pelvic fractures. Hobbles must be used with caution when any possibility of vascular impairment or swelling in the areas of the metatarsus or metacarpus exists. The first step in application of tape hobbles is wrapping of two or three layers of cast padding around the metatarsal or metacarpal areas. Adhesive tape, 1 or 2 inches in width (depending on the size of the dog), is carefully wrapped around the paw to form a sling. One must not wrap the tape tightly around the paws. Overlapping the tape ends unevenly to form a "tab" from each foot should be the desired goal. The two tape tabs are joined with additional stirrups of tape. Usually, the distance between the feet is about that of a normal standing position for that animal, which should allow for proper freedom of movement (Figure 64-8).

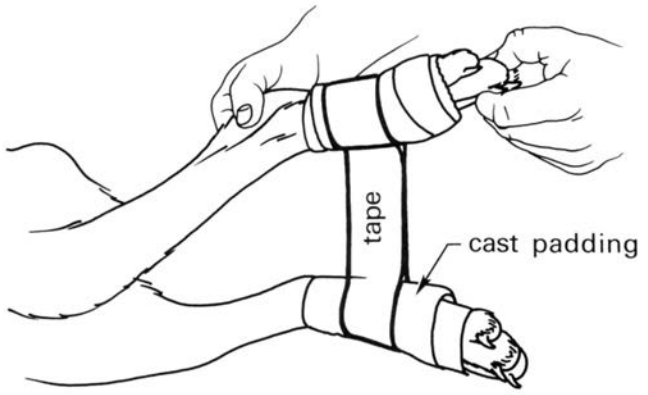


Figure 64-8. Application of hind leg tape hobbles.

Velpeau Sling

The Velpeau sling is used for immobilization of the shoulder joint postsurgically, for stabilization of the shoulder joint after closed reduction of luxations, for immobilization of scapular fractures, and for other conditions that require a front leg to be non-weight-bearing. A Velpeau sling should not be used on animals with oblique fractures of the distal humerus because compression by the sling may result in overriding of the fractured fragments and damage to the radial nerve. Olecranon fractures are also not amenable to this type of sling. A Velpeau sling is made of elastic gauze (2, 3, or 4 inches wide, depending on the size of the animal) or combine roll. It is started by loosely wrapping the conforming material around the paw in a lateral-to-medial direction. The wrap is continued laterally over the affected limb and shoulder and is placed around the thorax and behind the opposite axilla (Figure 64-9A). With the elbow, carpus, and shoulder joints flexed, the wrap is continued to the starting point. Several more layers of conforming material are applied in a similar pattern, but these layers enclose the elbow and paw (Figure 64-9B). Covering the entire limb prevents the lower limb or elbow from being forced out of the bandage if the animal tries to extend or flex the leg. The entire bandage is then covered with elastic tape in a similar manner.

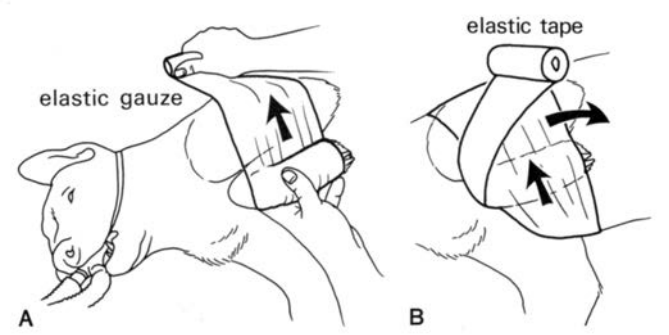


Figure 64-9. Application of a Velpeau shoulder sling. **A.** Elastic gauze is wrapped around the paw and is continued laterally over affected limb with flexed elbow, carpus, and paw. **B.** Several additional layers of elastic gauze are applied and enclose the elbow and paw; the sling is then covered in a similar manner with elastic tape.

The clinician must make the client aware that if the sling loosens and slips, besides the loss of immobilization, disastrous vascular impairment can occur. The animal should be strictly confined for the duration of the bandage's application. Animals usually tolerate the sling well, but it should be checked on a weekly basis. If it is used more than 2 weeks for immobilization, joint contracture can occur because the shoulder, elbow, and carpal joints are held in severe flexion.

Postapplication Management of Splints, Casts, and Slings

After application of any splint, cast, or sling, the limb should be observed every 4 to 6 hours to be certain that the device has been applied correctly. If it is constricting vasculature or lymphatic drainage and causing the proximal or distal aspects of the limb to swell, the device should be removed immediately and reapplied. At the time of discharge, clients must be educated in the proper care of the coaptation device. The splint or cast should be kept dry at all times. Cornstarch or talcum powder can be used to prevent chafing and pressure sores where the device irritates the axillary or inguinal areas.

Clients must feel free to seek professional advice concerning the coaptation device. If any of the following problems should develop, the animal must be examined as soon as possible:[4]

1. Any sign of excessive discomfort
2. Any changes in position or shape of the splint or cast on the leg
3. Any unusual foul odors coming from the splint or cast
4. Any unexplained soiling of the splint or cast that was not present previously
5. Any sores that develop at the top of the splint or cast that do not respond to talcum powder or cornstarch application
6. Swelling of the toes or the leg above the coaptation device
7. Inappetence, depression, or fever in the animal
8. Any excessive chewing of the splint or cast

No splint or cast can be worn in complete comfort by an animal. Minor licking and chewing can be expected; however, when an animal continues to mutilate the device, the device should be rechecked. If it has been properly applied and the animal continues to chew the splint or cast excessively, properly applied chemical or mechanical restraint devices may be needed separately or in combination.[13]

References

1. Tomlinson J. Complications of fractures repaired with casts and splints. Vet Clin North Am 1991;21:735-744.

2. Leighton RL. Principles of conservative fracture management: splints and casts. Semin Vet Med Surg 1991;6:39-51.

3. Manziaro CF, Manziaro JR. Walking plaster cast for repair of tibial fractures in dogs. J Am Vet Med Assoc 1970;156:581.

4. Nunamaker DM. Methods of closed fixation. In: Newton CD, Nunamaker DM, eds. Textbook of small animal orthopedics. Philadelphia: JB Lippincott, 1985.

5. DeCamp CE. External coaptation. In: Slatter D, ed. Textbook of small animal surgery. 2nd ed. Philadelphia: WB Saunders, 1993.

6. Holm RB. Principles and application of plaster casts. Vet Clin North Am 1975;5:291-303.

7. Leighton RL. Complications from mismanagement of fixation devices. Vet Clin North Am 1975;5:273.

8. Knecht CD, Allen AR, Williams DJ, et al. Casts and splints for small animals. In: Fundamental techniques in veterinary surgery. 2nd ed. Philadelphia: WB Saunders, 1981.

9. Robinson GW, McCoy L, Gili M. Feline bandaging and splinting. Feline Pract 1977;7:41.

10. Swaim SF, Vaughn DM, Spalding PJ, et al. Evaluation of the dermal effects of cast padding in coaptation casts on dogs. Am J Vet Res 1992;53:1266-1272.

11. Tobias TA. Slings, padded bandages, splinted bandages, and casts. In: Oimstead ML, ed. Small animal orthopedics. St. Louis: CV Mosby, 1995.

12. Knecht CD. Principles and applications of traction and coaptation splints. Vet Clin North Am 1975;5:177.

13. Seim HB, Creed JE, Smith K W. Restraint techniques for prevention of self-trauma. In: Bojrab MJ, ed. Current techniques in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1983.

Suggested Readings

Arnoszky SP, Blass CE, McCoy L. External coaptation and bandaging. In: Slatter DH, ed. Textbook of small animal surgery. Philadelphia: WB Saunders, 1985.

Brinker WO, Piermattei DL, Flo GL, eds. Principles of joint surgery. In: Handbook of small animal orthopedics and fracture treatment. Philadelphia: WB Saunders, 1983.

Leighton RL. Principles of conservative fracture management: splints and casts. Semin Vet Med Surg 1991;6:39-51.

Tobias TA. Slings, padded bandages, splinted bandages, and casts. In: Oimstead ML, ed. Small animal orthopedics. St. Louis: CV Mosby, 1995.

Principles and Application of Synthetic and Plaster Casts in Small Animals

Douglas N. Lange and Kenneth E. Bartels

The purpose of a cast is to provide rigid external coaptation to a reduced fracture or tenuous ligament repair so proper alignment and support are maintained during healing. Since 1851, the traditional plaster of Paris cast has been used when rigid external coaptation is required. Plaster casts provide an inexpensive means of providing molded external support, but they have the disadvantages of prolonged drying time, relative heaviness, decreased porosity, deterioration if exposed to moisture, and brittleness.[1] Synthetic casting materials have been developed and are available to veterinarians. The newer synthetic materials include polyurethane resin-impregnated fiberglass or polyester-cotton knit, and thermolabile plastic. These materials have the advantages of being lightweight, less bulky, immersible, radiolucent, and quickly "set," but they are more expensive and can be difficult to mold. Although newer methods of internal fixation (bone plates and screws) are indicated for most complicated orthopedic problems, closed reduction and external coaptation can be the treatment of choice for selected fractures and ligamentous injuries. Long leg casts are most appropriate for fractures below the elbow and stifle that only require bending and

rotational stability, such as incomplete or transverse fractures. The joint should be immobilized above and below the fracture in most cases, although functional below-the-knee casts have been used successfully.[2] Fractures of the humerus and femur require a cast in a "spica" configuration that immobilizes the shoulder or hip, respectively.

Plaster Casting Material

Characteristics

Plaster of Paris can be shaped and molded with ease and should usually be chosen for immobilizing severely displaced or unstable fractures that require a closer fit when coaptation is indicated. Because plaster is less expensive than the newer synthetic materials, it is indicated if frequent changes of casts are required. It is suitable for an initial or primary cast after fracture reduction when mild edema or swelling of a limb can be expected, because a change of cast is usually necessary after the edema subsides or becomes more severe.[3] Synthetic casts should be used with small patients requiring a lighter cast, with patients likely to abuse or moisten the cast, or when a plaster cast is likely to fail within the required time of immobilization.

Plaster of Paris is made of calcium sulfate crystals that have been reduced to powder and subjected to intense heat to expel the water. The resulting chalky white powder is then incorporated into gauze bandages. When water is added to the plaster, a crystallization process occurs, and the material hardens in an exothermic reaction. The time from which water is added to the plaster bandage until the material becomes hard is called its setting time. Plaster sets in 3 to 8 minutes, depending on whether it is fast or extrafast setting, the temperature of the water used, and the amount of water left in a roll after immersion. As the cast dries, the interlocking of the calcium sulfate crystals gives the plaster its strength. Further molding after a plaster cast has begun to set can prevent this interlocking of the crystals and may weaken the cast.

After the cast sets, the excess water must evaporate from the surface before the cast attains maximal strength. This period (curing time) while the cast is still "green" varies from 8 to 48 hours, depending on how large and thick a cast is, the type of plaster used, humidity, and air temperature. Excessive weight-bearing during drying of the cast should be avoided. A plaster cast is heavy at first, but it becomes lighter as the water in the plaster evaporates. The strength of a plaster cast is proportional to its thickness, but the smallest possible amount of plaster should be used. Placement of plaster "splints" or reinforcing strips of cast material along one surface strengthens a cast without increasing its entire mass; this technique is especially useful over areas where angulation occurs and the cast is susceptible to stress and fracture.

Application Technique

No special equipment is required for preparation and application of a plaster cast, and a standard cast cutter can be used for removal. Gloves should be worn during application, because plaster can be irritating to the hands. The patient and casting area in the hospital should be protected from dripping plaster by the liberal use of newspaper or a plastic drop cloth.

Preparation of plaster bandages involves immersing them in tepid water (70 to 75°F) for a few seconds until the bubbling from the roll has stopped; the plaster rolls then are squeezed to remove excess water. A plaster bandage should be unrolled on the leg, as it is applied, in an encircling manner with overlapping of half of the roll's width; it should never be stretched or tightened around the limb. It should be applied in a smooth, conforming manner so no thick or thin spots result. Tucks can be made in the rolls to change directions or to contour the plaster smoothly. Molding the cast by rubbing each section with wet hands before the plaster is set is essential for proper lamination, to produce a smooth surface, and for conforming the material to the proper configuration of the affected limb. During application, the cast should be supported by the palms of the hands and not indented with the fingers, because the "dimples" that result could produce pressure points on the interior, which can lead to skin excoriation.

Once the cast is dry, any rough edges should be covered with adhesive tape. The cast should not be washed, although a damp cloth can be used to remove excessive dirt if the residual moisture is wiped away afterward. Immersion of the plaster cast can cause deterioration of the plaster, resulting in skin irritation and maceration.

Some manufacturers (Duracast, Duraflex, Carapace, Caraflex, Cellona, Carapace, Inc.. Tulsa, OK; Gypsona, IMEX Veterinary, Inc., Longview, TX) supply plaster casting material in various widths (2, 3, 4, and 6 inches) and setting times (slow, medium, fast, and extrafast). For small animals, the 2- and 4-inch widths are the most versatile; fast or extrafast setting times are more appropriate for veterinary patients. Various setting times can be achieved by adjusting the temperature of the water in which the plaster bandages are immersed before application. Use of colder water increases setting times, and use of warmer water decreases it. Because plaster of Paris products are significantly less expensive than the newer synthetic materials, they will continue to be an essential moldable coaptation material.

Synthetic Casting Materials

Characteristics

Several newer synthetic cast materials are available as alternatives to plaster of Paris. These newer materials are recommended for use as primary casts for nondis-placed fractures with minimal swelling or for longterm wear when multiple cast changes are not required.[1,3-7] They can be divided into three classifications according to their composition: polyester-cotton knit, fiberglass, and thermolabile plastic. Manufacturers are introducing new materials every year, and each product obviously is recommended over a competitor's for many different reasons. Clinicians should be aware of the advantages and disadvantages of several of the materials and should choose the one with the characteristics they regard as the most important.

Polyester-cotton casting materials consist of a polyester and cotton, knitted, open-weave fabric impregnated with a water-activated polyurethane resin (Delta-Lite Fabric Casting Tape, Johnson & Johnson Orthopaedics, Inc., Raynham, MA). After immersion in cool tap water, this material is applied as casts or protective bandages. Casts formed from these products are lightweight, immersible, porous (permeable to water vapor), and fairly strong. Their biggest advantage is that they are virtually radiolucent.[4]

Fiberglass casting tapes consist of a knitted fiberglass fabric impregnated with a polyurethane resin that is activated by water (Delta-Lite Conformable Casting Tape and Delta-Lite "S" Fiberglass Casting Tape, Johnson & Johnson Orthopaedics, Inc.; Synthocast, Kirschner All Orthopedic Appliances, Marlow, OK; Scotchcast II, Orthopedic Products, Surgical Products Division/3M, St. Paul, MN; and Vet Cast and Vet Cast II, Animal Care Products/3M) The water-activated fiberglass casting tapes have met with success in veterinary medicine despite their expense. Differences among the products involve mainly their "handling" ability during application and the final "finish" or smoothness of the cast after it has set. Both these characteristics are primarily influenced by the knitted weave of a product; closely knitted materials generally are more conformable and easier to apply. Casts made from the fiberglass products are strong, lightweight, radiolucent, permeable to water vapor, and immersible in water.

The third type of synthetic casting material is an open-weave cotton fabric coated with high-density thermoplastic resin (Hexcelite, Kirschner All Orthopedic Appliances). A roll is immersed in hot water (65.5°C) for approximately 30 seconds until soft, it is drained of water, and it is applied when comfortable to the touch. The material begins to harden in approximately 3 minutes and achieves rigidity in 10 minutes. Specific areas can be remolded by application of heat with a 1000-watt portable hair dryer until the material is pliable. Thermolabile casting material is permeable to water vapor because of its open weave and does not exhibit an exothermic reaction while curing; it has a rough finish after application.

Bartels and associates evaluated some synthetic casting materials for their tensile strength, fatigue strength, exothermicity (evolution of heat during polymerization), permeability, radiolucency, and cost.[4] Although statistically significant differences were found for some of the criteria, no one material was best in all categories tested. Other "clinical" studies have revealed similar results.[8,9] They confirm that no one material is best in all areas because the newer synthetic casting materials, although easier to handle, are not as strong as the previous, tackier synthetic cast materials.

Packages of water-activated casting tape should be opened one at a time and used within 2 to 3 minutes because exposure to humidity in the air hardens the tape. Because unused packages can deteriorate on the shelf, sealed, unused rolls should be stored in a refrigerator to retard premature hardening. Most manufacturers date their products and recommend that the rolls of dated cast material be used within 6 months.

Application Technique

Water-activated synthetic casting products should be immersed in cool water (21 to 27°C), because warmer water temperatures greatly decrease setting time, and the heat produced during polymerization can be uncomfortable to the patient during cast application. Immersion in water can vary from 5 to 15 seconds, and the cast rolls should be drained of excess water. Gloves should be worn when handling any of the water-activated materials to protect the hands from any residue, which is difficult to remove. Four to five layers of material should be used, according to manufacturer's recommendations for weight-bearing casts in small animals.[4]

Techniques for applying synthetic casting materials differ from those usually recommended for plaster casting material. To change directions during application, tucks are made in plaster and thermolabile materials while fiberglass material is twisted. Synthetic materials are molded only in a horizontal motion to ensure lamination. Maximum bonding of the cast layers can be achieved by firmly blotting the exterior of the cast with the open palms in a rolling motion. Molding is achieved by maintaining a desired position for about 1 minute during the last few minutes of the setting period, which varies from 2 to 6 minutes, depending on the temperature of the water for activation. One manufacturer (Vet Cast, Vet Cast II, Animal Care Products/3M) supplies a hand cream to facilitate smoothing and molding of the cast, but water-soluble lubricating jelly (K-Y Lubricating Jelly, Johnson & Johnson Products, Inc., New Brunswick, NJ) can also be used for this purpose. Another manufacturer includes casting gloves that give the polyurethane resin-impregnated fiberglass substrate tack-free working properties (Johnson & Johnson Orthopaedics, Inc.).

Synthetic casts are lighter than their plaster counterparts and, when applied using polypropylene stockinette and polyester padding, they can be immersed in water. Synthetic casts are easier to keep clean because they can be washed with mild soaps, and hydrotherapy for postoperative orthopedic rehabilitation is possible with them. If inadequate drying of the cast occurs and the skin remains wet, irritation and possible skin maceration can occur. Hair dryers can be used to dry wet fiberglass casts.

Long Leg Cylinder Cast

Application Technique

If external coaptation is chosen for fracture repair, the fracture must be reduced before cast placement. Manipulation of the cast after placement causes creases and pressure points in the cast. General anesthesia facilitates fracture alignment and prevents the animal from disrupting reduction while the cast becomes rigid. At least 50% of the fracture ends should be in contact with each other to expect fracture healing, although perfect reduction is the goal for every fracture.[1] In addition, the limb should be reduced in a normal walking position to facilitate early usage of the casted limb and normal limb function after cast removal. The leg should be clipped and aseptically prepared as for surgery in case a closed fracture becomes an open fracture during

manipulation. The animal should be placed in lateral recumbency with the affected limb down; this positioning helps to prevent a valgus deformity at the fracture site during cast application.[2] The following description of application of a long leg cylinder cast to the front leg emphasizes points that can be recommended when using either plaster or synthetic casting materials:

Adhesive tape stirrups are applied to the cranial and caudal surfaces of the foot with the ends of the tape fixed to a tongue-depressor blade to facilitate separation later. The leg is elevated, and the stirrups can be fastened to an intravenous stand or held in an elevated position by an assistant. One or two layers of orthopedic stockinette are rolled up over the entire limb with no wrinkles and are snugly held by an assistant at the proximal end (Figure 64-10). The stockinette should be long enough to extend distally beyond the toes and into the axillary or inguinal region proximally. Synthetic cast padding that repels moisture is wound around the leg from distal to proximal as snugly as possible.

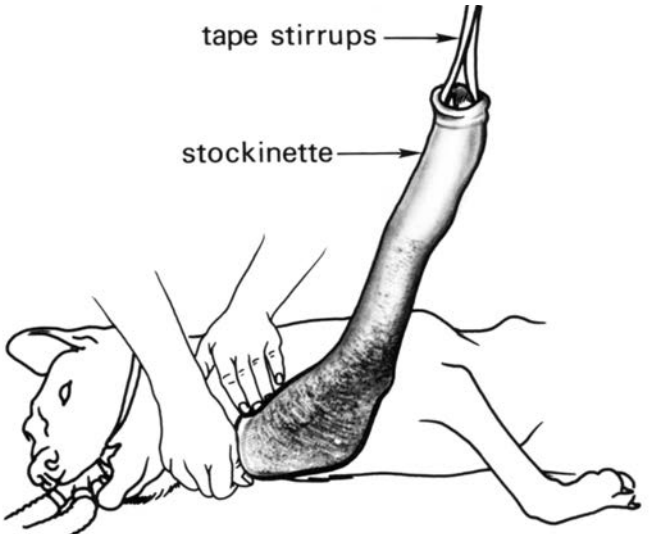


Figure 64-10. Animal placed in lateral recumbency with the affected limb down. Adhesive tape stirrups are applied to cranial and caudal surfaces of the foot; an orthopedic stockinette is rolled over the entire limb.

Wrapping the padding from cranial to caudal around the medial aspect of the limb helps to prevent supination when wrapping the forelimb.[10] Two layers are usually adequate, although extra padding may be needed at the proximal and distal aspects of the cast. Uniform full-length padding provides the best protection against dermal injury.[11] The cast material is rolled around the leg beginning at the distal end and overlapped by half the width of the roll. The material should be applied smoothly using even conforming pressure; smooth application is facilitated by rolling continuously around the limb in a spiral fashion and not raising the roll away from the skin.[5] Regardless of the casting material used, a cast should be supported with the palms of the hands and not the fingertips because indentations from the fingers may result in pressure sores. If applied properly, four layers of material are usually adequate for the average-size dog. The pads and toenails of the two central toes may be left exposed if there is no weight-bearing on the foot. If the animal is weightbearing on the limb, an aluminum rod walking bar can be applied to the end of the cast to prevent excoriation of toes and excessive wear to the cast.[1,2]

Longitudinal splints of cast material can be applied medially and laterally or cranially and caudally to strengthen the cast before the final layer of casting material is applied (Figure 64-11).

After application of the cast and while the material is still moldable, the leg must be positioned properly as described. The stockinette and padding at the ends of the cast and the tape stirrups are reflected over the ends of the cast. These are secured to the proximal and distal aspects of the cast with circular wraps of tape (Figure 64-12).

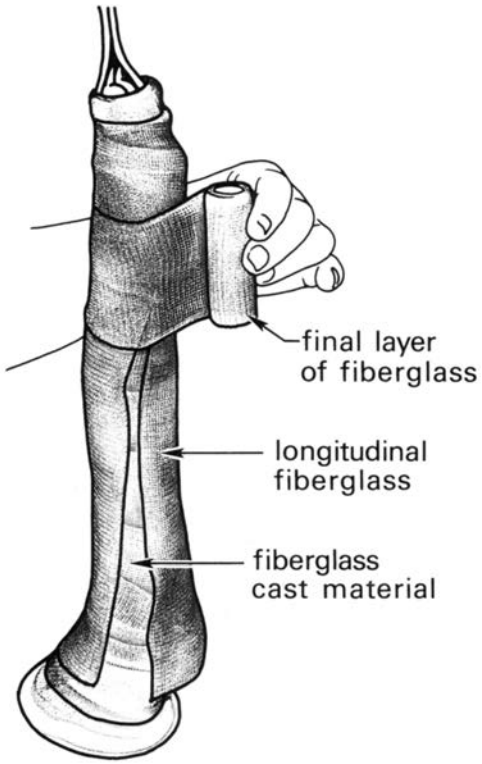


Figure 64-11. Longitudinal splints of cast material are applied cranially and caudally to strengthen the cast before rolling final layer of material. Layers of cast material are applied as shown.

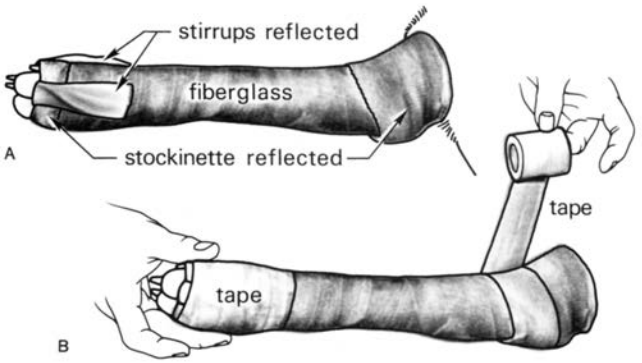


Figure 64-12. Final steps in cast application. **A.** Tape stirrups and stockinette are reflected back over the completed cast. **B.** Reflected stirrups and stockinette are taped to the distal and proximal aspects of the cast.

Postapplication Care

For plaster casts, the animal should be hospitalized for at least 24 hours after application to allow for adequate drying. Synthetic materials such as fiberglass can bear weight in as little as 20 minutes, but the animal should be observed closely for at least 12 to 24 hours to be certain that cast application has been correct and is being tolerated well. While the animal is in the hospital, the cast can be covered with a piece of stockinette to prevent soiling before discharge. Care of a cast is similar to care provided for any splint. The cast should be kept dry and as clean as possible. Routine rechecks should be scheduled, and particular care should be taken to educate the owner on cast management. At removal, the cast should be split longitudinally using a cast saw with short bites made perpendicular to the long axis of the cast, rather than sliding the cast saw down the length of the cast. Cutting a cast in this manner helps to reduce chances of damaging the underlying structures. Cuts should be made on either side of the limb, and the two "half-casts" should be removed carefully. Cast spreaders widen the groove made by the cast saw to facilitate cutting the deeper bandage layers with scissors. Windowing of casts should be avoided because of the danger of edematous tissue herniating through the window.[1,12] If the cast loosens, it should be removed and replaced, because immobilization is lost and pressure necrosis occurs as the cast slips and moves.

References

1. DeCamp CE. External coaptation. In: Slatter D, ed. Textbook of small animal surgery. 2nd ed. Philadelphia: WB Saunders, 1993.

2. Nunamaker DM. Methods of closed fixation. In: Newton CD, Nunamaker DM, eds. Textbook of small animal orthopedics. Philadelphia: JB Lippincott, 1985.

3. Marshall PD, Dibble AK, Walters TH, et al. When should a synthetic casting material be used in preference to plaster of Paris? A cost analysis and guidance for casting departments. Injury 1991;23:542-544.

4. Bartels KE, Penwick RC, Freeman LJ, et al. Mechanical testing and evaluation of eight synthetic casting materials. Vet Surg 1985,14:310.

5. Brinker WO, Piermattei DL, Flo GL, eds. Principles of joint surgery. In: Handbook of small animal orthopedics and fracture treatment. Philadelphia: WB Saunders, 1983.

6. Vet Cast Veterinary Casting Tape: Comparative study of commonly used cast materials. St. Paul, MN: Animal Care Products/ 3M, 1984.

7. Lane PL, Lee MM. New synthetic casts: what nurses need to know. Orthop Nurs 1982,1:13.

8. Bowker P, Powell ES. A clinical evaluation of plaster of Paris and eight synthetic fracture splinting materials. Injury 1992; 23:13-20.

9. Wilson DG, Vanderby R. An evaluation of six synthetic casting materials: strength of cylinders in bending. Vet Surg 1995; 24:55-59.

10. Tobias TA. Slings, padded bandages, splinted bandages, and casts. In: Olmstead ML, ed. Small animal orthopedics. St. Louis: CV Mosby, 1995.

11. Swaim SF, Vaughn DM, Spalding PJ, et al. Evaluation of the dermal effects of cast padding in coaptation casts on dogs. Am J Vet Res 1992;53:1266-1272.

12. Hohn RB. Principles and application of plaster casts. Vet Clin North Am 1975;5:291.

Suggested Readings

DeCamp CE. External coaptation. In: Slatter D, ed. Textbook of small animal surgery. 2nd ed. Philadelphia: WB Saunders, 1993.

Leighton RL. Principles of conservative fracture management: splints and casts. Semin Vet Med Surg 1991;6:39-51.

Tobias TA. Slings, padded bandages, splinted bandages, and casts. In: Olmstead ML, ed. Small animal orthopedics. St. Louis: CV Mosby, 1995.