# External Fixation in Small Animal Practice


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This book is dedicated to our wives, Bonnie, Gloria, and Judith, and is in memory of Colonel Charles (Chuck) Jones, November 4, 1952, to September 11, 2001

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*Tel:* +44(0) 1865 776868
Blackwell Publishing, Inc., 350 Main Street, Malden,
MA 02148-5018, USA
*Tel:* +1 781 388 8250
Iowa State Press, a Blackwell Publishing Company,
2121 State Avenue, Ames, Iowa 50014-8300, USA
*Tel:* +1 515 292 0140
Blackwell Publishing Asia Pty Ltd, 550 Swanston Street, Carlton
South, Victoria 3053, Australia
*Tel:* +61 (0)3 9347 0300
Blackwell Wissenschafts Verlag, Kurfürstendamm 57,
10707 Berlin, Germany
*Tel:* +49 (0)30 32 79 060



First published 2003 by Blackwell Science Ltd

Library of Congress
Cataloging-in-Publication Data
is available

0-632-05989-3

A catalogue record for this title is available from the British Library

Set in Sabon and Ocean Sans
by Prepress Projects Ltd
Printed and bound in Great Britain by
Butler & Tanner, Frome and London

For further information on
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www.blackwellpublishing.com

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# Introduction

The characteristics of a specific fracture will often dictate a single optimal repair method. However, much more often, a number of equally valid methods of management could be used, and, of these, linear external fixation is one of the more versatile treatment options available to the surgeon. The fundamental and unique characteristic of pins driven percutaneously into bone and supported externally is that they preserve an optimum biologic environment while at the same time providing a robust mechanical environment that can be varied, by the surgeon, according to the needs of the healing fracture. Veterinary external fixation continues to evolve, driven by both research and ever-increasing clinical experience. The result is improved technique, better instrumentation, and a continuing reduction in the incidence of complications and failure.

This book is a practical guide to the use of linear external fixators for the management of fractures in small animals. Divided into two parts, part I is a detailed review of the essential knowledge and technical detail that underpin the successful treatment of a clinical case. Much accumulated experience with veterinary external fixation was gained using the Kirschner–Ehmer (K–E) type of fixator systems, but recent years have seen the introduction of several second-generation veterinary fixator systems that address some limitations inherent in the K–E design and, at the same time, permit the surgeon to manipulate the fixator to respond to the varying biomechanical needs of a healing fracture. Three of these second-generation systems are described in detail – the Securos system, the IMEX-SK system, and the acrylic pin external fixation (APEF) system.

Chapters are arranged in chronological order following the patient through case selection, preoperative care, fracture reduction, pin placement, postoperative evaluation, and follow-up examinations. Part I concludes with a review of complications.

Part II is a collection of case studies – cases have been selected to cover the range of fracture types and fixator systems. Acknowledging that there is little virtue in publishing only perfect case studies, these are real, everyday cases presented "warts and all," with the intention of showing the practice of external fixation as it actually is. Not only a helpful guide for managing specific fractures, these case studies also act as a focus for discussion of treatment options and clinical decision-making. Unique is the number of follow-up radiographs, offering an insight into the normal radiographic appearance of healing and healed fractures.

Prior to collaborating on this book, the authors' experience of external fixation had evolved independently, yet, despite our disparate backgrounds and experience, we share remarkably consistent views on almost every aspect of the subject. However, we fully acknowledge that others may use methods different from ours with equally successful results. Although external fixators can be used successfully on a very wide range of fractures, many cases can be managed just as effectively by other means, and, in some cases, external fixators would be inappropriate.

The goal for this book will be accomplished if readers are directed to use external fixation appropriately and with good technique to the benefit of their animal patients.

# Part I
# THE PRACTICE OF EXTERNAL FIXATION

# Chapter 1
# Basics of External Fixation

## Components

An external skeletal fixator has two basic elements, regardless of the device or system being used. These fundamental components are the fixation pin and the connecting column (fixation frame).

*Fixation pins* are percutaneous devices that engage major bone segments. In the past, these were simple Steinmann pins with trocar points. These are held on the outside of the limb by the connecting column. Fixation pins can be further classified as half-pins or full pins, which defines both the design and method of use. A fixation pin always penetrates both cortices of a long bone as this provides the best interface with the bone. A half-pin penetrates the skin and soft tissues on one side of the bone, then the near cortex and far cortex of the bone to be stabilized, but no further. Half-pins are fastened to one connecting column on one side of the limb only. A full pin penetrates the skin and soft tissues on one side of the bone, the two cortices of the bone, then proceeds through the limb and out the opposite side. A full pin is fastened to two connecting columns, one on each side of the limb (usually medial and lateral). As a full pin is supported on both sides, it is much stronger than a half-pin.

The design and composition of fixation pins have developed to maintain the interface between the fixation pin and bone. Modern fixation pins in veterinary medicine are made from implant-grade, hardened stainless steel, and are much stiffer than conventional Steinmann pins. These pins resist bending and thereby protect the pin–bone interface. In the past, smooth pins were used in external fixation. In order to hold a bone fragment, smooth pins were placed at divergent or convergent angles. Modern fixation pins are threaded, increasing the pin–bone interface area. This also allows fixation pins to be placed parallel to each other and perpendicular to long bones, which is a mechanically superior orientation. Modern fixation pins have positive-profile threads, which means that the threads are raised above the core diameter of the pin. This preserves the core diameter of the pin, which greatly increases the stiffness and strength of the pin. Half-pins are threaded at the end, whereas full pins have threads at their center. In practice, fixation pins have become increasingly more like orthopedic screws in both form and function. The advent of superior fixation pins as well as improved pin insertion techniques has greatly reduced the incidence of pin loosening and expanded the application of external fixators to many of the most challenging fractures.

*Connecting columns* are located exclusively on the outside of the skin, and are fastened to and interconnect the fixation pins. The connecting column provides overall support for the fixation pins and fracture. It is in the design of the connecting columns that external fixator systems find their uniqueness. The traditional Kirschner–Ehmer (K–E) fixator connecting column consisted of clamps and straight connecting rods. The clamps connect fixation pins to one or more connecting rods. The Securos and IMEX-SK fixator systems also use clamps and connecting rods as the connecting column. However, both systems are superior to K–E fixators in terms of strength and versatility. These systems facilitate the use of positive-profile threaded pins and superior pin insertion techniques. Acrylic fixators, including the acrylic pin external fixation (APEF) system, use acrylic cement as the connecting column to both grip and interconnect the fixation pins. The diameter of the acrylic connecting columns can be increased to provide stiffness and can accommodate various pin placements, and acrylic columns also have the advantage that they can be contoured into complex bends.

More than one connecting column can be employed, and *linkage devices (articulations)* can be used to interconnect them. This increases the overall strength of the fixator. The bridge of a linkage device is often a steel rod. Double clamps are used with the Securos, IMEX-SK, and traditional K–E fixator systems. Specialized clamps or modified clamps accommodate two connecting rods. Standard clamps can be used if the linkage device is the diameter of a fixation pin. Linkage devices are also used with acrylic fixators. In this case, the acrylic serves to secure the linkage device to connecting columns, rather than clamps (Figure 1.1).

Each fixator system has additional components specific to that system. These components include augmentation plates, articulation rods, temporary reduction clamps, dynamization bolts, and modified clamps for making adjustable articulations when the fixator is used to immobilize a joint. These are discussed with each system.

## Nomenclature

A system of nomenclature for external fixators serves two purposes: it evokes a mental picture of what a given configuration should look like, which is helpful in clinical practice, teaching, and research; and it helps to predict the mechanical performance of one construct relative to others. One of the major advantages of external fixators is their ability to assume a wide range of different, and sometimes imaginative, configurations. The downside of this is that no classification system can encompass all possible assemblies. However, basic classifications are commonly used and accepted.

The initial description of a fixator must consider whether the construct is unilateral (type I) or bilateral (type II) (Figure 1.2). A unilateral or type I frame consists of half-pins and a connecting column that spans the fracture and connects the half-pins on one side of the limb. If a fixator is used alone, at least two and preferably more fixation pins per proximal and distal fracture segment must be used to stabilize a fracture.

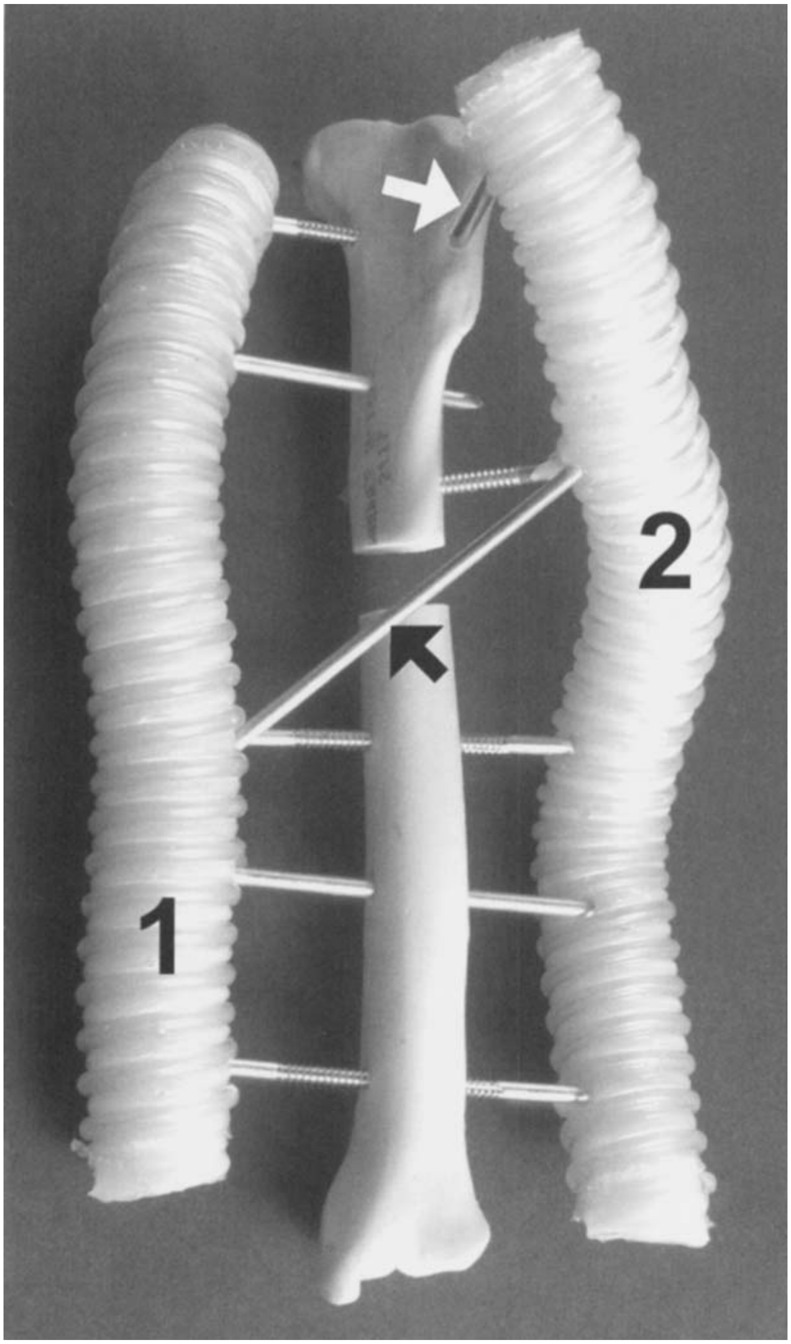



**Figure 1.1** Linkage devices using an acrylic pin external fixator. Craniomedial view of an acrylic frame fixator applied to the tibia. Frame 1 is medial and includes two half-pins proximally and three full pins distally. Frame 2 includes a cranially placed half-pin (white arrow) and a craniolaterally placed half-pin in the proximal segment and incorporates the three distal-segment full pins laterally. A diagonal linkage device (black arrow) interconnects the two frames.

A unilateral type I fixator with only one half-pin per major bone segment can be used as an ancillary device. If only one unilateral connecting column is used, the frame is designated type Ia.

Because the half-pins of a unilateral fixator are relatively weak, different strategies must be employed to enhance frame stiffness for the treatment of highly unstable fractures. The first would be to employ a more rigid connecting column in a type Ia fixator frame. This is achieved with modern fixation systems. If this is insufficient, two unilateral or type I frames (ideally at an angle of 90°, i.e. in orthogonal planes) can be applied, greatly increasing the overall fixator stiffness (Figure 1.3).

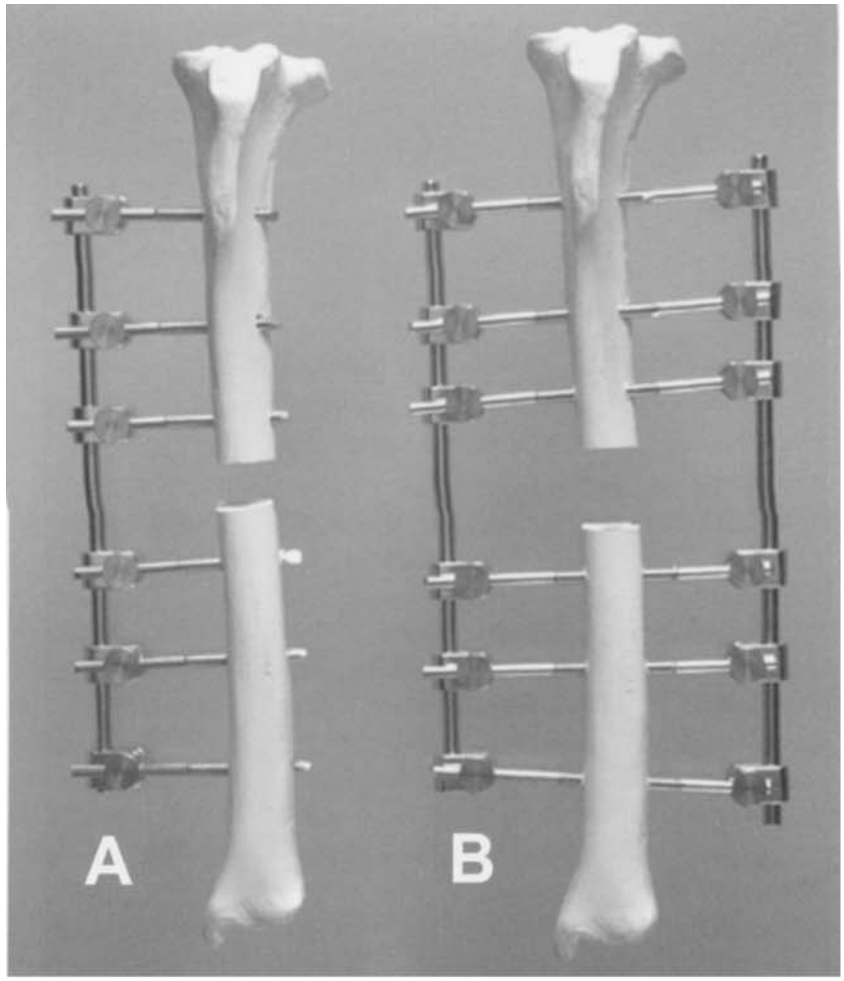



**Figure 1.2** Unilateral type I versus bilateral type II frames. (A) Unilateral or type I fixator with six half-pins applied to the tibia. (B) Bilateral or type II fixator with six full pins applied to the tibia.

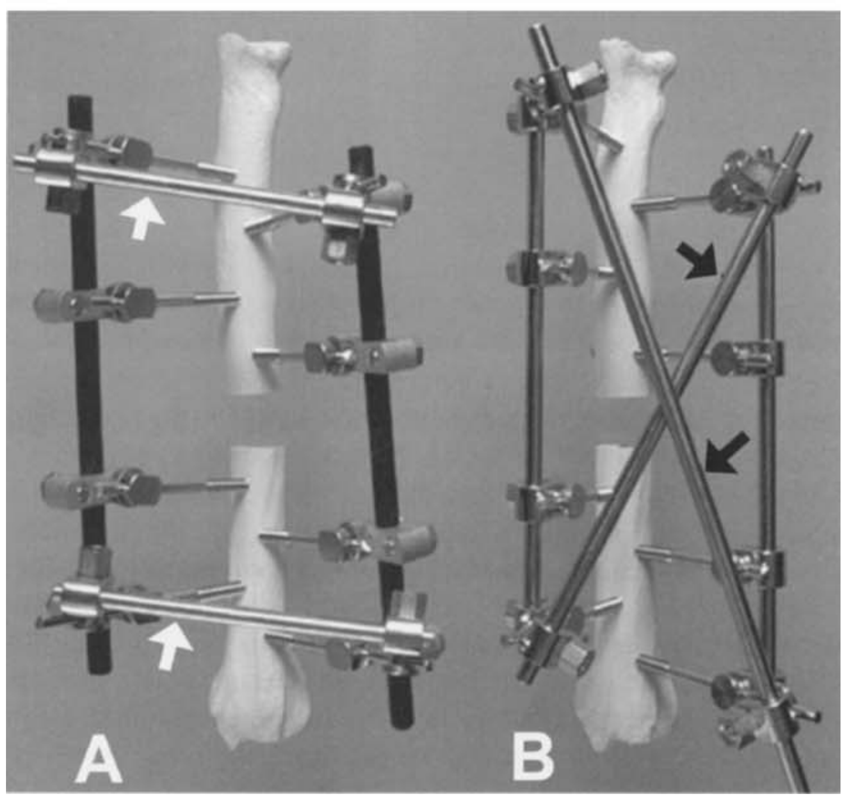



**Figure 1.3** Cranial views of type Ib fixators on the radius. (A) Two unilateral fixators each consisting of four half-pins using the IMEX-SK fixator have been applied to the radius, resulting in a type Ib fixator. Linkage devices connect the two connecting columns proximally and distally. (B) A type Ib fixator has been constructed using a Kirschner–Ehmer fixator. Medium rods (black arrows) have been used to make diagonal linkages. Note that these attachments span the fracture region promoting a stronger configuration than the one shown in (A).

These connecting columns can be connected with linkage devices. This configuration, two unilateral type I frames, is designated type Ib.

A second strategy that can be employed in the tibia, femur, and humerus to compensate for the relative weakness of half-pins is to incorporate an intramedullary pin in the fixator frame configuration. The intramedullary pin is connected (tied into) to the unilateral fixator (Figure 1.4). Being in a mechanically favorable position on the inside of the long bone, the intramedullary pin supports the remainder of the unilateral type I fixator, greatly enhancing frame stiffness. This configuration is called a type I tie-in configuration.

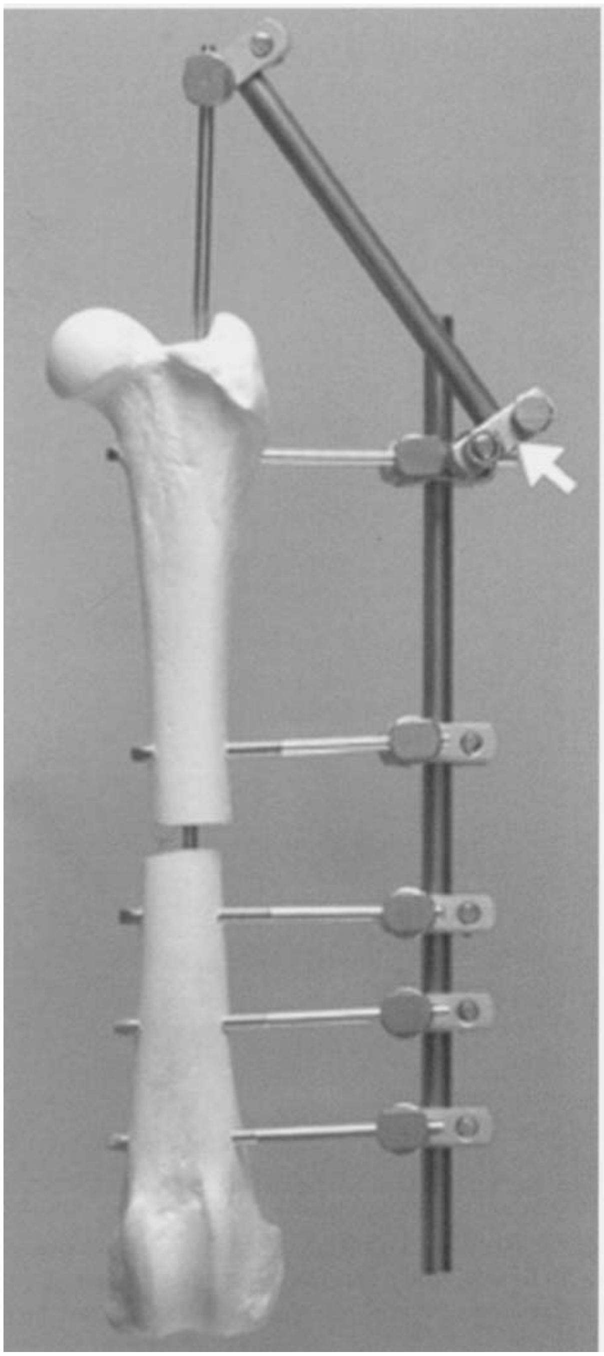


**Figure 1.4** Increasing construct stiffness with an intramedullary pin tie-in. Cranial view of a five-pin type Ia tie-in configuration on the femur. The intramedullary pin is attached to the IMEX-SK fixation frame (white arrow) at the most proximal fixator pin. A short connecting rod attaches this clamp and a single clamp applied to the proximal end of the intramedullary pin to complete the tie-in.

A bilateral or type II frame consists of at least one full pin per proximal and distal fracture segment, having two connecting columns that span the fracture and connect the fixation pins on either side of the limb (Figure 1.2). Of course, one fixation pin per major fracture segment would be insufficient, and one or more additional full or half-pins would be used in each proximal and distal bone segment. It is the presence of at least two full pins, one in the proximal bone segment and one in the distal segment, and two connecting columns that defines the configuration (Figure 1.5).

A multiplanar or type III frame consists of a unilateral or type Ia frame configuration added to a bilateral or type II fixator frame (Figure 1.6). In most cases, the additional unilateral fixator half-pins are at an orthogonal orientation to the full pins. This orientation of full and half fixator pins can provide the greatest degree of stiffness.

In general, strength and stiffness increase in ascending order of classification, i.e. type Ia < type Ib ≅ type I tie-in < type II < type III. The classification serves a practical purpose, in that, as the mechanical needs of the fixator frame become greater, a surgeon is encouraged through the

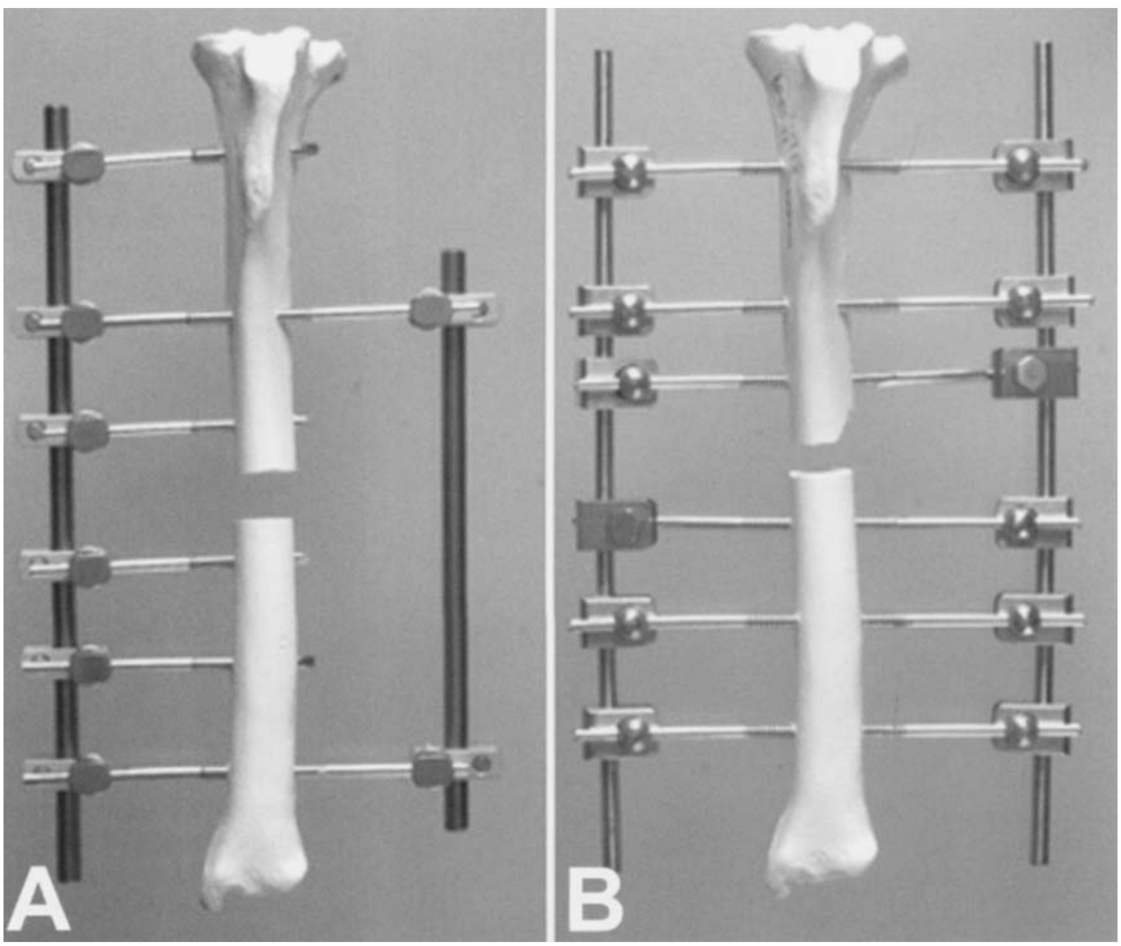



**Figure 1.5** Cranial views of bilateral type II fixators placed on tibias. (A) IMEX-SK type II construct with medially placed half-pins. Note that full pins are limited to one proximally and one distally. (B) Securos type II construct. Note that full pins have been used throughout the construct. Also note that the most central pins have been placed in planes that are different from the plane used for the remaining pins. This confers a mechanical advantage.

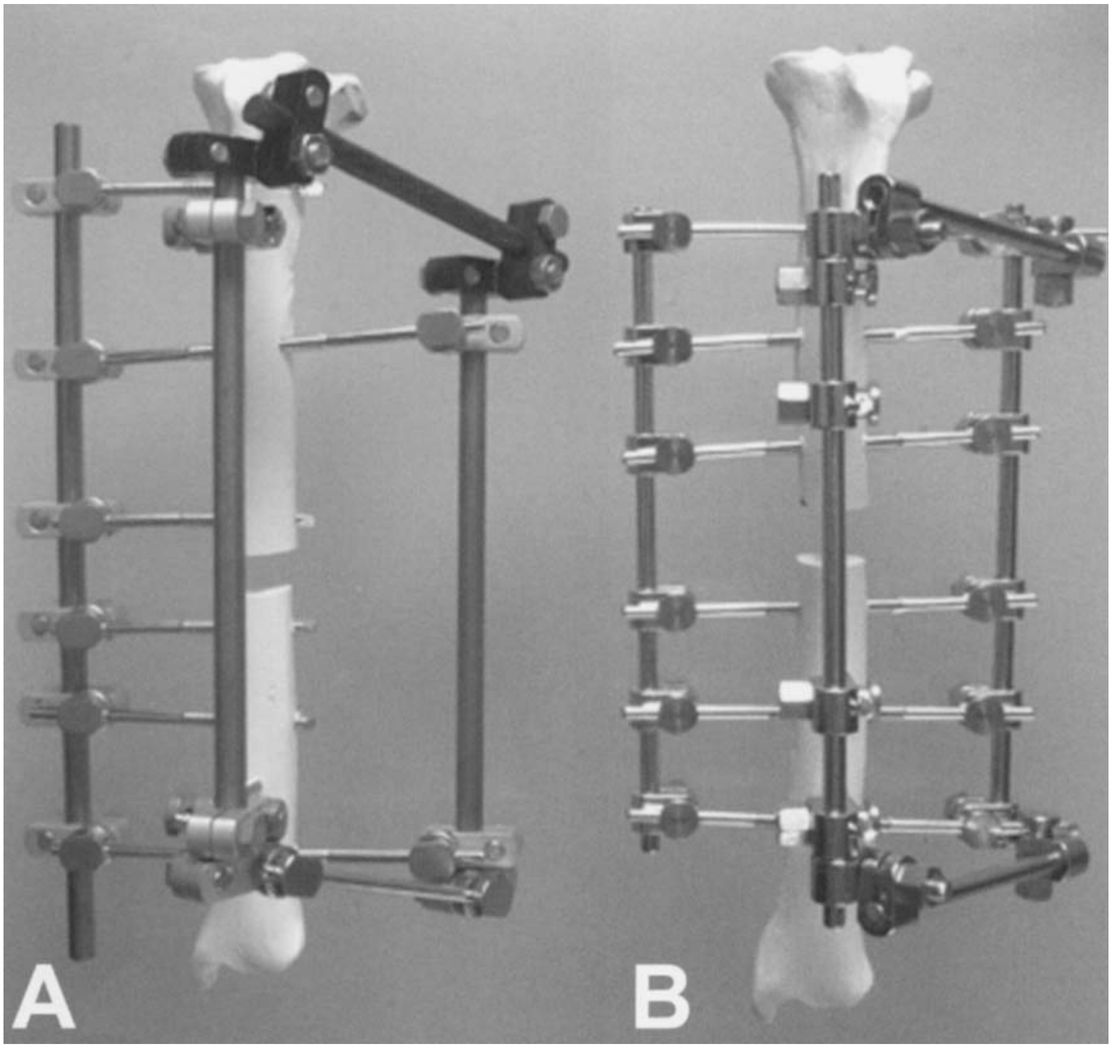



**Figure 1.6** Cranial views of bilateral type III fixators on tibias. (A) IMEX-SK type III construct. The bilateral portion includes a half-pin and a full pin proximally and two medially placed half-pins and a full pin distally. A two-pin unilateral frame has been placed cranially. These two frames have been interconnected with proximal and distal linkages. (B) Kirschner–Ehmer type III construct. The bilateral portion consists of six full pins. A four-pin unilateral frame has been placed cranially. Proximal and distal articulations have been made using double clamps attached to both ends of the cranial connecting rod, short rods, and stacked single clamps on the proximal and distal pins laterally.

nomenclature to choose a higher type. The factors that determine overall frame configuration are very complex, including the number of fixation pins, connecting column strength, the length of the fracture gap, and the distance of a fixation pin from the bone to the connecting column, as well as the fixator type (Figure 1.7). Exceptions to the hierarchy of fixator type with regard to stiffness are expected.

It is possible to imagine many different fixator frame configurations that do not clearly lend themselves to the above classifications. Although other classifications or subclassifications (not listed here) have been described, this basic nomenclature includes most commonly applied fixator frame configurations.

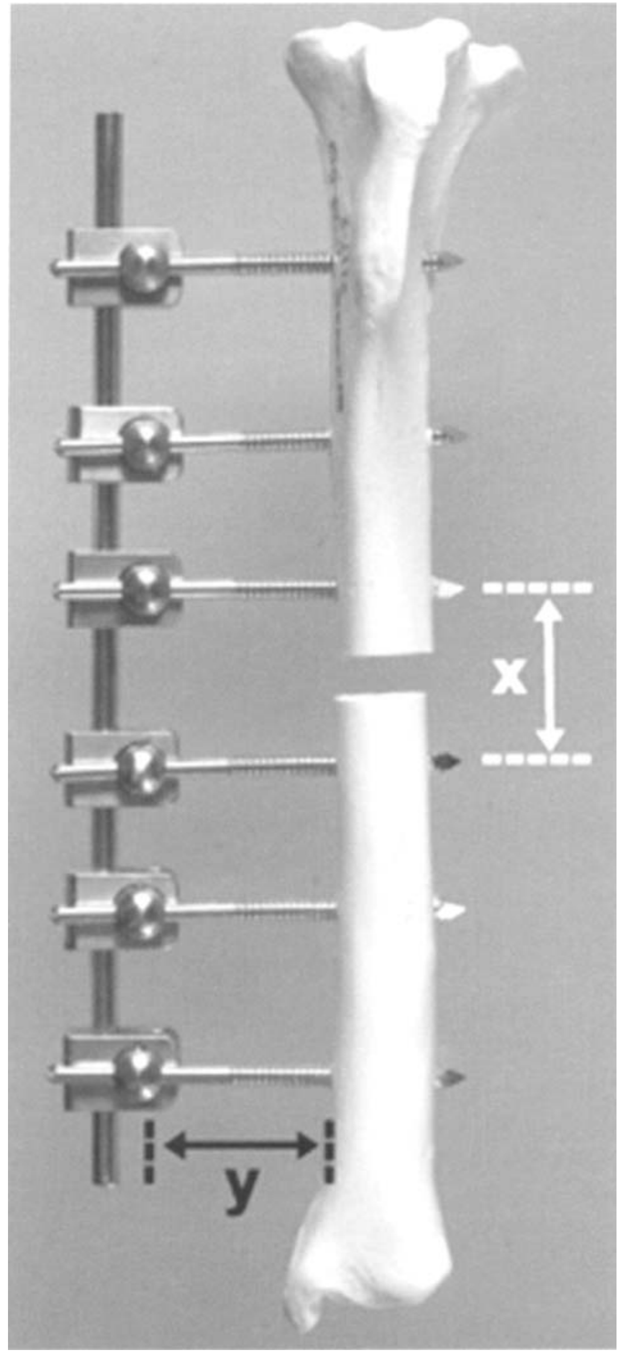



**Figure 1.7** Factors affecting fixator strength and stiffness. Cranial view of a six-pin type Ia Securos fixator on the tibia. Factors that influence overall frame stiffness include the number of fixation pins, connecting column strength, the distance between the pins adjacent to the fracture (x), and the distance of a fixation pin from the bone to the connecting column (y).

# Chapter 2
# Deciding when to Use External Fixation

There are three different fixation systems capable of managing unstable, comminuted fractures of major weight-bearing long bones. These are the external skeletal fixation system, the bone plate and screw fixation system, and the interlocking nail fixation system. Adjunctive fixation with cerclage wires, hemicerclage wires, or lag screws may be used to supplement any of these major fixation systems in a given case. Adjunctive use of an intramedullary pin to form plate–rod constructs or external fixator "tie-in" constructs also expands the capabilities of these two systems. A full appreciation of the inherent advantages and disadvantages of the external skeletal fixation system is required to select appropriate patients for treatment with this method rather than others.

The external skeletal fixation system is the only one that allows for adjustments in fracture alignment both during and after surgery. It is also the only fixation system that can be applied without making an approach to the fracture site. The ability to use a closed application technique preserves surrounding soft tissues, thus maximizing the potential for transient extraosseous blood supply to the healing fracture region. Additionally, foreign materials (fixation devices) are not placed directly onto or in the fracture region, which can be advantageous when dealing with contaminated fractures secondary to gunshot injury or other penetrating wounds.

The ability to progressively transfer an increasing percentage of weight-bearing forces to the healing bone has been shown to accelerate the later stages of fracture healing. External fixation can accomplish this in closed fashion using the axial dynamization capability provided by the Securos fixator and some ring fixators. Progressive staged disassembly techniques can be used with any of the various external fixation devices. This involves removal of externally placed components to reduce the rigidity of the fixation frame in sequential fashion. The other fixation systems require at least a limited surgical approach to remove fixation elements to accomplish staged disassembly. Dynamization may be possible with some interlocking nail repairs, but not with bone plate and screw fixation.

Once a long bone fracture has progressed to clinical union, removal of fixation is often required to enable the final remodeling stages of healing. At clinical union, the remaining portions of the external fixation frame and fixation pins can easily be removed from the bone without surgery. Heavy sedation with meditomidine and a narcotic or brief general anesthesia with propofol is usually sufficient to accomplish external fixator removal. In contrast, removal of an interlocking nail or a bone plate and screw fixation requires general anesthesia and surgery.

External skeletal fixation may also offer an economic advantage over the other fixation system. The clamps and rods of most external fixation devices are relatively inexpensive and many can be reused. With bone plate and screw repairs and interlocking nail repairs, none of the fixation elements is reusable. The cost of instrumentation required to apply each of the three major fixation systems is least for external skeletal fixation, intermediate for interlocking nail fixation, and most expensive for bone plate and screw fixation.

No fixation system is perfect, and the external skeletal fixation system has some inherent disadvantages that must be understood and overcome in order to obtain successful results. The connecting elements of the external fixator are placed distant to the central axis of the bone and are, therefore, at a mechanical disadvantage when confronted with disruptive forces acting at the fracture site. The interlocking nail is in the best position to deal with these. Bone plates are also located close to the central axis and can be protected with an intramedullary pin (plate–rod construct) when the plate is asked to function in buttress mode. The external fixator is in the least advantageous position by virtue of its external frame.

The distance of an external fixator from the central axis of a bone depends upon the thickness of the surrounding soft tissues. On the basis of what regional anatomy will allow, a differential degree of difficulty exists regarding the application of external fixators to given bones. The tibia is most amenable to repair with a fixator, followed by the radius/ulna, and finally by the femur and humerus. In bones with thick surrounding soft tissues, such as the femur and humerus, a "tied-in" intramedullary pin is generally required if the external fixator is required to function in buttress mode.

The fact that fixation pins start on the outside of the body and must penetrate soft tissues to transfix the bone creates several additional challenges. Soft-tissue corridors for fixation pins (pin tracts) breach normal physical defense barriers and thus offer an avenue of entry for contaminating bacteria. Additionally, careful attention must be paid to cross-sectional anatomy at each intended pin site to avoid damage to important neurovascular bundles and musculotendinous units. Postoperative care is more demanding with external fixators than with the internally placed fixation systems. Aftercare must address pin tract hygiene and the potential for externally placed elements to injure the patient, owner, or veterinary hospital personnel.

The following general guidelines are offered regarding when and when not to use an external fixator. For fracture repair, external fixators are most applicable to shaft fractures, especially those involving the tibia or the radius/ulna. They are especially effective when applied in closed fashion to highly comminuted fractures of the diaphyseal region of these bones. External fixators can be successfully applied to shaft fractures of the femur and humerus although, when buttress fixation of highly comminuted fractures is necessary, plate–rod fixation or interlocking nail fixation may be preferable. For less demanding fractures of these bones, an external fixator with an intramedullary pin "tie-in" is certainly a viable option.

In extremely small patients, interlocking nail fixation is not an option, and even veterinary cuttable plates and small screws may be inappropriately large. Acrylic frame fixators utilizing Kirschner (K)-wire-sized end-threaded fixation pins (miniature interface fixation pins) alone or in combination with a small intramedullary pin work well in these cases.

Long-bone fractures with a short proximal or distal segment may be amenable to repair with an external fixator if a sufficient number of fixation pins can be applied to the short segment. Generally, a minimum of three fixation pins is recommended although, if the fracture is likely to heal quickly and the patient is tractable and cooperative, two fixation pins may be sufficient. With a short proximal radial segment in a mature patient, the proximal ulna can also be used as a target for fixation pins. Another method that can be used in various locations in mature patients is extension of the fixator across the joint in order to obtain additional fixation pins. When this strategy is employed, the joint should be placed at a functional angle and the transarticular portion of the fixator should be removed as soon as possible. Articular fractures require anatomic reduction and internal fixation, although occasionally an external fixator is useful to span and protect a tenuous internal repair.

When orthopedic injuries dictate immobilization of a joint, use the simplest technique capable of producing the desired results. For example, if a collateral ligament reconstruction of the hock must be protected and the surrounding soft tissues are not compromised, immobilization with a cast is much easier than using a transarticular external fixator. However, if the collateral ligament injury occurred as part of an extensive shearing wound that will require daily management, an external fixator provides easy access to the wound and rigid stabilization of the injured joint.

External fixators may be used alone or in combination with internal fixation for joint arthrodeses. When soft tissues surrounding the joint are normal, plate and screw fixation is usually preferable for pancarpal arthodesis. External fixation is one of many options that have been employed for tarsocrural arthodesis. When a joint must be fused secondary to a severe soft-tissue shearing wound, external fixation is often an important part of the overall fixation strategy.

In the case of fractures affecting a very short segment but including an open growth plate, other fixation techniques should be seriously considered. It is important that an external fixator does not span a physiologically active growth plate (as opposed to a radiographically open but physiologically inactive growth plate). Even when a fixator can be placed without spanning the growth plate, it is important that the nearest fixation pins do not disrupt growth plate function. In fractures of the distal radius and ulna repaired with type Ib constructs, it is important that half-pins transfix only the radius and not any portion of the ulna.

Because aftercare with an external fixator is more demanding than with internally applied fixation systems, it is important to match the fixation technique to the specific patient and client. If the patient is intractable or vicious, internal fixation is preferable. If the owner is squeamish or is unable for other reasons to participate actively in the required postoperative management of the fixator, internal fixation is preferable.

# Chapter 3
# Preoperative Care

## Initial treatment and physical examination

Appropriate fracture management begins with the initial care of the patient on presentation after sustaining trauma. Alhough the fracture is often the most dramatic aspect of the injury, treatment of the patient in a simple and stepwise manner will insure that the clinician addresses the metabolic needs of the patient and does not overlook concurrent injuries. Appropriate initial treatment of the fracture and associated wounds is also very important. Wound care and appropriate bandaging will provide patient comfort, decrease the incidence of infection, enhance the health of soft tissues, and decrease hemorrhage and edema. Appropriate attention to all of these factors will result in easier fracture repair and better fracture healing, whereas inappropriate care will complicate both (Figure 3.1).

The type of trauma that results in a fracture will give an indication of the overall degree of injury the animal sustained. Following a mild trauma, such as a fall from a short height or a trip, animals are usually in good physiologic condition. An animal sustaining a fracture from a motor vehicle accident almost always has other concurrent injuries. The patient is often presented in some degree of shock. Signs of shock include pale mucous membranes, long capillary refill times, and high heart and respiratory rate. Venous access should first be established and treatment for shock using crystalloid fluids initiated. In most cases, lactated Ringer's

**Figure 3.1** Preoperative care of the limb. Failure to apply a bandage to this limb has resulted in excessive swelling, which has obscured anatomic landmarks.

solution (LRS) is administered, with 40 ml/kg given within the first 30 minutes. The patient should then be reassessed. If shock persists, another 40 ml/kg LRS should be administered over the next few hours. If normal capillary refill time, heart rate, and urine production are restored, then maintenance LRS at 15 ml/kg/day should be administered thereafter.

A careful physical examination should always be performed. If the patient is not stable on presentation, a thorough examination may not be immediately possible. If a complete physical examination is not performed initially, this should be noted in the patient record; physical examination should proceed as soon as the patient is stabilized and before further treatment is administered or radiographs taken.

A neurologic examination should be performed, assessing brain or spinal cord injury. If a patient is in a stuporous state after initial shock therapy, cranial trauma should be suspected. Pupillary light reflexes and cranial nerve examination should be performed. Signs of brain injury would include anisocoria, mydriatic or miotic pupils with inappropriate light responses, or loss of cranial nerve function.

Assessment of spinal cord trauma should be performed after initial shock therapy and prior to administration of potent analgesics. If an animal is in shock, or in a stuporous state as a result of head trauma or administration of potent analgesics, accurate spinal cord assessment may not be possible. If the patient has normal mentation, the neurologic examination should start with an assessment of pain sensation to the distal limbs. Sensation to the forefoot is supplied by the radial, ulnar, and median nerves. The second digit (median and ulnar nerves), fifth digit (ulnar nerve), and skin on the dorsum of the foot (radial nerve) should be grasped with forceps and squeezed until mental recognition of a painful stimulus is noted. Withdrawing the limb is not necessarily a sign of an intact sensory pathway and could occur in the presence of a high cervical or cranial injury. Sensation to the pelvic foot is supplied by the sciatic and femoral nerves. The second digit (femoral nerve) and lateral fifth digit (sciatic nerve) should similarly be grasped to assess the presence of recognition of a painful stimulus. Again, withdrawal of the limb does not constitute mental recognition and could occur in the presence of spinal cord injury rostral to the third lumbar vertebra. It is important to realize that a patient that has been treated with potent analgesics may not respond to mild to moderate stimuli. In addition, an animal may not respond to mild or moderate toe stimulation because of the intensity of pain from a fracture of that limb.

Following trauma, a single fracture may be most obvious, but the clinician must be sure that there are no other fractures or concomitant spinal cord injury. An animal with a single fracture should be able to support weight on the other three limbs. If an animal cannot and has appropriate mentation, then spinal cord trauma or trauma to other limbs should be suspected. Thoracic and abdominal radiographs should be taken (see below) and the other limbs should be palpated for fractures or luxations. If the patient can stand on the other three limbs then the presence of proprioceptive deficits should be assessed by placing examination of the other three feet, which will reveal any mild neurologic trauma. The patient should be supported during this test. Placing examination of the affected limb need not be performed as an animal will rarely properly place the foot of a fractured limb. Segmental reflexes of the functional limbs should also be tested.

If an animal is obviously in extreme pain or is fractious, a complete orthopedic examination should be performed after analgesics and/or sedatives are administered. The oral cavity should be inspected for tooth fractures. The orthopedic examination should include all four limbs, with the affected limb being examined last. The examination should start at the toes and proceed proximally, evaluating each bone and joint for fracture and laxity. The affected limb is palpated gently, looking especially carefully for wounds under the hair suggesting an open fracture. The pelvis is palpated for lack of symmetry and the spinal column for pain and congruity. The physical examination should also include abdominal palpation and auscultation of the chest.

## Radiographs

Thoracic radiographs should always be taken and must include a lateral and ventral/dorsal view. Frequently, an animal that has been involved in a motor vehicle accident will have concurrent thoracic and pulmonary trauma, and radiographs should always be taken. Concurrent thoracic pathology can also be found in patients that have experienced lesser traumas. Analgesics should be administered to facilitate obtaining radiographs and for the comfort of the patient. The thorax should be evaluated for signs of pneumothorax, pulmonary contusions, diaphragmatic hernia, and appropriately sized heart and great vessels. The spinal column and ribs should be evaluated. Radiographs of the abdomen should be taken as well, although some clinicians will omit these films if the trauma causing the fracture was mild, abdominal palpation normal, and thoracic radiographs are within normal limits. Lateral and craniocaudal radiographic views should be taken and evaluated for signs of loss of abdominal detail suggesting hemoabdomen or uroabdomen, streaking of the sublumbar musculature with ventral displacement of the viscera suggesting sublumbar hemorrhage, and the presence of an intact abdominal wall and bladder.

At this time, a lateral view of the affected fracture may also be taken for a preliminary evaluation of the fracture, client communication, and surgical planning. High-quality craniocaudal and lateral views should be taken just prior to surgery, under anesthesia or preanesthetic medication if possible. These radiographs are needed to assure proper positioning and technique, and to detect the presence of fissures.

## Bandaging



After the patient has been stabilized and appropriate radiographs and ancillary diagnostic tests have been taken, the limb should be properly attended to. Fractures of the distal limb, specifically of the radius/ulna and tibia, must be bandaged. It is preferable to sedate and anesthetize (see below) the patient for a short period of time to allow the correct bandage to be applied. Usually, a Robert Jones bandage is applied. The purpose of the bandage is several-fold. First and foremost, the Robert Jones bandage immobilizes the limb. It does this by virtue of its size and the amount of padding. Being large, it is impossible for the animal to bend the limb by inadvertent weight bearing or moving. After being compressed, the large amount of padding will reduce and prevent edema. At surgery, fracture reduction and pin placement are much easier as a result of the reduced swelling afforded by a properly placed bandage. The bandage also reduces hemorrhage and the interfragmentary motion that exacerbates hemorrhage and soft-tissue damage. An added benefit of immobilization and padding is that the bandage provides comfort for the patient until the limb is surgically stabilized. This is as important as analgesics in providing pain relief.

The primary layer of the Robert Jones bandage depends on the specific injury. If the injury is a closed fracture, no primary layer should be applied. Nonadherent dressings are used for abrasions and lacerations. Moistened gauze is used with degloving wounds and grade III open fractures. The secondary layer of a Robert Jones bandage should be roll cotton, except in the case of very small dogs. The amount of cotton used seems excessive, specifically one roll of cotton (1 lb or 500 g) for every 20 kg of body weight. Roll cotton is readily available and inexpensive and encourages an appropriately large bandage. It is the outer diameter of the bandage that immobilizes the limb, therefore the bandage should be very large. The paper between the layers of cotton should be removed and the cotton broken in two for large dogs, and into thirds for medium to small dogs. After this, stretch gauze then an elastic occlusive bandage is applied (Figure 3.2).

The patient should be heavily sedated or anesthetized. Stirrups are applied to the limb, which is then suspended from an intravenous (i.v.) stand, with the patient being almost lifted off the table, similar to a hanging leg preparation for fracture repair (Figure 3.3). This allows the limb to be aligned and allows the bandage to be placed very high.

The cotton is applied (over the primary layer) from distal to proximal. The cotton should form a cylinder (Figure 3.4). The next step is to apply the stretch gauze. The gauze bandage should be applied very tightly and without billows. There are three important "tricks" to applying the stretch gauze properly. First, apply the first layer with only light force; consecutive layers will then be applied with ever-increasing force. Second,

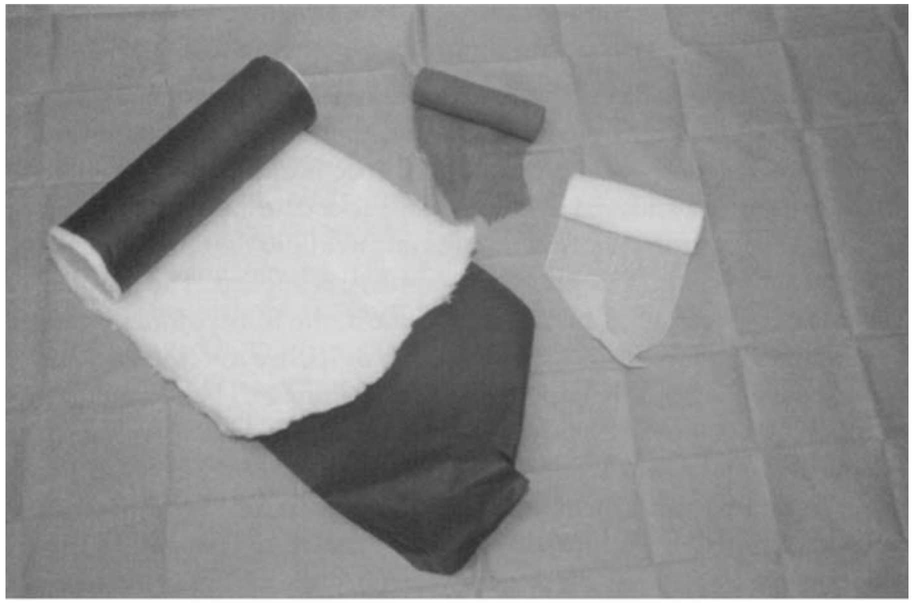


**Figure 3.2** Materials for the secondary layer of a Robert Jones bandage. Roll cotton is economic and provides sufficient bulk for an appropriately large bandage. Gauze is used to compact the cotton.

**Figure 3.3** The hanging limb technique. This method facilitates application of a Robert Jones bandage. This straightens the limb, distracts the fracture, and aids in placing the bandage sufficiently proximal.

use relatively wide gauze and keep the roll close to the bandage. Third, apply the gauze in a diagonal or weaving pattern, not in circles (Figure 3.5). The next layer is the occlusive elastic bandage, and Vet Wrap works best. Apply the Vet Wrap tightly as well (Figure 3.6).

A Robert Jones bandage should never be applied to fractures of the humerus and femur. The bandage can be quite heavy, and the top of the bandage will end very close to the fractures. The bandage is intended to immobilize the fracture by immobilizing the joint above and below the fracture. A Robert Jones bandage will not immobilize the hip or shoulder

**Figure 3.4** Applying roll cotton. A large amount of cotton is placed in a cylinder. The cotton is placed as proximal as possible and should extend past the toes.

**Figure 3.5** Applying gauze. Apply the first layer snug and the consecutive layers with ever-increasing force. Use wide gauze and keep the roll close to the bandage. Apply the gauze diagonally in a weave pattern.

**Figure 3.6** Tertiary layer. Vet Wrap or similar material is used for the outer tertiary layer of the bandage. In a Robert Jones bandage, the outer layer is applied tightly.

joint. Also, a Robert Jones bandage that allows movement of a joint is not a Robert Jones bandage.

## Open fractures

Open fractures of the distal limb are also treated with a Robert Jones bandage, but the wound must be attended to as well. Open fractures are graded according to the degree of soft-tissue damage and how the bone fragments were exposed. Grade I open fractures occur when a bone is fractured and a fracture fragment is briefly forced out through the skin. The sharp fracture fragment lacerates tissue, without causing excessive tissue necrosis, leaving a communicating wound in the skin. The fracture is usually simple, suggesting that minimal energy has been imparted to bone and surrounding soft tissues. All treatment of open fractures should be performed with sterile technique, including sterile gloves, mask, and cap. Under anesthesia or heavy sedation, sterile water-absorbable jelly is placed into the wound. The limb is then clipped with the jelly, preventing hair from entering the wound and becoming entrapped in subcutaneous tissues. The limb is scrubbed and prepared as one would for a surgical operation. The wound is gently probed with a hemostat, looking for debris, extensive soft-tissue damage, or purulence. The wound is lavaged with 500–1000 ml of 0.9% saline or LRS. Antibiotics or antiseptics should not be added to lavage solutions. The lavage should be allowed to exit the wound freely and should not be injected into tissue or allowed to dissect through tissue planes. An 18-gauge needle with a 35-ml syringe is very good for this purpose and tends to provide the appropriate amount of lavage pressure. If necessary, the edges of the skin wound are excised and the skin wound closed with nonabsorbable monofilament sutures in a simple interrupted pattern. The wound should be covered with a nonadherent dressing and a Robert Jones bandage placed. If the wound is grossly contaminated with debris, is over 6 hours old, or is obviously infected, the wound should not be closed and should be treated as a grade II open fracture.

Grade II open fractures occur when an external force causes fracture to a bone. As an external force imparts energy to bone through tissue, moderate tissue damage occurs. There is usually an area of skin loss or devitalized skin of larger than 1 $cm^2$ in size. Often, debris and hair are forced into the soft tissues. The patient should be anesthetized and the wound probed and lavaged in similar manner to grade I open fractures. Any nonviable skin, fascia, or muscle should be sharply debrided. The amount of lavage solution used for these wounds should be two or more liters. Debridement and lavage should be continued until all tissues are free of foreign matter and appear healthy and viable (Figure 3.7). If all tissues appear viable and are clearly not infected, no foreign material is left in the wound, minimal hemorrhage is present, the wound is less than 6 hours old, and closure can be performed without tension, the wound may be closed. Deeper structures are apposed with monofilament absorbable sutures and the skin is apposed with monofilament nonabsorbable sutures. If nonviable tissue remains, substantial inflammation or hemorrhage is present, or the wound is not easily closed, the wound should be left open. If there is any question about whether the wound can be safely closed, it

**Figure 3.7** Debridement and lavage of open fractures. Grade II and III open fractures (see text) should be debrided and copiously lavaged until they are free of foreign matter and appear healthy and viable.

should be left open. Saline-moistened gauze sponges are placed over the wound and a Robert Jones bandage applied.

Grade III open fractures occur when excessive energy has been imparted to bone and surrounding tissues, leading to physical or functional loss of a large amount of tissue. Physical loss of tissue includes shearing or degloving injuries. Functional loss of tissue includes devitalization owing to contusion or loss of vascular supply. Examples of this include shearing and degloving wounds to the distal extremities with fracture or bone loss, high-velocity gunshot wounds, short-range shotgun injury, and blunt injury with fracture and impaction of debris, as in a lawnmower wound or crushing injury into dirt or pavement. An infected wound should always suggest a grade III open fracture classification, even if the initial classification would have been grade I or II, as infection extends the amount of tissue necrosis. Treatment of grade III fractures requires meticulous attention. The patient is anesthetized and the limb prepared as described for grade I and II open fractures.

Debridement should be performed under sterile conditions in a surgical suite, not in the nonsterile treatment area. Meticulous debridement is the single most important aspect in the treatment of open fractures. Failure to completely debride devitalized tissue leaves a substrate that supports bacterial colonization of the wound. Debridement of the skin should be conservative in the distal limbs, but dead or severely devitalized skin should be removed. Skin should be excised until cut edges bleed and appear pink. If skin in a distal limb appears potentially viable, it should be retained and reassessed during a secondary debridement procedure 24 hours later. Fascia should be freely debrided as it is expendable and easily infected because of its relatively low vascularity (Figure 3.8). Exposed tendons and ligaments will become nonviable and should be debrided if not serving a critical supporting function. If major supporting tendons and ligaments (e.g. the common calcanean tendon) are exposed, they must

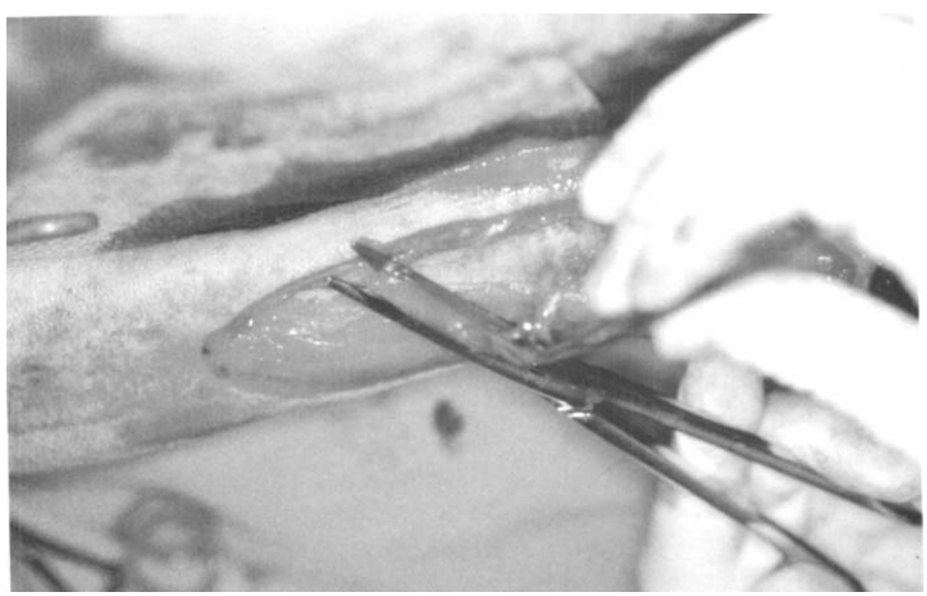


**Figure 3.8** Debridement of a grade III open fracture. Devitalized skin is debrided sharply with a scalpel, and devitalized fascia with Metzenbaum scissors.

be kept moist and covered as soon as possible with vascular soft tissue. Muscle is debrided if not viable. Bone fragments should be left when providing a supportive function or if they have a soft-tissue attachment. Small pieces of bone without soft-tissue attachment should be removed. Nerves and large blood vessels should be spared.

Grade III open fractures can be kept open and immobilized with a Robert Jones bandage for 1–2 days until definitive fracture repair with an external fixator, allowing healing of soft tissue and cessation of hemorrhage. This is especially true for distal degloving wounds with luxation, as surgical stabilization very soon after injury may compromise blood supply. Delaying surgery for 1 or more days allows time for distal limb vascularity to improve. However, open fractures with even modestly sized exposed fragments should be stabilized before the bone becomes devitalized. It is often necessary to stabilize these grade III open fractures surgically on an emergency basis. Having a fixator in place in this case has the advantage of allowing daily bandage changes and repeated debridement without manipulation of the fracture early in the treatment.

Open fractures of the humerus and femur are treated in a similar manner to open fractures of the distal limb. However, instead of a Robert Jones bandage, which would be contraindicated, a tie-over bandage is used to cover small, upper-extremity wounds. Many loose sutures of large-gauge (2–0 to 0) monofilament suture are placed 4–5 cm from the wound. A nonadherent dressing or saline-soaked gauze is placed over the wound, followed by several dry gauze sponges. A water-impermeable drape material is cut to size and placed over the gauze. Umbilical tape or large-gauge suture is then applied through the suture loops to secure the bandage as one would lace a shoe.

## Sedation, anesthesia, and analgesia

Taking radiographs, applying a bandage, and debridement require sedation and often a short period of anesthesia. Several different medications can be administered. Protocols vary in different regions of the world, based on drug availability and popular usage. One author uses the following combinations. For sedation and preanesthesia, a combination of butorphanol, acepromazine, and glycopyrrolate is used. These medications are mixed in a 50-ml vial in these proportions:

| | | | |
|---|---|---|---|
| Butorphanol | 10.0 mg/ml | (0.20 mg/kg) | 10.0 ml |
| Acepromazine | 10.0 mg/ml | (0.05 mg/kg) | 2.5 ml |
| Glycopyrrolate | 0.2 mg/ml | (0.01 mg/kg) | 25.0 ml |
| 0.9% saline | | | 12.5 ml |
| Total volume | | | 50.0 ml |

This combination is given at a dose of 0.1 ml/kg intramuscularly (i.m.) or 0.05 ml/kg i.v. It may take 15–20 minutes for the drugs to take full effect. This combination is often sufficient for applying a bandage or taking radiographs. If a brief period of anesthesia is needed to apply a bandage to an animal in great pain or for wound care and debridement, propofol can be given in addition to this at a dose of 4 mg/kg slowly and to effect. Another short-acting anesthetic is the combination of ketamine and diazepam. These two medications are mixed equally and given at a dose of 0.1 ml/kg (1 ml/10 kg) i.v. to effect. One-fourth of this dose may be repeated as needed. Occasionally, recovery from ketamine and diazepam will not be smooth. In this case acepromazine should be given at a dose of 0.05 mg/kg i.v. Many other sedative and anesthetic protocols can be used at the discretion of the surgeon.

Analgesics should be given once the patient has been stabilized and before surgery. A commonly used analgesic is buprenorphine (0.01 mg/kg i.m. or i.v. every 6 hours). Although butorphanol is often more readily available, its analgesic qualities are much less. Butorphanol can be given at a dose of 0.4 mg/kg i.v. or subcutaneously (s.c.). Morphine is quite inexpensive and is becoming more easily available. Morphine is given at a dose of 0.3 mg/kg every 4–6 hours. Fentanyl patches are becoming increasingly popular. They are placed on a shaved area of skin and provide a continuous administration of analgesic. It takes 12–36 hours to achieve therapeutic blood levels. The doses are one 25 μg/h patch for dogs weighing 10 kg or less, one 50 μg/h patch for dogs weighing 10–20 kg, and one 75 μg/h patch for dogs weighing 20–30 kg. Two 50 μg/h patches are used for dogs weighing over 30 kg. In the case of cats, one-half of a 25 μg/h patch is used for smaller cats and a whole 25 μg/h patch is used for larger animals.

These medications may also be given to provide pain relief after surgery. In addition, after the first 1–2 days, postoperative nonsteroidal anti-inflammatory drugs (NSAIDs) can also be given. The authors commonly prescribe carprofen 2 mg/kg per os (p.o.) for 1 week following surgery, starting on the second day after surgery. NSAIDs and narcotics provide synergistic pain relief when given in this manner.

# Chapter 4
# **Fracture Reduction**

## Hanging limb technique

Reducing limb fractures is the most important and often the most difficult aspect of fracture repair. One technique that is very helpful when placing fixators on distal limb fractures is hanging the limb over the surgery table. This technique accomplishes several things. Properly performed, hanging the limb will tend to reduce the fracture. As the limb extends, the fracture is distracted, the soft tissues of the limb tighten, and the bone fragments are pulled into alignment. The joints proximal and distal to the fracture tend to be brought parallel to each other as well. The surgeon can correct rotational deformity by aligning the distal and proximal portions of the limb. This also has the technical advantage of having the limb aligned at eye level and dispensing with the need for an assistant.

The equipment needed to hang the limb is a hook directly over the surgery table and a surgical table that can be raised and lowered. Halter hooks, rings, or an overhead i.v. hook secured to the ceiling work very well for this purpose. Surgical lights and an i.v. pole can be used; however, they are less secure and more difficult to maneuver without disturbing the pole or contaminating the sterile surgical field.

The limb is prepared for surgery in a typical manner as one would prepare any surgery on a distal limb. Orthopedic tape is secured to the foot, leaving very long ends (Figure 4.1). The orthopedic tape should be placed on the foot securely so that it will not fall off with tension, but should not be so tight that it will constrict blood supply. With the surgical table elevated, the patient is placed on the table and the limb tied to the overhead hook with mild to moderate tension. The surgeon should assure that the hook, tape, and limb are in a straight line when viewed cranially or caudally and laterally (Figures 4.2 and 4.3). The paw and proximal limb should be palpated to ensure that there is no torsional malalignment. The final surgical preparation is made similarly to any hanging limb preparation for orthopedic surgery of a distal limb, except that the limb is not cut down. Four quarter-drapes are applied and two patient drapes are applied from either side as the limb will not be placed through a hole in the drape. The foot and tape are covered with sterile self-adhering elastic tape as high as the surgeon can reach (Figure 4.4). The surgeon should pay attention to the rotational alignment of the foot during application of the sterile tape to the foot as this can cause the limb to rotate.

Shortly before surgical reduction, the surgical table is lowered until the patient's body rises slightly above the surgical table. There can be considerable tension, especially in large patients, but not so much that injury will be caused to the patient, i.e. about half the patient's weight.

**Figure 4.1** The hanging limb technique. The limb is suspended at eye level directly above the surgery table using a hook. The limb is extended by lowering the surgery table until moderate tension is applied to the limb.

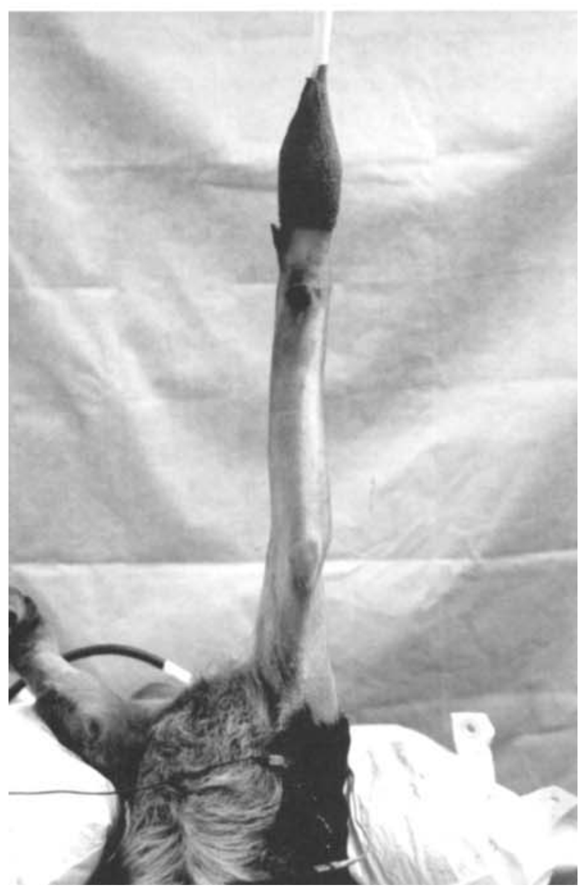


**Figure 4.2** Caudal to cranial alignment. In this radius and ulna fracture, a straight line can be visualized down the length of the limb and the joint surfaces appear to be parallel to each other.

**Figure 4.3** Lateral alignment. The radius and ulna appear straight and the paw, distal radius, proximal radius, and elbow are in rotational alignment.

**Figure 4.4** Sterile preparation. Wrapping a sterile drape around the limb and securing it with hemostats drapes the limb. The foot is wrapped with sterile elastic tape.

In tibial fractures there is a tendency for the proximal fragment to be deviated caudally and for the distal fragment to be deviated cranially. The limb will be held somewhat straighter if the tape originates from the tarsus and not the toes.

## Reduction of simple fractures with a limited approach

One of the greatest advantages of external fixators is that they can be placed with minimal disruption of the biologic environment of the fracture. Unlike bone plates, fixation pins coursing transversely through bone are placed with minimal elevation of soft tissues and periosteum. And, unlike intramedullary pins, fixation pins minimally disrupt the intramedullary blood supply. In many cases, a fracture can be reduced and a fixator applied with minimal exposure of the fracture. As the periosteum is a primary source of stem cells needed for fracture healing, and soft-tissue attachments will encourage a rapid temporary extraosseous blood supply, fractures stabilized with external fixators heal very quickly. Fixators can be placed with complete exposure of the bone as well, and this technique is commonly performed if an external fixator is used as an ancillary device in addition to intramedullary pins and/or cerclage wires.

Transverse and short oblique tibia and radius fractures with minimal comminution are best reduced with a limited approach. Although closed reduction is possible, the major fracture fragments are often overriding and cannot be adequately reduced without direct manipulation of the major fracture fragments. With simpler fractures, viewing the fracture line will assure proper reduction and alignment. In addition, the fracture ends can be observed for major fissures. Exposure of the fracture facilitates placement of fixation pins, which should be close to, but not invading, the fracture ends.

The goal of a limited approach is to view the fracture line but not invade the biologic fracture environment. As much as possible, the periosteum and soft tissues should be left intact and not elevated from the bone. Pointed reduction forceps can be used to reduce the fracture without crushing or elevating periosteum or soft tissues.

In the case of radius fractures, a medial approach is made at the level of the fracture between the extensor carpi radialis and the flexor carpi radialis. The radius is easily palpated in the distal limb, but the pronator teres covers the radius in the proximal antebrachium. Usually, a skin incision of 5–8 cm is sufficient. The deep antebrachial fascia is incised to visualize the fracture. Transverse fractures can be reduced by using a periosteal elevator to lever the two fracture fragments into apposition. Reduction forceps can also be used to manipulate the fracture, although care is necessary to avoid propagating fissures. Placing sharp-pointed bone reduction forceps across an oblique fracture can hold these fractures in apposition. It is often possible to place a small temporary K-wire across a transverse or short oblique fracture to hold it in alignment (Figure 4.5). This wire is removed after fixator application. Final reduction is

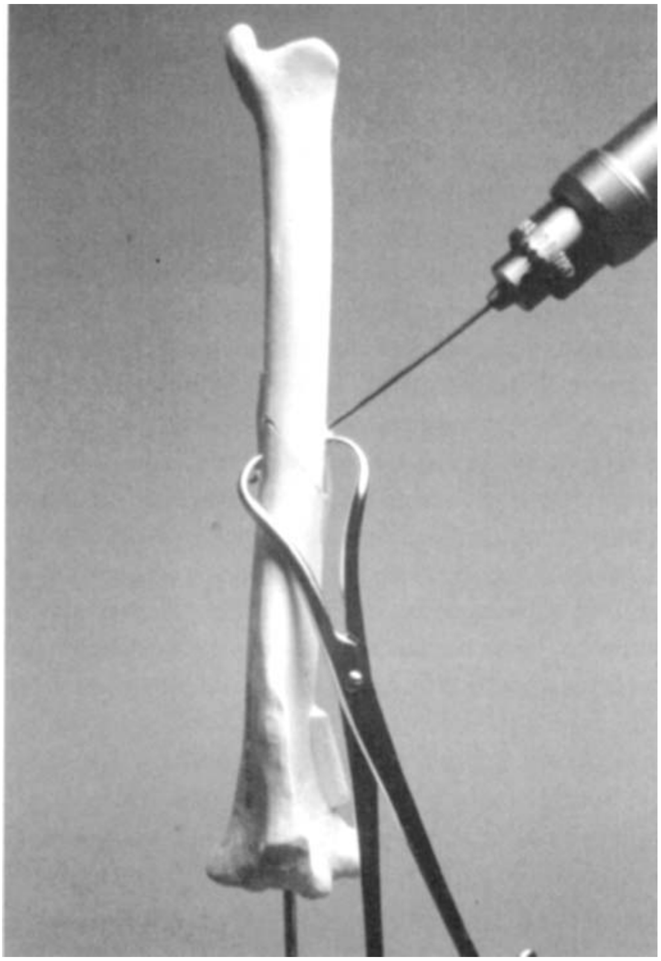


**Figure 4.5** Temporary reduction. Oblique fractures can be held in temporary reduction with pointed reduction forceps. Transverse and short oblique fractures can be held in reduction by placing a small temporary Kirschner wire across the fracture.

achieved and confirmed after placement of the first two fixation pins and connecting columns.

For tibia fractures, a medial approach is made at the level of the fracture. Care should be taken to avoid the cranial branch of the medial saphenous artery and vein and the saphenous nerve. These can usually be palpated through the skin or after the skin has been incised. Reduction of the fracture is also achieved using periosteal elevators and reduction forceps. In addition, as for reduction of the radius, placing a small Kirschner wire across the fracture is very helpful to hold the fracture in reduction while the external fixator is placed.

## Reduction of comminuted fractures using a closed approach

Highly comminuted fractures of the distal limb can be effectively repaired with external fixation without an open approach. Multiple small fragments may not lend themselves to reduction, and exposing multiple fracture lines will not aid in reducing the fracture. In addition, exposure of the fracture will further disrupt the soft tissues and blood supply to these fragments, increasing the chance of sequestration and delaying the healing process. For these reasons, highly comminuted distal limb fractures are stabilized without an open approach.

High-quality radiographs are essential for placement of fixation pins and for the detection of fissures that may propagate during reduction and pin placement so that they can be avoided. Tabletop radiographs with the bone under tension will most closely mimic the operative situation and are performed under anesthesia. The desired location of pins should be determined from the radiographs and measurements from bony landmarks made with a ruler. A limb that was severely traumatized or one to which a proper Robert Jones bandage was not applied will be considerably swollen, making accurate location of the underlying bone difficult. It is helpful to measure from obvious landmarks such as the accessory carpal bone, olecranon, patella, and tuber calcanei. The proximal and distal pins should be 5–10 mm from the joint surface, and two pins should be placed close to the fracture. How close to the fracture site a pin can be placed depends on the ability of the surgeon to place these pins accurately and the presence or absence of fissures, but the pins should be 20–40 mm away from the fracture.

A fixator is placed using the hanging limb technique alone to reduce the fracture. Special care is warranted to make sure that the limb is aligned properly in all planes and that the joints proximal and distal to the fracture are parallel. The most proximal and distal fixation pins are placed first and may be used to further align the limb. Intraoperative radiography or fluoroscopy is helpful to assure bony alignment, although these techniques may not be available and are not essential. The most important axes for alignment are in the medial to lateral plane and torsion. Malalignment in the medial to lateral plane will lead to valgus or varus angular deformity of the limb. This causes abnormal stresses in the adjacent joints and should be avoided. Slight malalignment in the cranial to caudal plane can be tolerated. Because the adjacent joints (elbow and carpus, stifle and tarsus) bend in this plane, some deviation will not place abnormal forces across the joints.

The remainder of the fixator is then applied using the radiographs to guide pin placement. A small K-wire can be helpful to probe through the skin to locate bone and to avoid the fracture. During pin placement, when drilling a pilot hole or placing a pin, if two distinct cortices are not encountered, or if the pin does not feel solid in the bone, it should be replaced.

# Chapter 5
# Placement of Pins

The importance of the pin–bone interface in external fixation cannot be overstated. The concept of placing a pin into a bone is overwhelmingly simple, yet, as with much in the practice of external fixation, the devil is in the detail. The quality, integrity, and longevity of the pin–bone interface is heavily influenced by even very minor variations in technique. To avoid problems and complications the external skeletal fixation (ESF) surgeon needs a sound knowledge of proper pin placement technique as well as a full understanding of why even minor variations of that technique will lead to premature weakening or even failure of the pin–bone interface.

Bone is a living, reactive tissue. If a fixator pin is expected to remain in bone throughout fracture healing, typically 8 weeks or more, then it is necessary to guard against provoking any adverse reaction that might lead to bone resorption and pin loosening. In practice, such adverse reactions are usually caused by localized thermal bone injury, excessive local stress, or a combination of these two factors.

## Avoiding thermal bone injury

Premature pin loosening related to thermal bone injury is a very common but often unrecognized complication of ESF. Although the amount of bone thermally injured is remarkably small – perhaps as little as 0.1 mm around the pin – it is of crucial importance, being the entire "bone" side of the pin–bone interface. This thermally injured bone becomes necrotic and is replaced with a collar of fibrous connective tissue that allows micromovement of the pin, which in turn leads to further, stress-related, bone damage and resorption. The end result is a prematurely loose pin – an avoidable complication that would have been prevented by careful attention to the detail of proper pin placement technique.

Because thermal bone injury can be avoided by meticulous attention to the technical detail of pin placement, it is of particular importance to the surgeon. Bone exposed to a temperature as low as 50 °C will undergo microvascular damage, subsequent resorption, and replacement by fibrous connective tissue. Unfortunately, it is remarkably easy to achieve such temperatures in bone through the heat of friction generated while placing fixator pins. Most fixator pins in use today are armed with *trocar points* and, although these points are inexpensive to produce, they are very inefficient cutters of bone. The potential for trocar points to heat bone is exacerbated by the fact that bone shards produced as the pin cuts through bone have no easy egress route and so become impacted around the rotating pin. (Contrast the design of the trocar point pin with the shaft of bone drills, which have spiral channels to release bone shards.) The impacted bone shards further increase the heat of friction and, obviously, the faster a trocar point pin is driven into bone, the greater will be the local temperature rise.

A number of strategies have been devised to prevent, or at least moderate, the amount of frictional heat generated during pin placement. Hand placement (i.e. without the use of any kind of power tool) has been advocated, but this is too slow and laborious to be practical for most surgeons. Furthermore, a degree of "wobble" is unavoidable during hand placement, and this results in misshapen, oversized holes – the resulting pin–bone interface is poor and prone to premature pin loosening. Continuous irrigation of pins during placement has the potential to limit temperature increase, but this is rather laborious, impractical, and perhaps even ineffective when pins are being placed through a significant depth of soft tissue. Relatively few surgeons irrigate fixator pins as a routine. Power drills or powered pin drivers permit easy accurate pin placement and, if insertion speeds are kept to 50 rpm or less, thermal bone necrosis can be avoided in most instances. However, the technique of predrilling holes for placement of fixator pins is optimum. By using a *sharp* bone drill that is as much as 98% of the diameter of the fixator pin, a hole can be made accurately, quickly, and without significant risk of thermal bone necrosis. Subsequently, the pin is driven into the predrilled hole for an accurate, tight pin–bone interface featuring viable, live bone adjacent to the fixator pin.

## Avoiding excessive local stress

Excessive stress at the pin–bone interface can be mitigated in a number of ways, most of which are aimed at increasing the area of contact between fixator pin(s) and bone. Larger-diameter pins have a proportionally larger area of pin–bone contact and therefore generate correspondingly lower levels of local stress at the pin–bone interface. However, pins greater than about 30% of the bone diameter will weaken the bone unduly and might cause pathological fractures, so excessively large pins should be avoided. Increasing the number of pins placed into each fracture fragment will reduce the stress at each individual pin–bone interface; thus, maximizing the number of pins in an external fixator construct will help to reduce premature pin loosening. However, other factors (fragment size, bone morphology, etc.) effectively limit the number of pins which can be used, and so, in practice, three or four pins (and sometimes two) in each major fragment is appropriate. Pins with threads have a number of advantages over smooth pins, not least that the threads significantly increase the area of pin–bone contact, which reduces local stress and protects the pin–bone interface (Figure 5.1). It has been shown in several clinical reviews that threaded pins (especially those with positive threads) are more resistant to loosening than smooth pins. Another factor that may influence premature pin loosening is pin stiffness – different pins of similar diameters may have varying stiffness. Relatively stiff pins will tend to spread load more evenly

**Figure 5.1** Placement of positive-profile threaded pins. Three pins – one full pin and two half-pins – of suitable size have been placed in the distal fragment of this radius fracture. The pins are driven such that the positive-threaded portion has fully engaged both cortices. To resist axial compressive (and other) forces most effectively, the pins have been placed perpendicular to the long axis of the fractured bone.

between the pin–bone interfaces at the near and far cortices, whereas more flexible pins will tend to bend and flex, so loading the near cortex preferentially. This local stress phenomenon will cause bone resorption and may contribute to early pin loosening. A similar argument can be applied to fixator frames that are relatively flexible – these too might be expected to encourage early stress-related pin loosening.

In summary, to protect the pin–bone interface and minimize premature pin loosening due to excessive local stress, the surgeon should use more pins (at least three and rarely two per fragment) which are relatively large (up to 30% of the bone diameter), noting that stiff fixator pins featuring positive threads should be used in preference to smooth or more flexible pins.

## Techniques of fixator pin placement

All pins must be placed with due consideration to the limits of safe, hazardous, and unsafe corridors as defined and described by Marti and

Miller (1994a,b). Ideally, "safe" corridors will be used exclusively, but the nature of limb anatomy and ESF is such that the ideal is not always achievable, and in most cases a degree of compromise is unavoidable. A knowledge of the cross-sectional anatomy will help avoid neurovascular structures and minimize impingement on soft tissues (Figures 5.2 and 5.3). To offer maximum resistance to axial loading of the repaired bone and to minimize soft-tissue transfixion, fixator pins are placed perpendicular to the long axis of the bone. However, this can only be achieved using threaded fixator pins, which are inherently resistant to "pullout." Should smooth fixatory pins be used, then additional strategies will be needed to prevent external fixator failure by pin pullout. This is why smooth pin fixators *must* always incorporate a degree of divergent or convergent pin angulation. However, angled fixator pins inevitably occupy a greater length of bone than a perpendicularly placed threaded pin, so the use of smooth pin fixators is effectively limited to fractures featuring relatively long fragments (Figure 5.4). Few experienced external fixator surgeons now build fixators using only smooth pins, and most advocate using at least one positive-thread pin on either side of the fracture. There is an increasing move toward the exclusive use of positive-thread pins in veterinary external fixation.

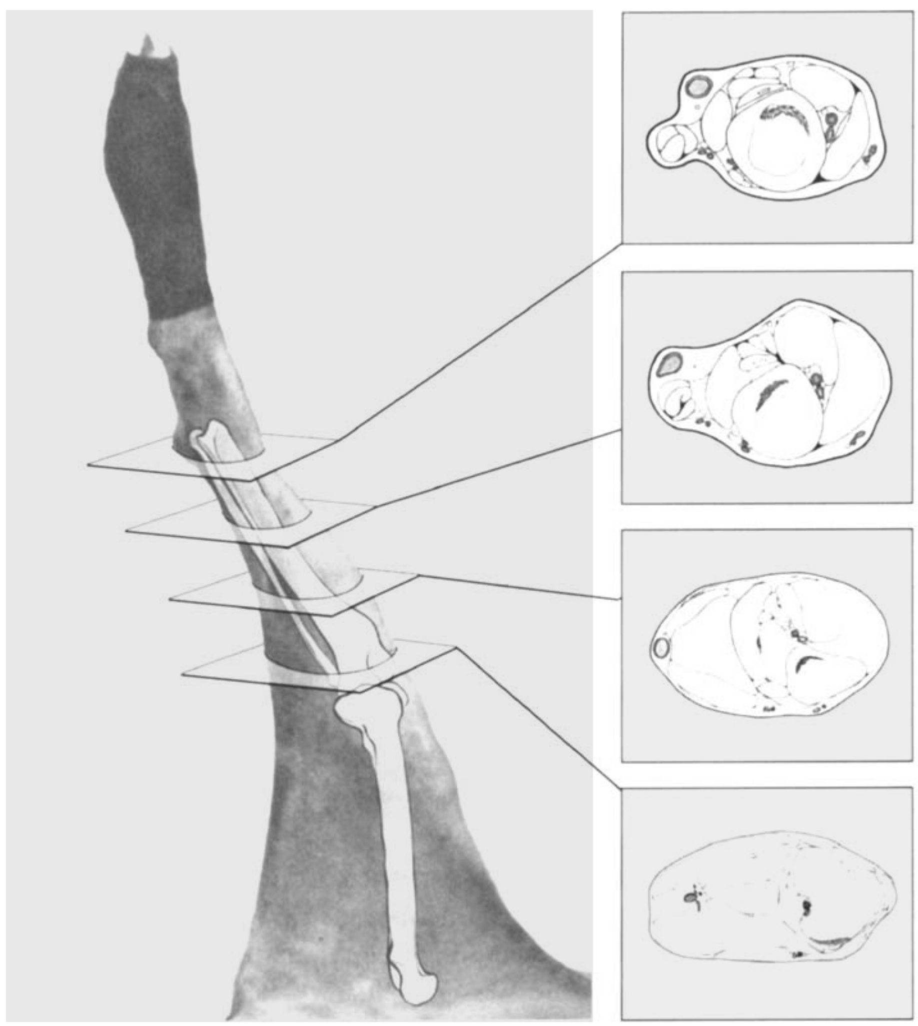


**Figure 5.2** Cross-sectional anatomy of the tibia. The caudal limb is shown suspended with drawings of underlying bone structures. Four cross-sectional anatomic drawings are shown without annotations. Rings in the anatomic cross-sections denote vascular structures. White circles denote nerves. The photographic view is medial. Each cross-section is oriented with the cranial aspect to the right of the page and the lateral aspect to the top of the page.

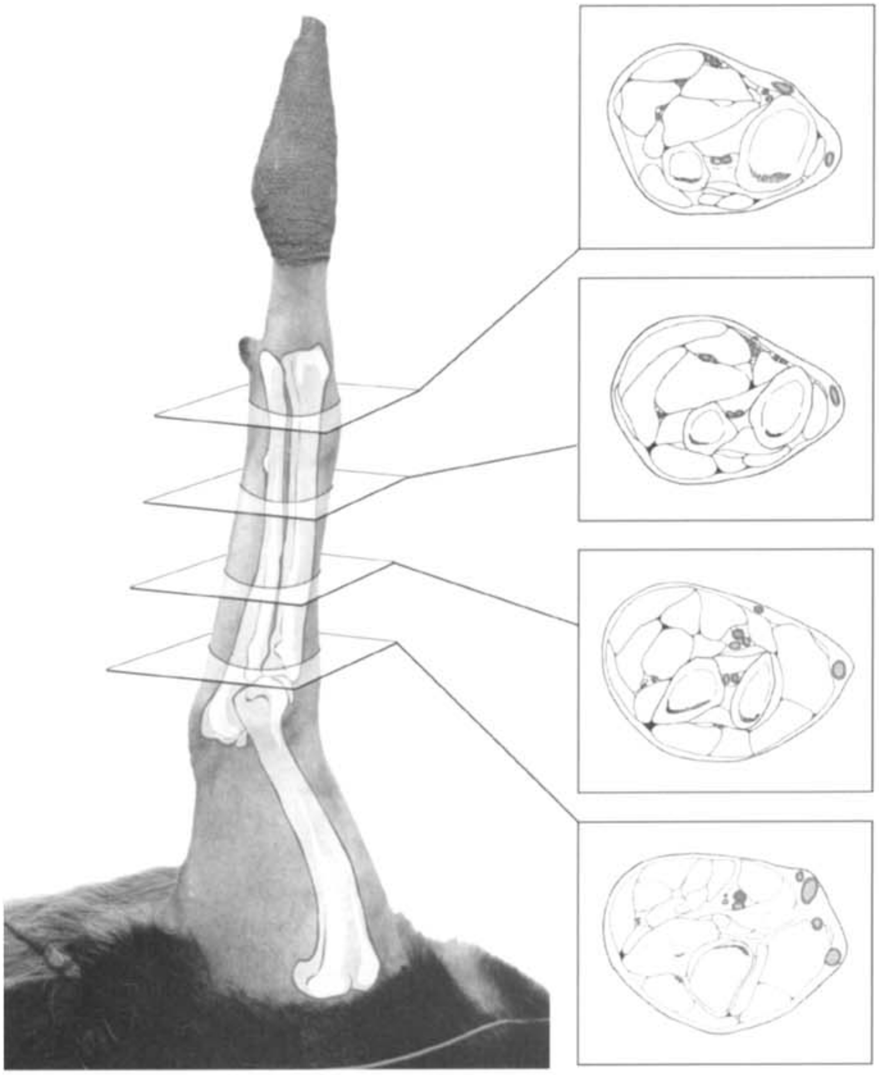


**Figure 5.3** Cross-sectional anatomy of the radius and ulna. The cranial limb is shown suspended with drawings of underlying bone structures. Four cross-sectional anatomic drawings are shown without annotations. Rings in the anatomic cross-sections denote vascular structures. White circles denote nerves. The photographic view is lateral. Each cross-section is oriented with the cranial aspect to the right of the page and the medial aspect to the top of the page.

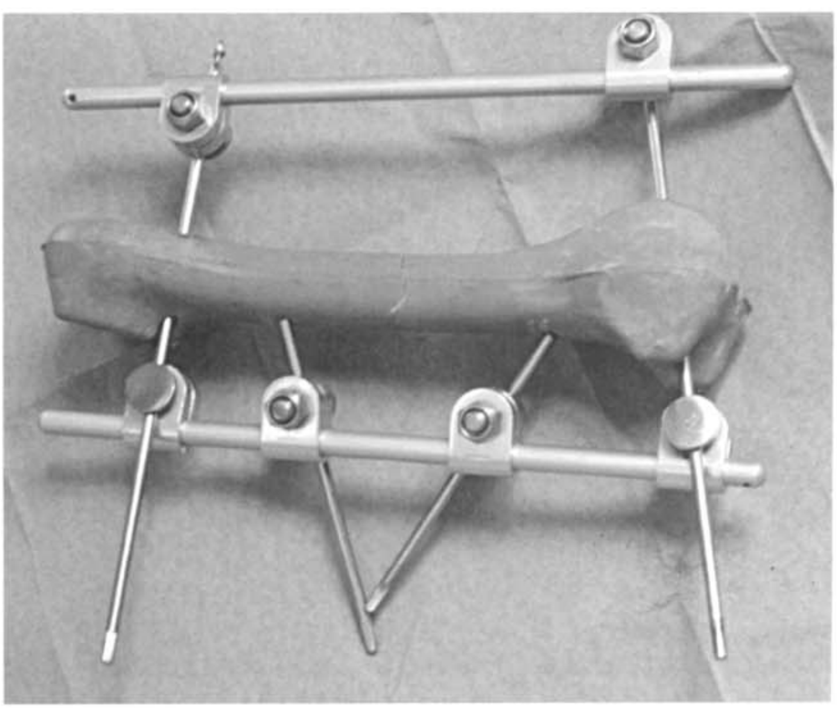


**Figure 5.4** Placement of smooth pins. Whenever smooth (i.e. nonthreaded) fixator pins are used, it is essential to use angled placement to avoid pullout. The exclusive use of smooth fixator pins in any ESF construct is not recommended.

## Placement of half-pins

The technical detail of half-pin placement is illustrated in Figures 5.5–5.10.

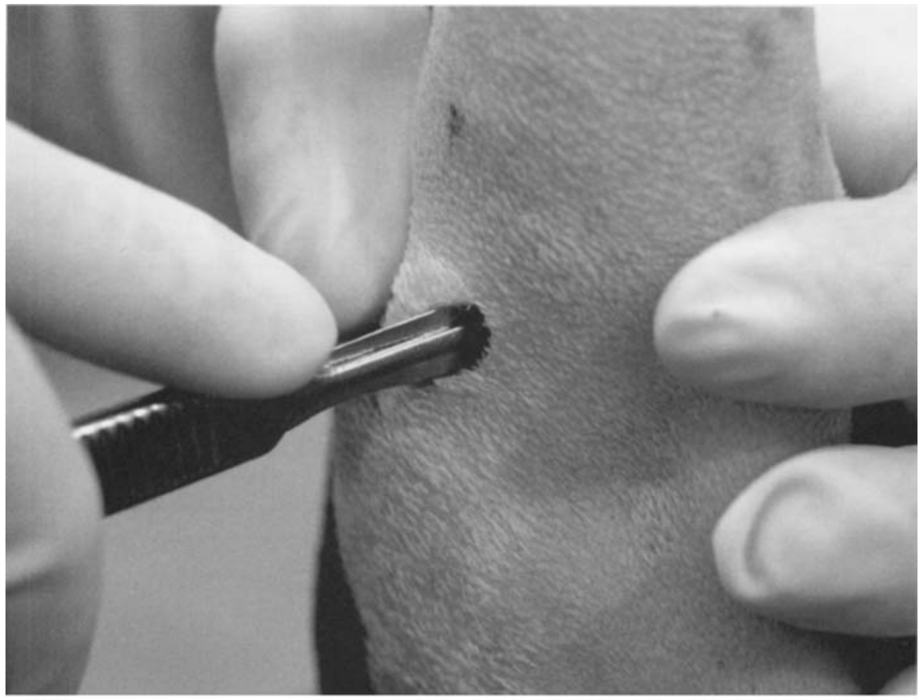


**Figure 5.5** Releasing soft tissues. A stab incision is made which extends through the skin and all the underlying soft tissue down to the bone.

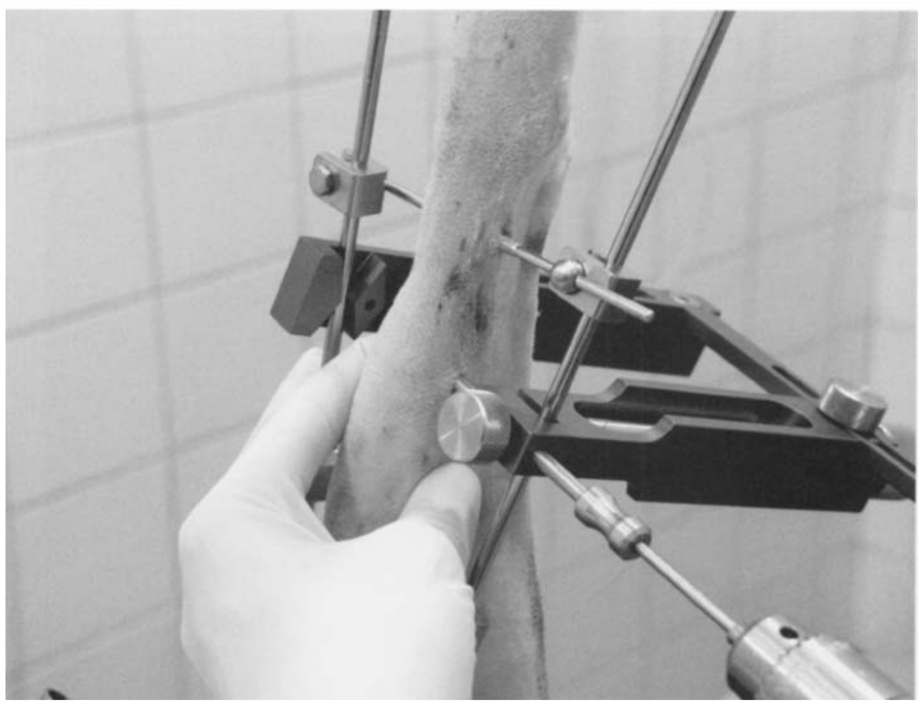


**Figure 5.6** Protecting soft tissues. "Windup" of subcutaneous soft tissues must be prevented. To achieve this the use of tissue protectors is recommended. The use of a tissue protector/drill guide with the Securos aiming device is shown here. The Securos aiming device is designed to facilitate accurate placement of multiple full pins.

**Figure 5.7** Tissue protector. This tissue protector can be used with the K–E and other external fixator systems. The instrument is placed between the clamp on the preassembled frame and the skin. After drilling and pin placement, the sprung "clam-shell" design allows easy removal of the instrument.

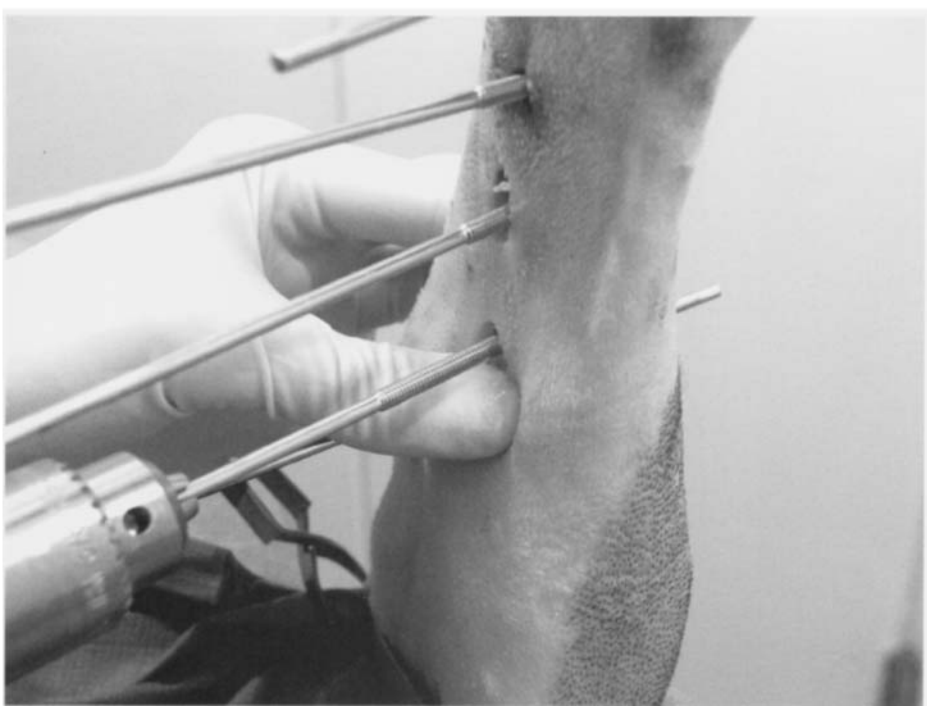


**Figure 5.8** Predrilling pin holes and placing fixation pins. A hole up to 98% of the pin diameter is made and the pin is driven using a low-speed power tool. On occasion, it may not be feasible to use a tissue protector; in that instance, windup of soft tissues can be controlled by firm digital pressure applied close to the pin as it is placed.

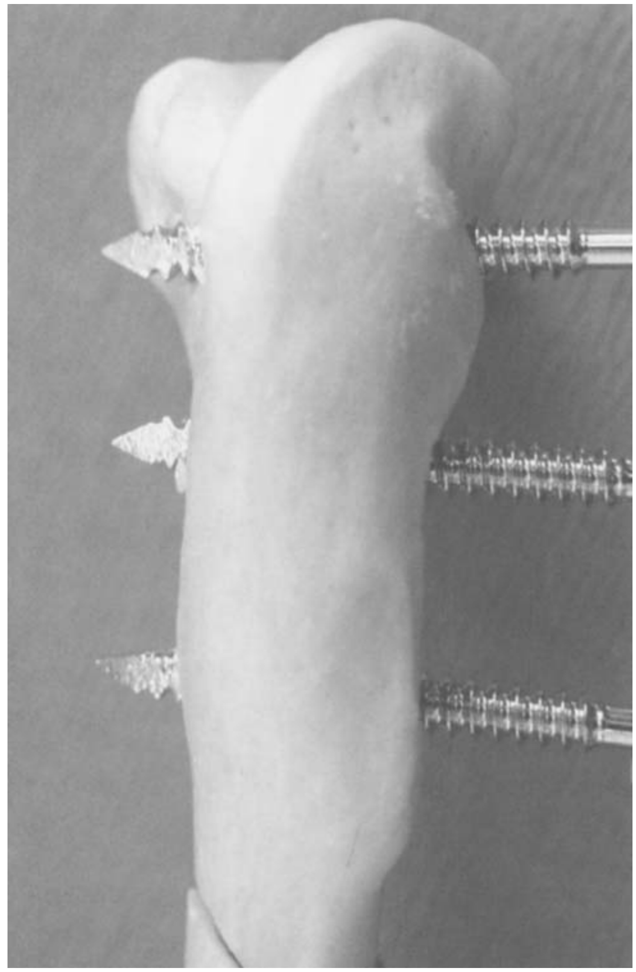


**Figure 5.9** Correct placement of half-pins. Half-pin threads should engage both cortices fully. This means that a short part of the trocar point will protrude beyond the surface of the trans cortex.

A

B

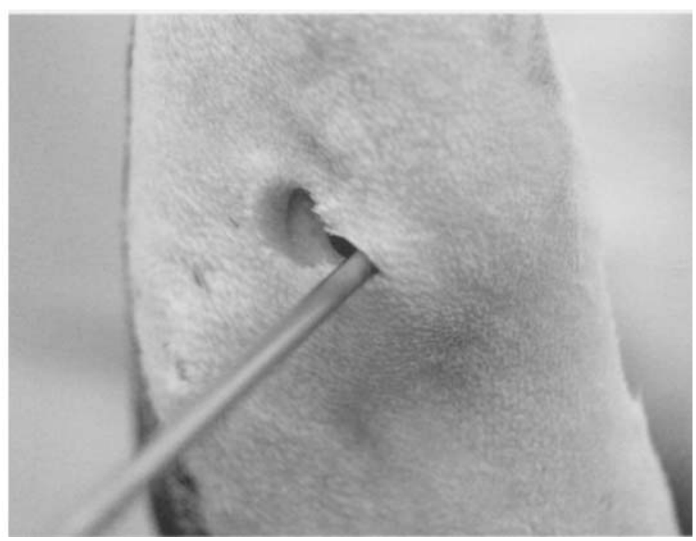


**Figure 5.10** Releasing skin tension. It is important that the skin is not left under tension around the pin. Any remaining tension (A) is relieved by making a small releasing incision (B). No attempt is made to suture skin closed around a pin.

## Placement of full pins

The fundamentals of this technique are identical to those described for half-pin placement. However, the degree of compromise required when using full pins is greater because there are very few locations where a full pin can be placed to enter *and* exit the limb through safe corridors. The advantage of using full pins lies in the construction of bilateral fixator frames, which are both stiffer and stronger than unilateral constructs. With experience, the fixator surgeon will recognize when the extra strength and stiffness of bilateral frames outweigh any disadvantage associated with the placement of a full pin in what might be a less than ideal anatomical location.

A second specific difficulty associated with the use of full pins is geometric and relates to the use of multiple full pins in ESF constructs. Such frames demand careful alignment of *all* full pins in *exactly* the same plane if each pin is accurately to engage *both* connecting bars. A number of strategies have been evolved to deal with this difficulty. One solution is to apply a second, temporary, connecting bar exactly parallel to either the medial or lateral connecting bar. This is done immediately after placement of only the most proximal and the most distal full pins. This establishes a plane, and all subsequent full pins are placed using the two parallel pins as a guide (Figure 5.11). Obviously, this is cumbersome and laborious, and in practice gives rather disappointing results. The Securos fixator system overcomes these difficulties with the use of a specially designed instrument (Figure 5.6), which is described fully in Chapter 6. However, many surgeons choose to avoid the problems of placing multiple full pins by settling for a compromise solution involving a bilateral, uniplanar fixator in which only one full pin is placed in each of the proximal and

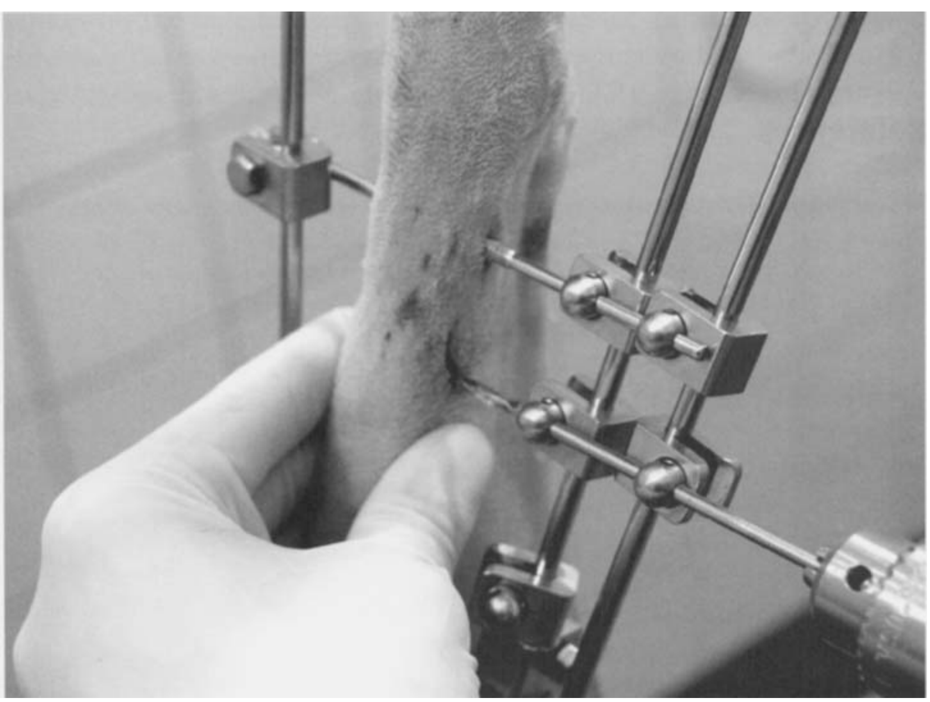


**Figure 5.11** Aiming full pins without guides. To aim multiple full pins, the first two pins are united with connecting bars in the usual method and a third bar carries clamps to act as "drill guides" for placement of all subsequent pins. In practice, this technique is flawed, and many surgeons find it more effective to merely aim pins "by eye."

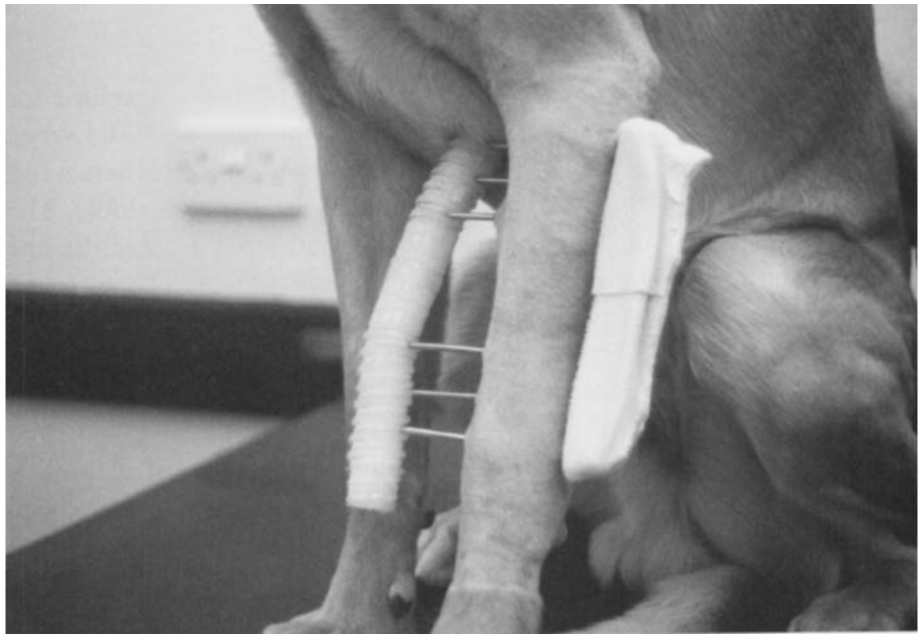


**Figure 5.12** Using only two full pins in a type II fixator. This ulna/radius fracture has been stabilized using a modified type II fixator in which only two full pins have been used. Such constructs, although not as stiff and strong as frames with multiple full pins, are much easier to build.

distal fragments (Figure 5.12). Such constructs, although not as stiff and strong as fixators featuring exclusively full pins, are significantly easier and quicker to assemble.

When using rigid connecting bar fixator systems, the importance of accurate reduction and limb alignment *prior* to pin placement cannot be overemphasized. The potential for intraoperative adjustment and realignment of a fracture after pin placement is minimal. This is particularly true of external fixator constructs with multiple full pins, with the potential for adjustment of a fixator after pin placement limited to what can be achieved by stressing pins, reversing clamp orientation, etc.

## References

Marti JM and Miller A (1994a) Delimitation of safe corridors for the insertion of external fixator pins in the dog. 1. Hindlimb. *Journal of Small Animal Practice* **35**: 16–23.

Marti JM and Miller A (1994b) Delimitation of safe corridors for the insertion of external fixator pins in the dog. 2. Forelimb. *Journal of Small Animal Practice* **35**: 78–85.

# Chapter 6
# The Securos External Fixation System

The Securos external fixation system was introduced in 1997 and was designed to promote optimal technique with familiar and easy to use components. The system overcomes many of the limitations of the K–E fixator, including adding and subtracting fixator clamps transversely, stronger connecting frames, a guide for predrilling pilot holes and placing full pins, positive-profile fixation pins, and methods of dynamization. The clamps, pins, connecting rods, and wrenches are compatible and interchangeable with K–E components.

## Fixation pins and connecting rods

Fixation pins are available in three sizes: 1/16 inch, 3/32 inch, and 1/8 inch. 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. This is far greater than the stiffness of regular Steinmann pins. The thread profile is like an orthopedic screw called a buttress thread and is self-tapping (Figure 6.1). This thread profile results in less bone being removed during insertion and therefore less damage to the bone. The diameter of the core of the pin in the area of the 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 pushes on the hole to a small extent. This effect, called radial preload, enhances the bone–pin interface. The connecting rods are 9.5 mm for large (carbon fiber), 4.8 mm for medium, and 3.2 mm for small fixators.

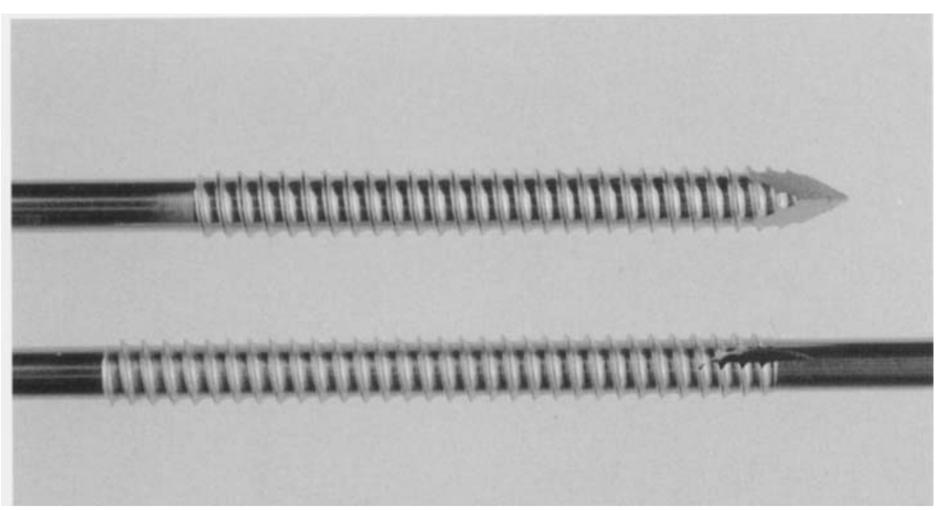


**Figure 6.1** Fixation pins. End-threaded and center-threaded fixation pins. The thread profile is a buttress thread that decreases the amount of bone removed. They are made of spring-hardened 316L stainless steel, making them much stiffer than a standard Steinmann pin.

## Clamps

The clamp is composed of three components: a U-shaped part, a head part, and a bolt (Figure 6.2). There are three sizes of clamps. The large clamp accommodates 3.2-mm fixation pins, the medium clamp accommodates 3.2-mm and 2.4-mm 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 onto a connecting rod (Figure 6.3). 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. The U-shaped component bends only elastically. As a result, during use it acts like a lock washer, preventing loosening. Also, as the clamp does not deform plastically, it is easier to reuse. Double connecting clamps are made by using two U-shaped components, a head component, a longer bolt, and a small sleeve (Figure 6.4). 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.

## Aiming instrument

An aiming instrument allows simple predrilling of pilot holes and accurate placement of half-pins or full pins (Figure 6.5). The handle contains a drill sleeve for drilling pilot holes for fixation pins. Once two pins are placed and connecting bars are installed, the handle connects to the connecting

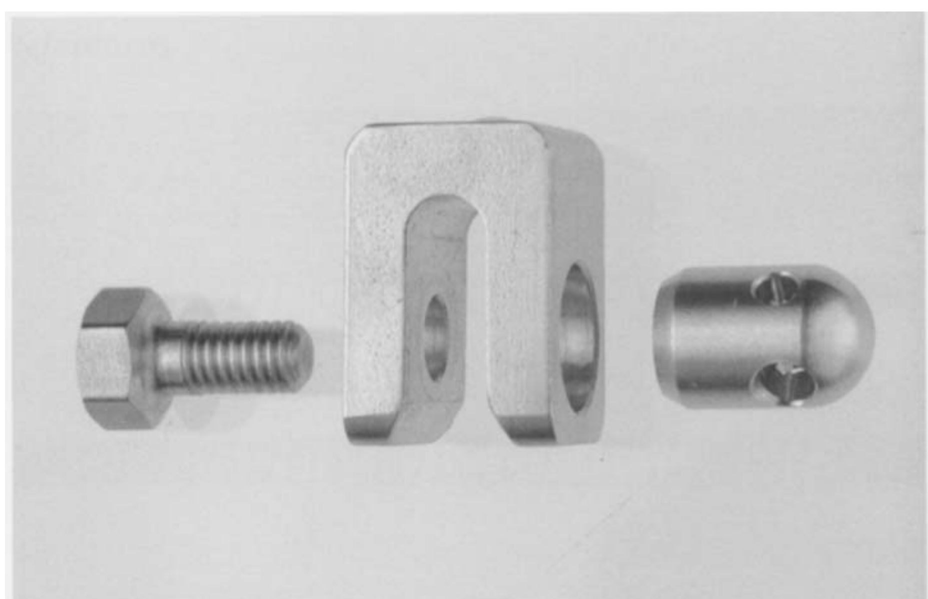


**Figure 6.2** Clamp. The Securos clamp consists of three components: a U-shaped component, a head, and a bolt. This clamp snaps transversely onto a connecting rod and provides a very rigid connection with a fixation pin.

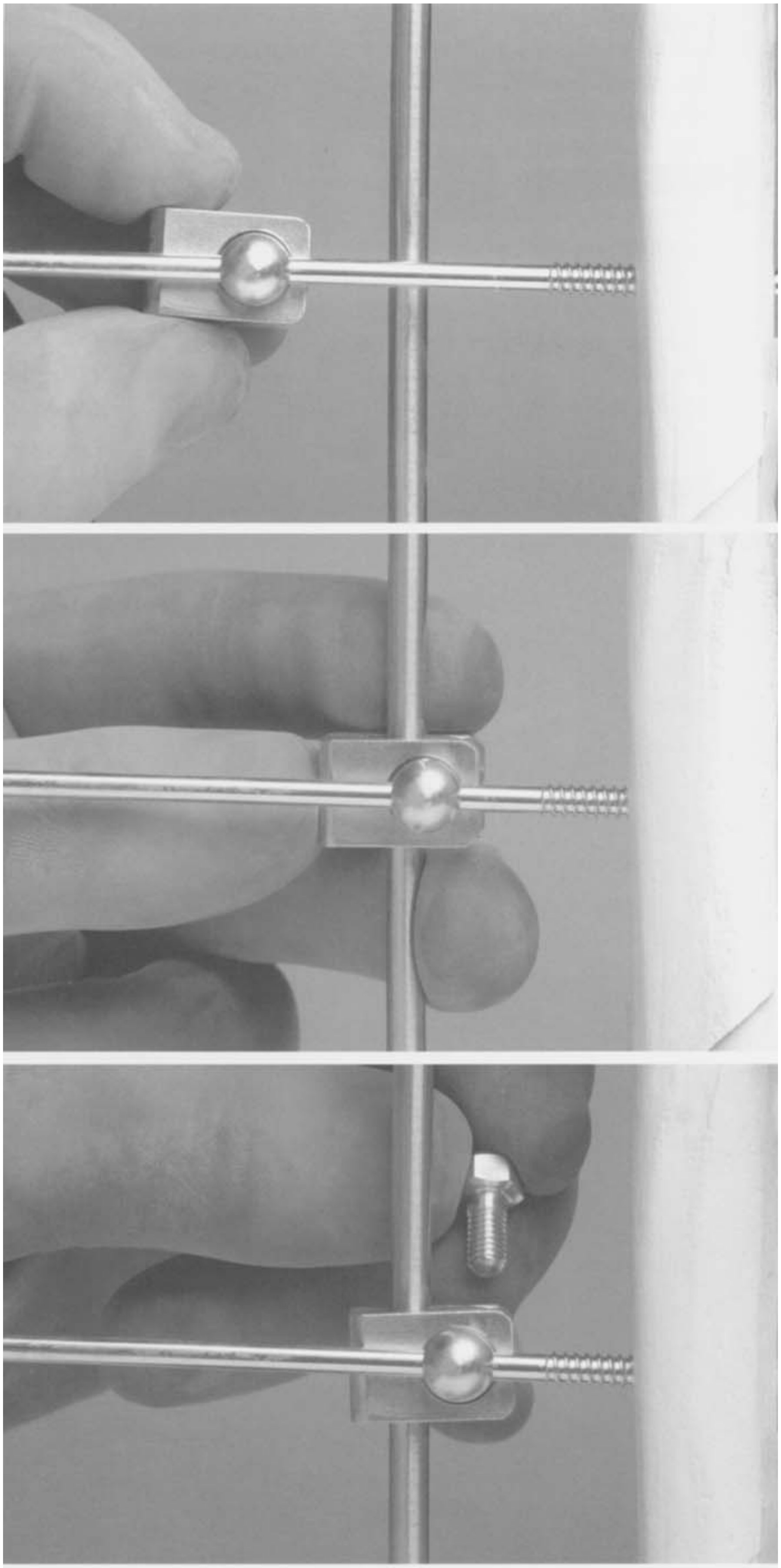


**Figure 6.3** Transversely adding clamps. Once the first two fixation pins and a connecting rod are in place, consecutive fixation pins are added. Clamps are transversely added by placing the U-shaped component and head component together and sliding them down a fixation pin (top). The clamp is snapped onto the connecting rod (middle), then a bolt is applied (bottom).

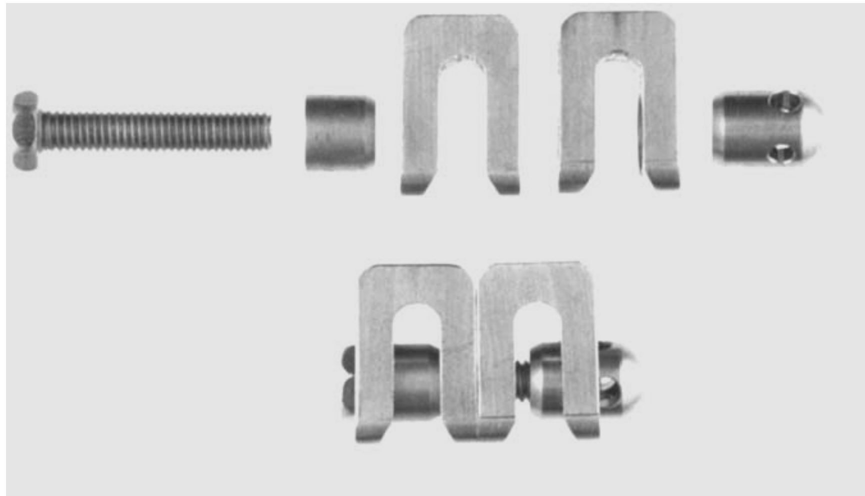


**Figure 6.4** Double clamps. Double clamps are composed of two U-shaped components, a head component, and a sleeve and longer bolt. When appropriate, the double clamp may also accommodate a fixation pin.

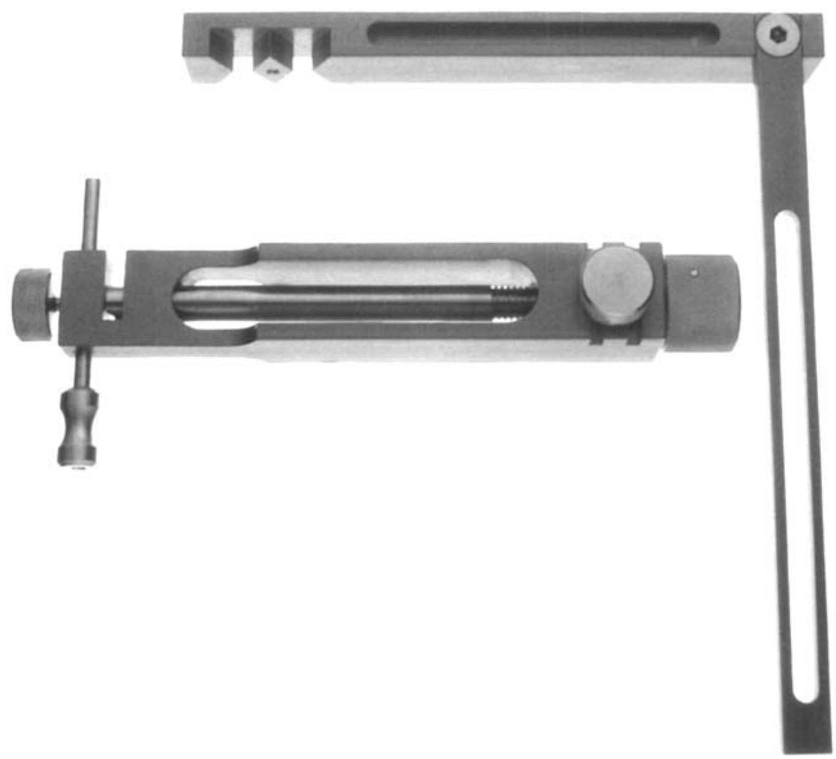


**Figure 6.5** Aiming instrument. An aiming instrument is used to predrill pinholes, guide fixation pins into the pilot hole, and place full pins accurately to the opposite connecting rod.

bar. The drill guide places a fixation pinhole in exact relationship to the connecting bar for application of a clamp. The pin can be angled in any direction proximally and distally by up to 30°, and cranially and caudally in any direction. 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 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°.

To increase the stiffness of unilateral fixators when using 4.8-mm connecting bars, augmentation plates can be added to the two central clamps. This increases axial stiffness by 450%, medial to lateral bending stiffness by 450%, and cranial to caudal stiffness by 150% (Figure 6.6).

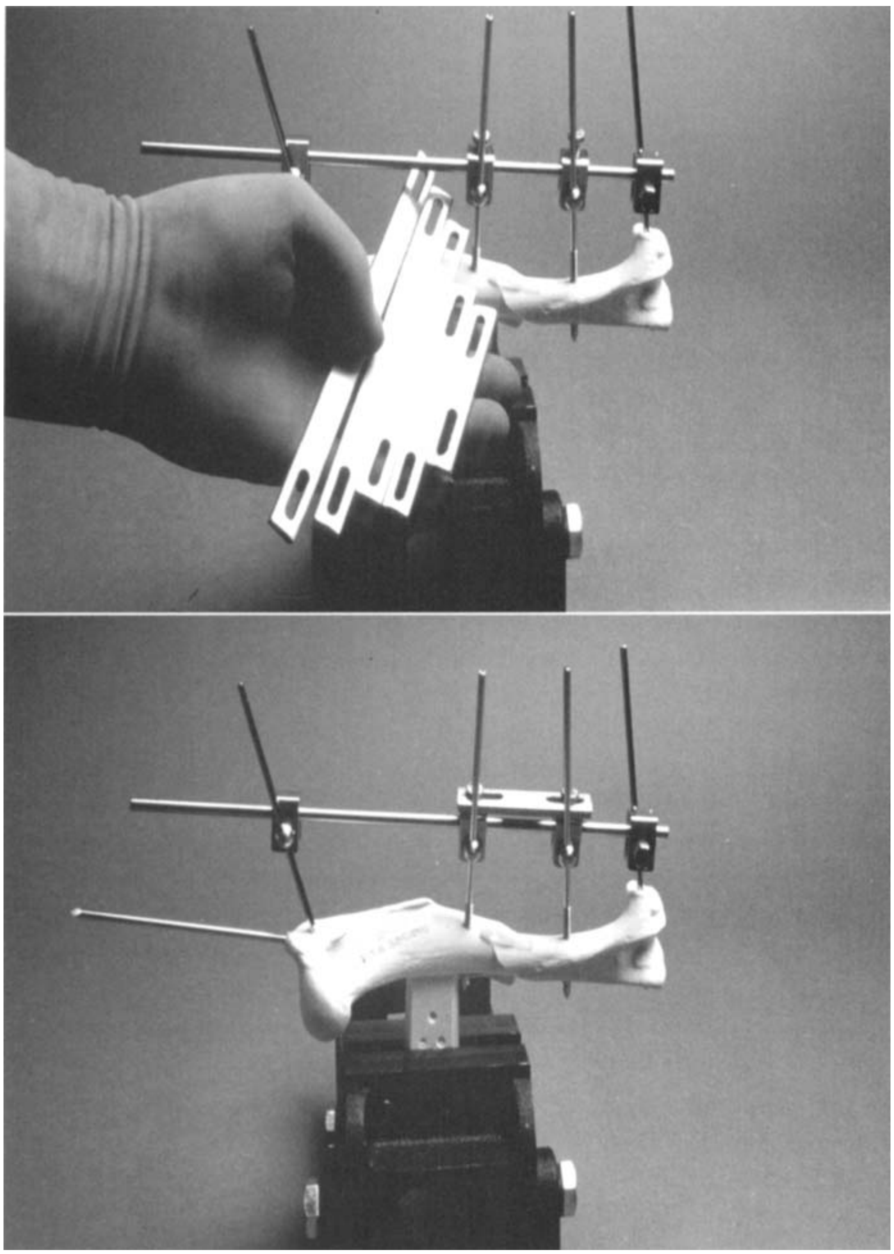


**Figure 6.6** Augmentation plates. When using 4.8-mm connecting rods, augmentation clamps and plates can be added to the two innermost fixation pins. This increases the axial stiffness by 450%, the medial to lateral bending stiffness by 450%, and cranial to caudal stiffness by 150%.

Unique to the Securos system are two methods of simply changing the fixation frame to allow weight-bearing forces to go through the long axis of the bone (axial dynamization) without the need to remove fixation pins. In unilateral frames that employ the augmentation bars, the bars can be removed, decreasing stiffness to 25–30%. 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 6.7). Thus, weight bearing will cause pure axial loads to be exerted on a healing fracture while the bone is supported in torsion, translation, and bending.

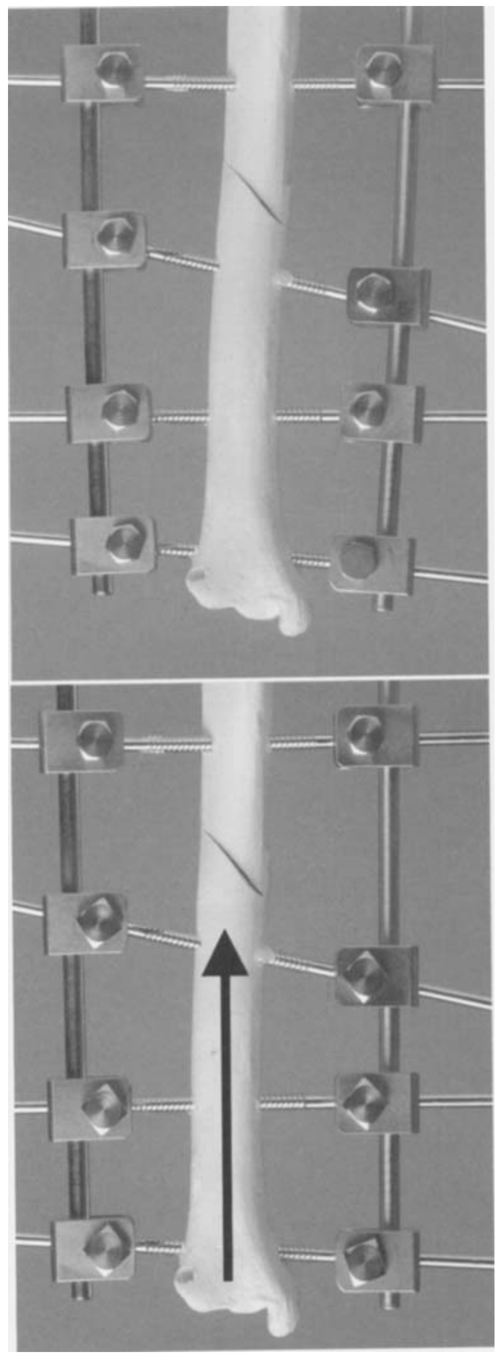


**Figure 6.7** Dynamization bolts. With bilateral fixators, axial dynamization is achieved by replacing the bolt of the fixation clamp with a slightly longer bolt with a square head (for identification) on one side of the fracture. This allows the fracture to carry axial loads (arrow) while being supported in torsion, translation, and bending.

## Technique



The fracture is reduced and proximal and distal fixation pins are placed near the ends of the long bones. Connecting bars are secured to the fixation pins with clamps and the clamps are tightened. Clamps are not preplaced 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 6.8). It is placed on the connecting rod with the drill sleeve. An intramedullary pin is advanced to the desired location and used as a trocar to facilitate correct placement in the bone. The

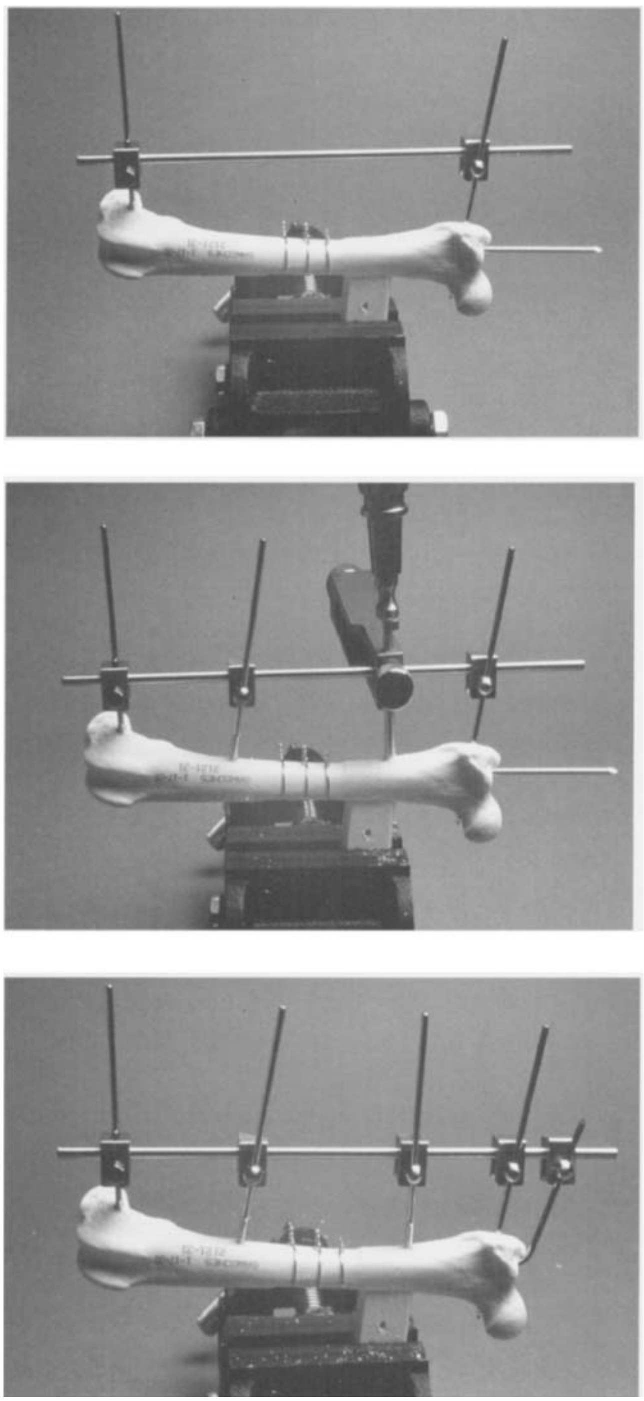


**Figure 6.8** Application of unilateral fixator frames. Unilateral fixators are applied placing the first two pins and connecting rod in standard fashion. Consecutive fixation pins are added using the aiming instrument by drilling a pilot hole, inserting a fixation pin through the device, removing the device, and snapping on a clamp.

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. A pilot hole of the same diameter as the shaft of the fixation pin is drilled. In the case of the large clamp, a 3.2-mm hole is drilled, and for a medium clamp either a 3.2-mm or 2.4-mm hole. There is a separate drill sleeve for each drill. For smaller clamps, either a 2.4-mm or 1.5-mm pilot hole is drilled.

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 low speeds and high torque. The fixation pin is placed so that it penetrates both cortices and only the trocar point can be felt protruding from the opposite cortex. The aiming instrument is removed. A clamp is then applied by holding together the U-shaped component and the head-shaped component and sliding the assembly over the fixation pins. Together, the components are snapped onto the connecting rod. The bolt is then inserted and tightened.

Full pins in bilateral fixators are placed in a similar manner, except that the arm on the aiming instrument is used. The most proximal and distal fixation pins are placed with connecting bars on both medial and lateral aspects of the limb. The aiming instrument is placed on either connecting rod with the arm in place (Figure 6.9). There are two grooves on the far end of the arm. The arm is slid so that the opposite connecting bar rests in either of these two grooves. A 3.2-mm Steinmann pin is inserted into the drill sleeve and through the skin to determine whether it will contact bone. A 3.2-mm Steinmann pin is also inserted in a hole between the two grooves on the arm and through skin, again to determine whether it will contact bone. This ensures 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 start from the opposite side of the connecting rod. This allows four possible positions for a full fixation pin and therefore four opportunities to place a full pin. If any of these positions do not result in a full pin being placed, then a half-pin can be placed. Pilot holes are drilled in a similar manner, 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 removed and clamps are slid onto the fixation pins and then snapped onto the connecting rod and tightened (Figure 6.10).

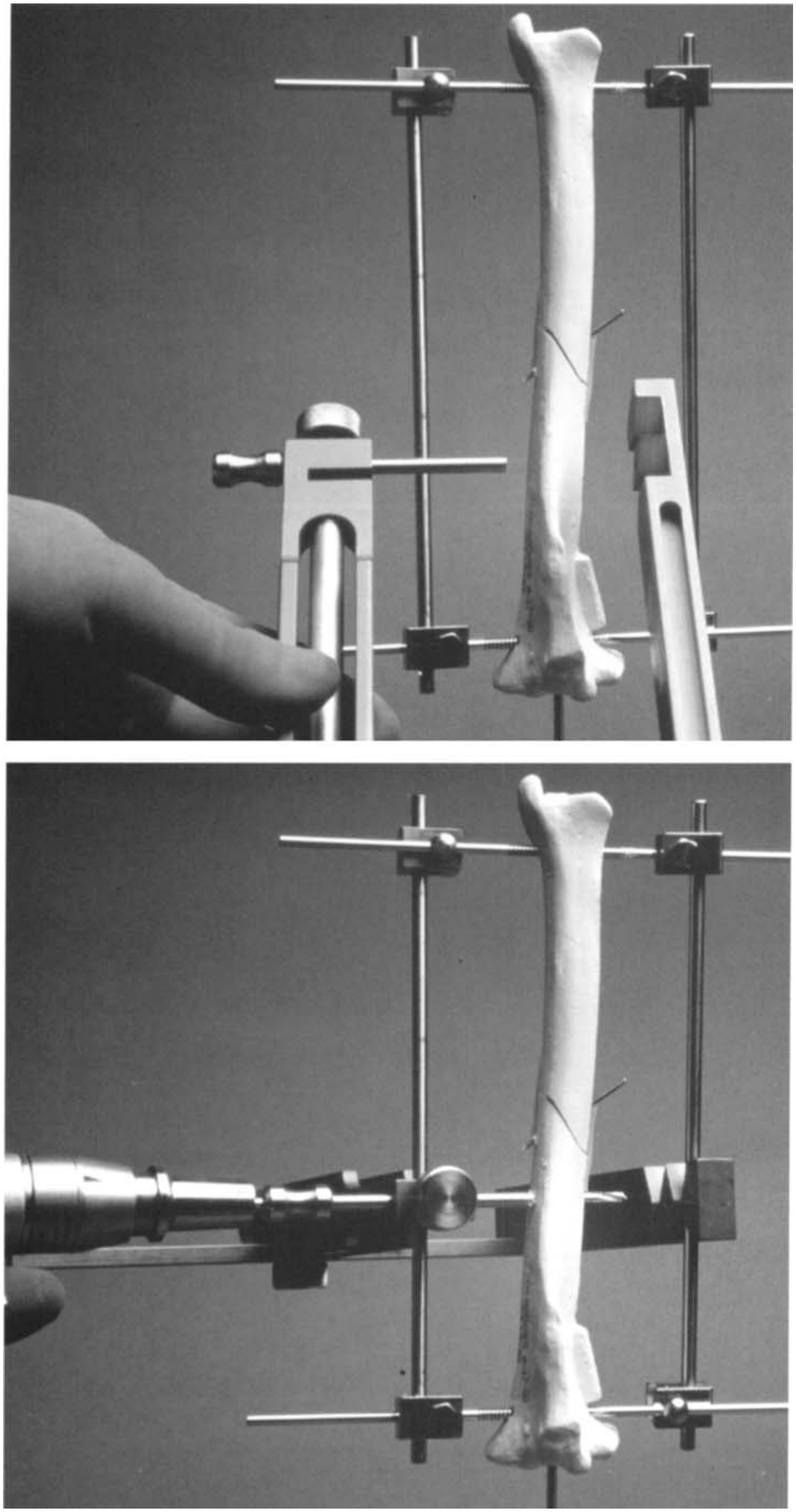


**Figure 6.9** Application of bilateral fixator frames. Bilateral fixators are applied by placing the first two pins and connecting rods in standard fashion. Consecutive fixation pins are added using the aiming instrument with its arm for full pins. Full pins need not be placed in one plane and can be placed in front of or at the back of either connecting rod, allowing four pin orientations to the connecting rods. Pilot holes are drilled that will direct the fixation pin accurately to both connecting rods.

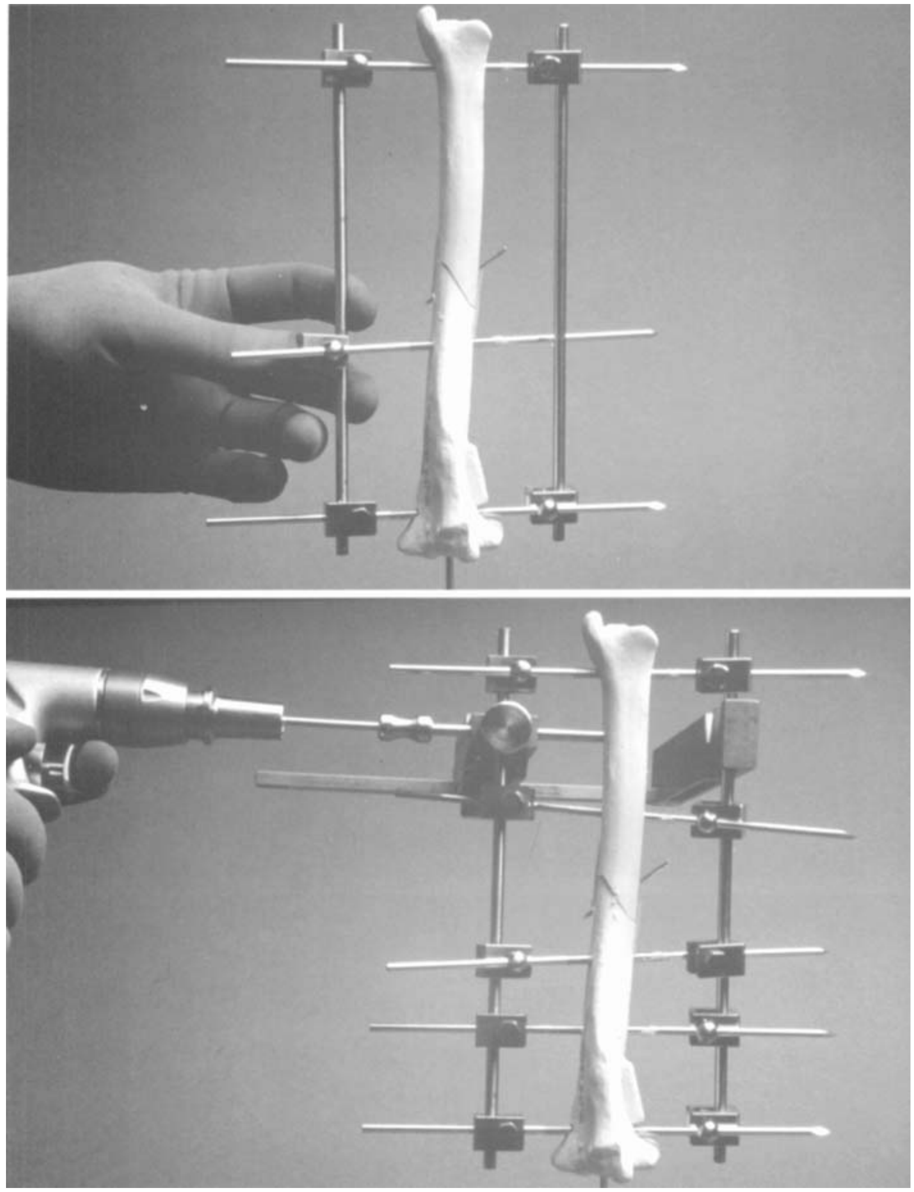


**Figure 6.10** Application of multiple full pins. Once the fixation pin is applied, clamps are snapped on and the bolts inserted and tightened. Additional full or half-pins can be applied as appropriate.

# Chapter 7
# The IMEX-SK External Fixation System

Like the Securos external fixator, the IMEX-SK external fixator was designed to overcome the problems that were experienced with the K–E splint (inability to easily apply positive-profile threaded pins to the central positions of a construct; inability to alter pin diameter without sacrificing pin–clamp–rod security; inability to add clamps to or subtract clamps from an existing assembly; inability to tighten clamps securely without permanently deforming them; and the necessity of applying complex configurations to highly comminuted fractures to protect weak frame components). Although SK clamps are compatible with fixation pins designed for the Securos fixator and K–E splint, the SK rods and wrenches come in metric sizes (Table 7.1) and thus are not interchangeable with those of the other two clamp and rod external fixators.

## Fixation pins

IMEX fixation pins include centrally threaded full pins (*centerface* pins) and end-threaded half-pins (*interface* pins). Seven different sizes are available with positive-profile cortical thread. The smallest of these has a 2-mm shank and 2.5-mm thread and the largest has a 4-mm shank and 4.8-mm thread. Three different sizes are available with a positive-profile cancellous thread. The smallest of these has a 2.4-mm shank and 3.5-mm thread and the largest has a 4.8-mm shank and 6.3-mm thread. Use of the cancellous fixation pins should be confined to areas of soft bone such as the proximal metaphyseal region of the tibia or humerus and the distal metaphyseal region of the femur.

## Clamps

SK clamps consist of a two-piece, aluminum body, a primary pin-gripping clamp bolt with a slotted washer, a nut to tighten the primary bolt, and a

**Table 7.1** Pin, rod, wrench, and bolt sizes for IMEX-SK fixators

| Clamp size | Fixation pin shaft diameter | Connecting rod diameter (mm) | Wrench/bolt/ nut size (mm) |
|---|---|---|---|
| Small | 3/32 to 5/32″ (2.4–4.0 mm) | 6.3[a] | 8 |
| Large | 1/8 to 3/16″ (3.2–4.8 mm) | 9.5[b] | 10 |

Superscript letters indicate types of rods available: [a]carbon-fiber composite rods and titanium rods; [b]carbon-fiber composite rods and aluminum rods.

secondary lag bolt that tightens the top portion of the clamp (Figure 7.1). The two components of the clamp body differ slightly. The B1 portion has threads in the top hole for the secondary bolt, whereas the B2 portion has a smooth gliding hole at the top. Both components have a smooth hole in the bottom portion for the primary clamp bolt. The rod-gripping channel is in the center of the assembled clamp body. Clamps can be preplaced on the connecting rod but can also be assembled on the rod at any location desired.

Clamp design enables the use of different fixation pin diameters at any position within the construct. The primary clamp bolt includes a gliding washer with a slot that enables it to grip securely a wide range of different pin shaft diameters (Table 7.1). The hole in the primary bolt is large enough to enable sleeved predrilling and application of positive-profile pins directly through the clamp. The slotted washer of the primary clamp bolt has a multitoothed surface that engages the outer surface of the clamp body when the clamp bolt is tightened (Figure 7.2). 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 of the washer enables positive retention at any desired angle using either half-pins or full pins.

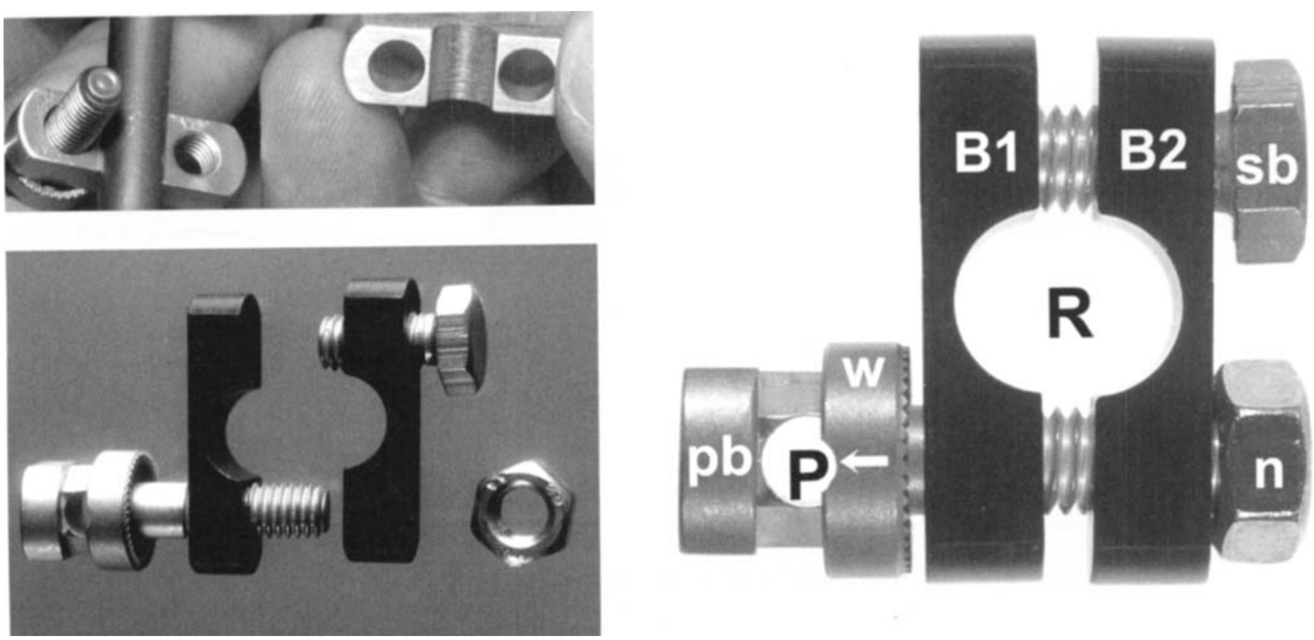



**Figure 7.1** IMEX-SK single clamp. B1 and B2 are the two halves of the clamp body. The B1 portion has threads in the top hole for the secondary bolt (sb), whereas the B2 portion has a gliding hole for the secondary bolt that allows the top portion of the clamp to be tightened by "lag effect." The rod-gripping channel (R) is in the center of the clamp. The pin-gripping bolt (pb) has a washer (w) with a slot or meniscus (arrow), enabling a wide range of pin sizes to be effectively 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. The top-left picture shows a clamp being removed from a type I construct. The bottom-left picture shows orientation of the different parts for correct assembly of the single clamp.

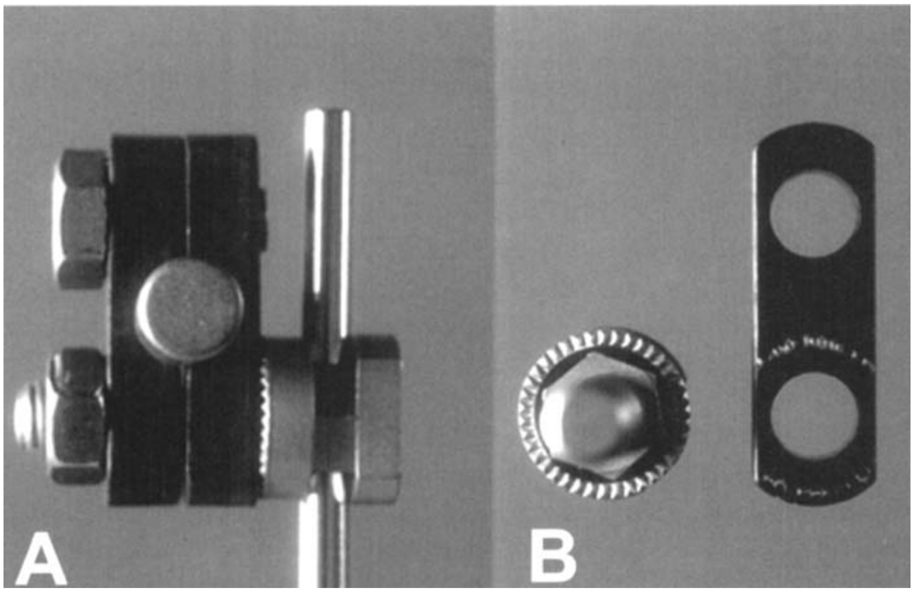



**Figure 7.2** (A) The IMEX-SK single clamp tightened to grip the fixation pin and the rod. Note that the teeth of the washer engage the clamp body. (B) Portions of the disassembled clamp. Note that the teeth of the washer have made indentations in the B1 body part.

The secondary bolt serves several functions. It provides secure tightening of the clamp on the rod without deforming the clamp and it enables the empty clamp to serve as a targeting device as follows. A drill sleeve is placed through the pin-gripping channel of the primary bolt and aligned in the same plane as an adjacent full pin (when multiple full pins in a segment are desired). Partial tightening of the secondary bolt on the rod and the primary bolt on the drill sleeve maintains this alignment during predrilling of the bone. The nut on the primary bolt is loosened, the drill sleeve is removed, and the fixation pin is passed through the hole in the primary bolt. Clamp position and alignment are maintained during application of the pin by the partially tightened secondary bolt.

## Connecting rods

Small (3.2 mm) and medium (4.8 mm) stainless-steel connecting rods were evaluated and determined to be the weak link in simple K–E fixator constructs. This limitation necessitated the use of more complicated bilateral and biplanar configurations when the K–E splint was used to manage highly comminuted fractures of the radius or tibia. The IMEX-SK fixator addressed this problem by using larger connecting rods. Small SK clamps use 6.3-mm connecting rods made of either titanium or carbon-fiber composite. Large SK clamps use 9.5-mm connecting rods made of either carbon-fiber composite or aluminum. Bending stiffness values of small and medium stainless-steel rods and the various SK rods are summarized in Figure 7.3. Compared with the K–E splint, the larger, stiffer connecting rods of the SK fixator enable the use of simpler frames for stabilization of comminuted fractures. In cases in which maximal type II or type III constructs would be required with a K–E splint, a type Ib

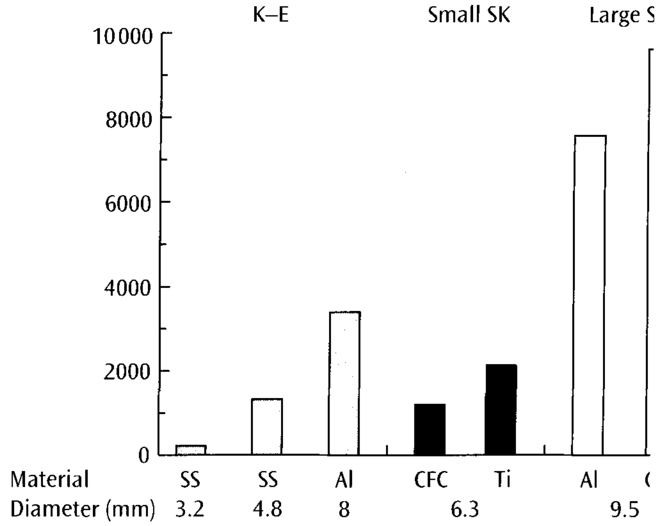



**Figure 7.3** Comparative bending strength of connecting rods used with different sizes of the K–E fixator and small and large IMEX-SK fixators. Al, aluminum; CFC, carbon-fiber composite; SS, stainless steel; Ti, titanium.

or a minimal type II construct is generally sufficient with an IMEX-SK fixator.

SK double clamps are available for making rod to rod articulations in biplanar or multiplanar frames, but simpler, more compact articulations can be made using K–E or Securos stainless-steel rods to interconnect SK single clamps placed on the ends of the SK frame rods (Figure 7.4). Additionally, SK or K–E single clamps can be "stacked" on the ends of fixation pins and interconnected with stainless-steel rods to build articulations or diagonals.

Modified SK single clamps can be assembled from standard parts to build an adjustable articulation that is quite useful when an external fixator is applied to immobilize a major weight-bearing joint (transarticular ESF). Modified clamps are built with two B2 body parts, two primary pin-gripping bolts, and two nuts (Figure 7.5). The articulation is built with two modified clamps and two short pieces of Securos or K–E stainless-steel rod (Figure 7.5). The angle of this articulation is adjustable, which can be used to the surgeon's advantage when a transarticular fixator is employed in the management of Achilles tendon repairs. Adjustments in the articulation angle to increase the amount of flexion of the hock enable progressive loading of the tendon during the later stages of healing.

The IMEX-SK fixator does not offer the dynamization feature of the Securos fixator, but staged disassembly can be accomplished is several ways. With the large SK fixator, carbon-fiber composite rods can be replaced with aluminum rods to reduce frame stiffness. Another strategy involves removal of large SK clamps and rods at about 6 weeks and replacing them with small SK clamps and rods. With the small SK fixator, titanium rods can be replaced with carbon-fiber composite rods to reduce frame stiffness. Additional disassembly options applicable to either size of SK fixator include removal of components to convert bilateral or biplanar frames to simple unilateral frames and removal of central fixation pins to increase the working length of the fixation frame.

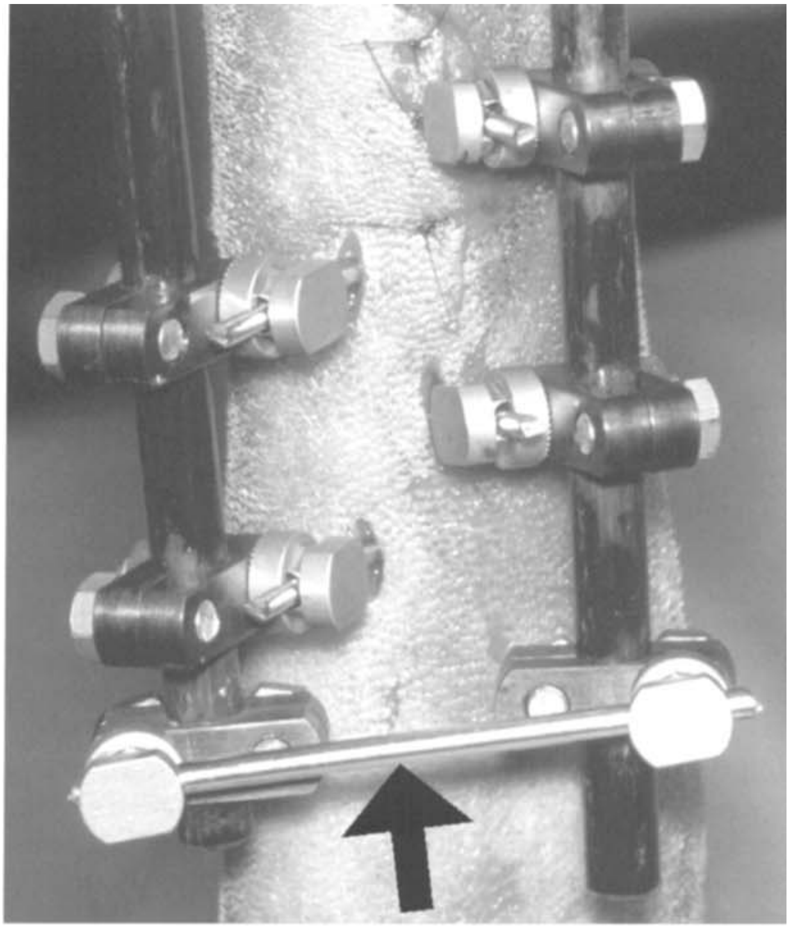


**Figure 7.4** Large SK type Ib fixator on the radius of a large-breed dog. A simple articulation has been made proximally (arrow) by placing single clamps on the ends of the carbon-fiber composite connecting rods and interconnecting them with a “rod” cut from a $^{3}/_{16}''$ (4.8 mm) Steinmann pin.

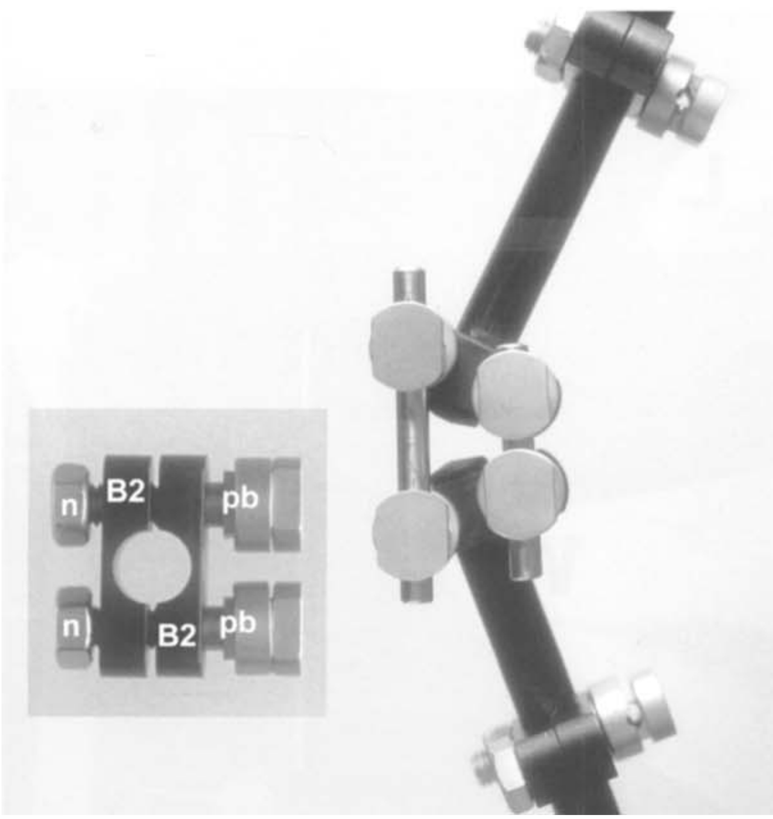



**Figure 7.5** Modified SK clamps for adjustable transarticular fixator constructs. Connecting rods can be rigidly stabilized at a given angle using two modified SK single clamps and a pair of short stainless-steel rods. Each modified articulation clamp is built with two B2 body parts, two pin-gripping bolts (pb), and two nuts (n). The angle of the articulation can be changed by loosening the modified clamps, flexing or extending the joint to the desired position, and retightening the articulation.

## Technique

Using the hanging limb technique (for fractures of the radius/ulna or tibia), the fracture is reduced, and predrilling technique and low-rpm power insertion are used to apply proximal and distal fixation pins to the bone. Single clamps and a connecting rod are applied to form the medial portion of the frame. This process is then repeated on the opposite side of the limb to complete the lateral portion of the frame if a type II configuration is being applied. Fracture alignment is verified and clamps are carefully tightened to maintain this alignment. An open-end wrench can be placed on the flat surfaces of the outside of the pin-gripping bolt to counter disruptive torque forces on the frame while the nut and secondary bolt are tightened with an L-shaped wrench (Figure 7.6).

An ample release incision is made prior to applying each fixation pin. Correct centering is verified prior to predrilling of the bone with an appropriately sized twist drill bit at high rpm through a drill sleeve mounted in an empty clamp applied to the rod. The pin should be placed with a low-rpm, high-torque power insertion technique. The majority of pins placed in SK frames are generally half-pins. If more than one full pin is needed in a major fracture segment, an empty clamp applied to the rod and a drill sleeve can be used to target them in the correct plane as previously described (Figure 7.7). Generally, at least three fixation pins are applied to both the major proximal and major distal fracture segments. Postoperative radiographs are usually taken prior to the application of any articulations or diagonals used in biplanar frames.

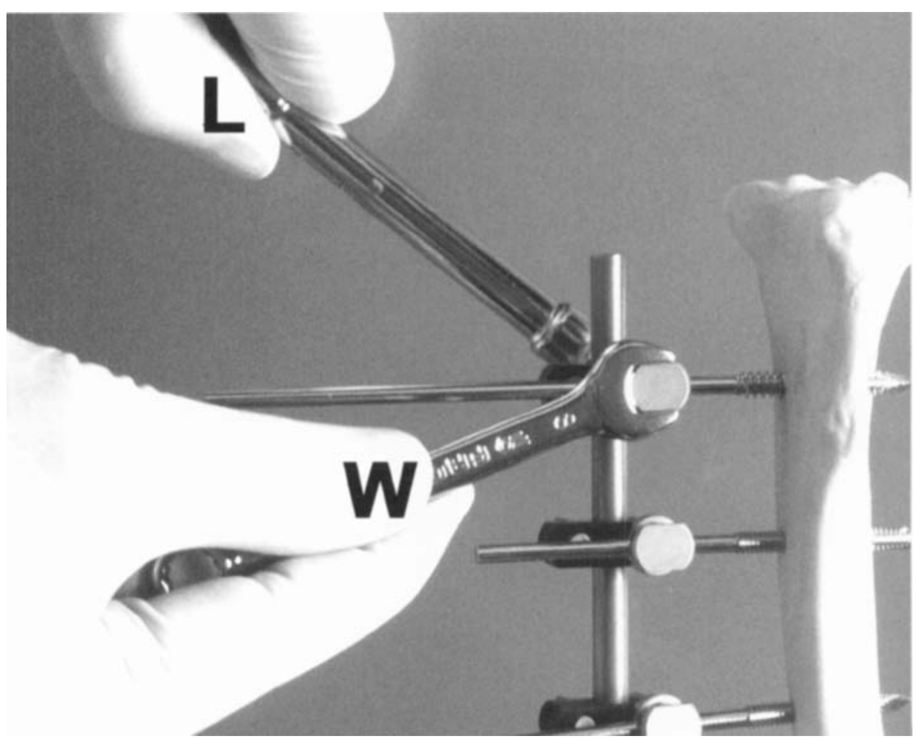



**Figure 7.6** Neutralizing disruptive torque forces while tightening an SK clamp. When clamps are tightened, uncontrolled torque forces may disrupt fracture alignment. To prevent this, an open-end wrench (W) is placed on the flat surfaces of the end of the pin-gripping bolt to counter torque forces on the frame while the nut and secondary bolt are tightened with an L-shaped wrench (L).

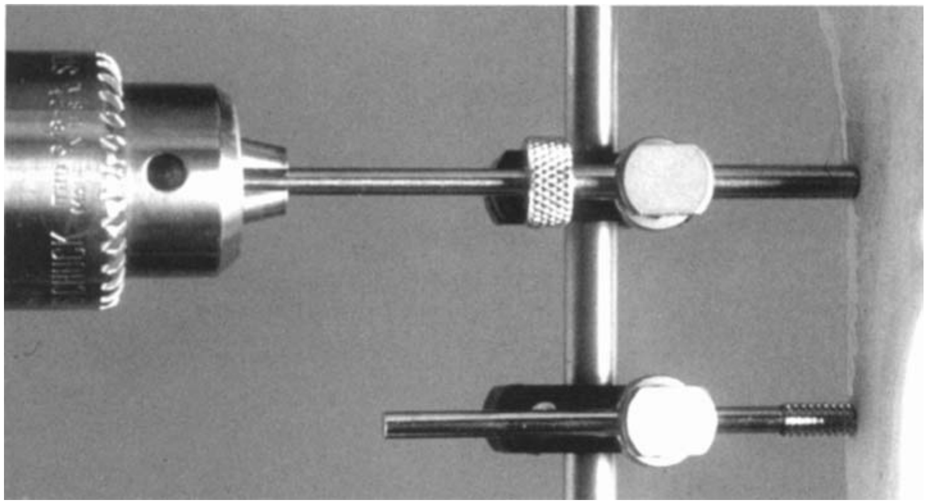


**Figure 7.7** Use of drill sleeve and clamp to properly align multiple full pins. When passing multiple full pins through a bone segment, an SK clamp and drill sleeve can be used to target them in the same plane. The drill sleeve is passed through the channel in the primary pin-gripping bolt and then aligned in the same plane as the adjacent full pin. The secondary bolt is tightened on the rod to maintain the proper position of the drill sleeve so that predrilling of the near and far cortices will be accurate. The nut on the primary pin-gripping bolt is partially tightened to lightly grip the drill sleeve (overtightening may crimp the drill sleeve). The bone is then drilled with the appropriate-size drill bit.

# Chapter 8
# The Acrylic Pin External Fixator System

As the practice of veterinary ESF became established, surgeons became increasingly aware of the limitations imposed by existing instrument systems (the K–E system and its derivatives). These had not changed significantly since their first use in the early part of the twentieth century. The more obvious of these limitations would include the following:

- no potential for using smaller (or larger) pins and difficulty in utilizing the newly developed positive-profile pins;
- inability to add or subtract clamps from an existing assembly;
- frequent failure, loosening, or deformation of clamps during normal use;
- the need to apply overcomplex frames solely to protect weak frame components.

Additionally, the straight, rigid connecting bars dictated to an uncomfortably large extent the location of fixator pins, with the result that some pins had to be placed in less than ideal locations because biologic or mechanical considerations were subservient to constraints dictated by the use of a straight connecting bar.

## Acrylic connecting columns

Many surgeons have experimented with acrylics to join pins to rigid connecting bars – effectively replacing the function of the K–E-type clamp. The only reason for this always was (and still is) cost – to avoid purchasing proper fixator clamps. However, results are unpredictable (and often poor!) The resulting fixators retained *all* the shortcomings of K–E-type systems and, in addition, were very prone to failure by premature loosening or fracture of the acrylic "clamps." Such "Heath Robinson" fixators are not used by experienced fixator surgeons and have little, if any, place in contemporary veterinary ESF.

Recognizing the shortcomings inherent in the K–E-type ESF systems, Dr Erick Egger and his colleagues researched and engineered the use of poured acrylic to replace both the clamps and the connecting bar. Several papers were published in the veterinary literature throughout the 1980s comparing acrylic with existing ESF systems and validating the poured acrylic system for clinical use. Using flexible plastic tubing pushed over the end of fixator pins, it proved possible to produce a column with acceptably consistent mechanical properties, and further investigation led to the development of systems comparable to the small, medium, and large K–E systems. These were subsequently marketed as the acrylic pin external fixation (APEF) systems (Figure 8.1). The acrylic columns of the APEF system are made to a size that will match or exceed the stiffness and strength of the comparable K–E systems. It is important to appreciate that these data refer to the relatively straight connecting bars. Recent work has confirmed that tight-angled bends in the acrylic will substantially weaken the columns and must be avoided. However, the degree of angulation needed to weaken the columns significantly is rarely necessary in practice.

Compared with the K–E-type fixators, the more obvious advantages of the APEF system include:

- ease of use;
- no restriction of pin size or type;
- no need for preassembly complex planning or preassembly of fixator frames;
- minimal risk of pin or connecting bar loosening and failure.

However, the most significant single advantage of using the APEF system is the freedom to place pins into bone exactly where the surgeon wants them to go, with consideration given only to pertinent biologic and biomechanical factors and no restrictions imposed by straight, rigid connecting bars. Pin location is no longer subservient to connecting bar position.

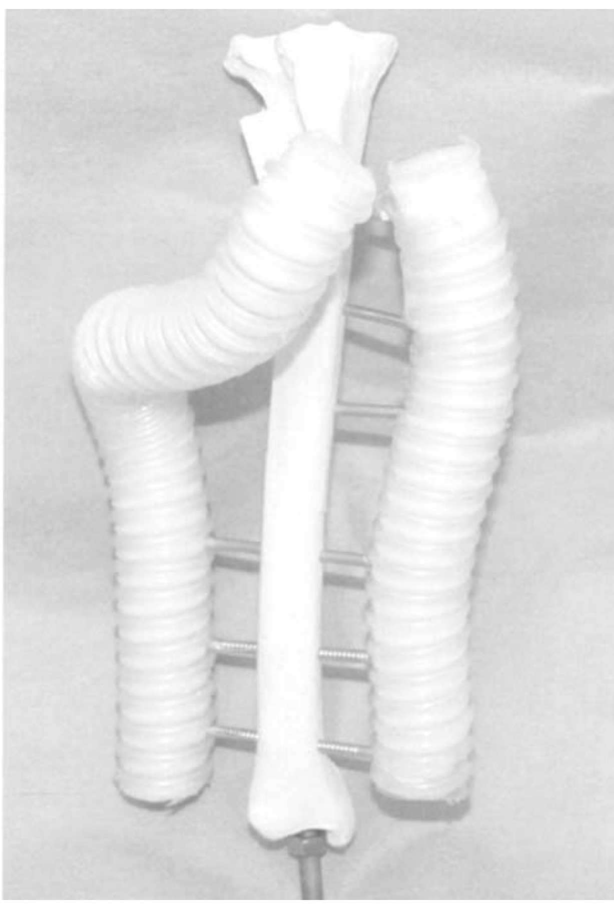


**Figure 8.1** APEF flexible acrylic columns. The APEF system features acrylic columns in place of the more familiar clamp and connecting bar arrangements. The acrylic columns are created *"in situ"* by pouring liquid acrylic into a flexible plastic mold placed over the pins.

## Technique

A relatively modest and inexpensive inventory of APEF components gives potential for managing many types of fracture in patients across the entire size range. The acrylic is supplied in a divided polyethylene pouch along with mold tubes in several diameters (Figure 8.2) Removal of the divider allows the liquid and powder components to mix (Figures 8.3 and 8.4). This initiates a mildly exothermic polymerization reaction, which is the first step toward producing a hard, rigid acrylic column (Figure 8.5). After 2 minutes or so, the pouch is opened and the still liquid acrylic is poured into a flexible plastic tube which has been positioned over the fixator pins (Figures 8.6 and 8.7). It is essential that the fracture has been satisfactorily realigned *before* the acrylic is mixed. The acrylic becomes viscous 2 minutes or so after mixing and solidifies within a further 2–3 minutes. Cure is complete after a further 10 minutes. To maintain fracture alignment during mixing, pouring, and curing, a steel bar is fixed, temporarily, across the fracture between tube and limb. The APEF temporary alignment clamps are designed to be dismantled and removed without having to be slid off the ends of the pins (Figure 8.8). Although useful in some circumstances, these temporary clamps may be unnecessary if the hanging limb technique is used because fracture realignment is maintained passively by virtue of the patient positioning, limb restraint, and gravity.

When more complex fixator frames are required (bilateral, uniplanar; bilateral, biplanar; or quadrilateral) the surgeon has the option of using multiple acrylic columns (Figure 8.9; see also Figure 8.12) or making hybrid frames incorporating acrylic columns and steel connecting bars

**Figure 8.2** APEF kit. The basic kit includes a length of a plastic tubular mold, endcaps for the mold, and a quantity of ready-to-mix acrylic.

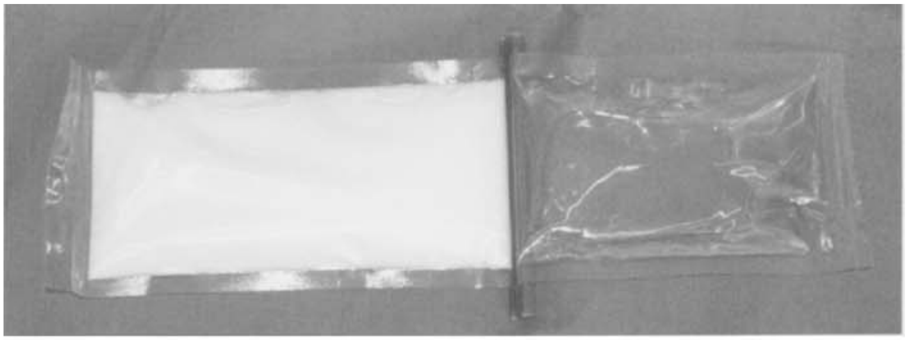


**Figure 8.3** Acrylic bi-pack. The liquid and powder components of the acrylic are supplied in a single pouch separated by a removable plastic divider.

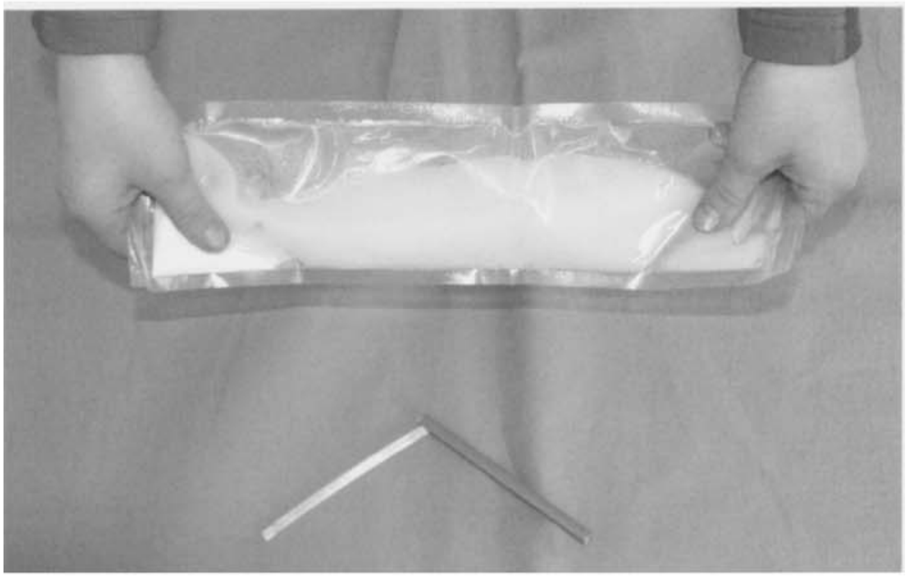


**Figure 8.4** Mixing the acrylic. Removal of the plastic divider allows mixing of the chemicals, which starts a mildly exothermic polymerization reaction and will ultimately produce solid acrylic.

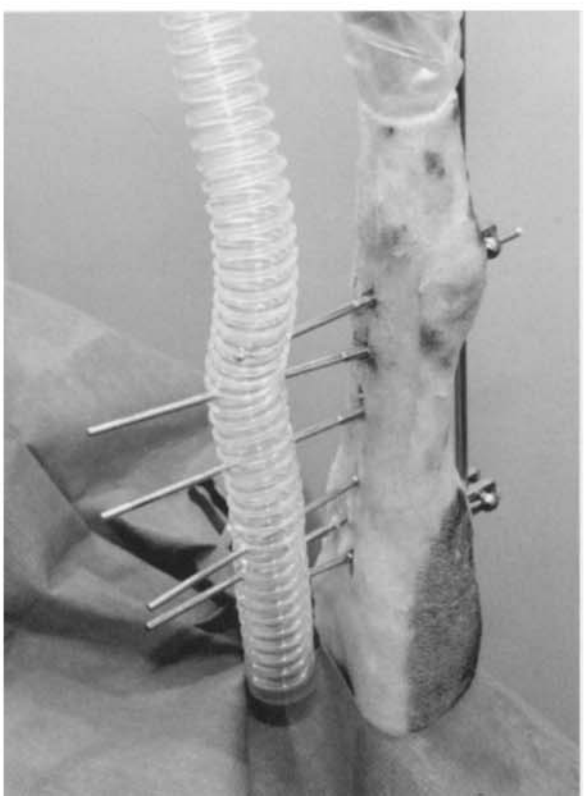


**Figure 8.5** Fracture alignment. Following final pin placement *and* alignment of the fractured bone, the tubular mold is pushed over the ends of the fixator pins. Limb alignment is checked once more prior to mixing then pouring the acrylic.

**Figure 8.6** Opening the pouch. After approximately 2 minutes the liquid acrylic starts to become more viscous; at this point a corner is cut from the mixing pouch to permit pouring.

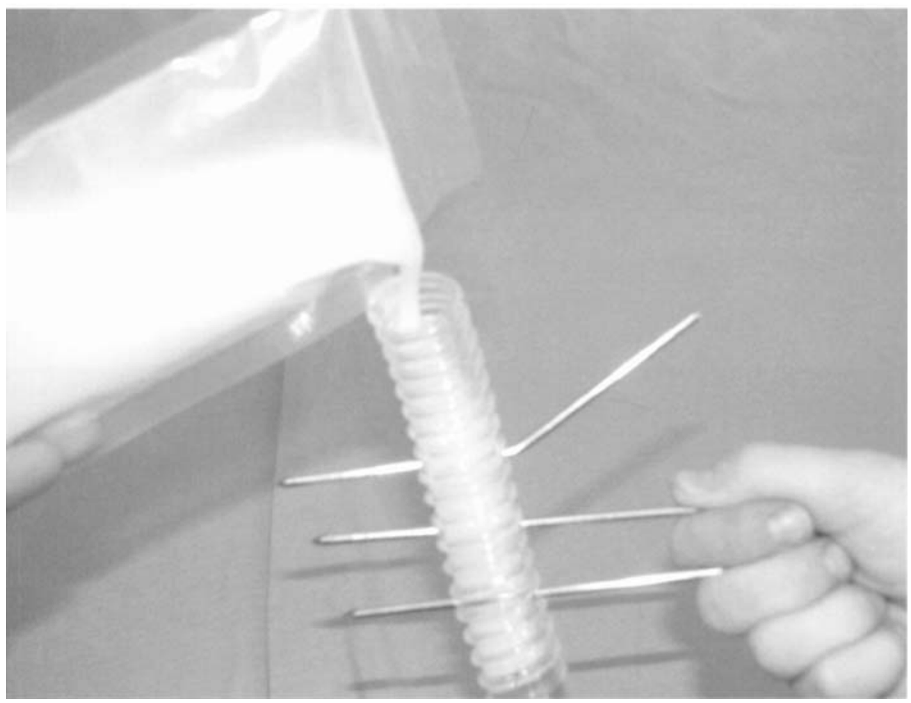


**Figure 8.7** Pouring the acrylic. The viscous but still liquid acrylic is poured into the mold, taking great care to ensure regular filling and to avoid trapping air bubbles. Some minor leakage around the pins is not uncommon, but this soon stops as the acrylic solidifies. The column hardens fully within 10 minutes.

(Figure 8.10). The APEF system is particularly convenient for use with "tied-in" intramedullary pins (Figure 8.11). In such cases, use of acrylic places no restriction upon implant diameter and avoids the need for the complex and weak multiple clamp arrangements necessary when using an intramedullary pin of nonstandard size with an inflexible K–E-type fixator.

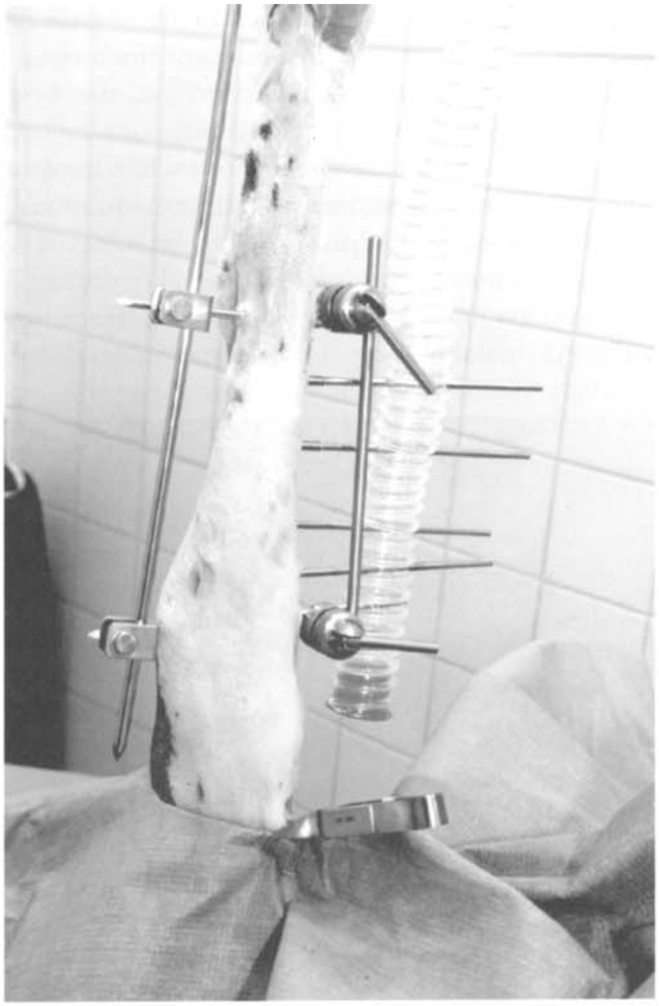


**Figure 8.8** Temporary alignment clamps. These APEF temporary alignment clamps may be used to maintain reduction while the acrylic cures. They can be removed from around the pin without disturbance once the column has hardened. Using the hanging limb technique, alignment is maintained passively so that temporary alignment clamps are rarely necessary.

**Figure 8.9** Flexibility. A femoral fracture in a 65-kg Great Dane treated with a single intramedullary pin and double-column, modified type I (unilateral, uniplanar) APEF fixator.

In common with all other currently available fixator systems, the APEF system is not perfect, and two significant limitations are worthy of mention. First, although quick and easy to use, the APEF system is single use and there is no potential for mitigating costs by reusing clamps or connecting bars as is the case with most other ESF hardware. Second, following APEF application, postoperative adjustment or realignment of the repair is not at all simple. Adjustment can be achieved by removing a 2- to 3-cm length of the midportion of the acrylic column. This is most easily achieved using a small hacksaw. The limb alignment is corrected before the cut acrylic column is repaired using fresh acrylic poured into a

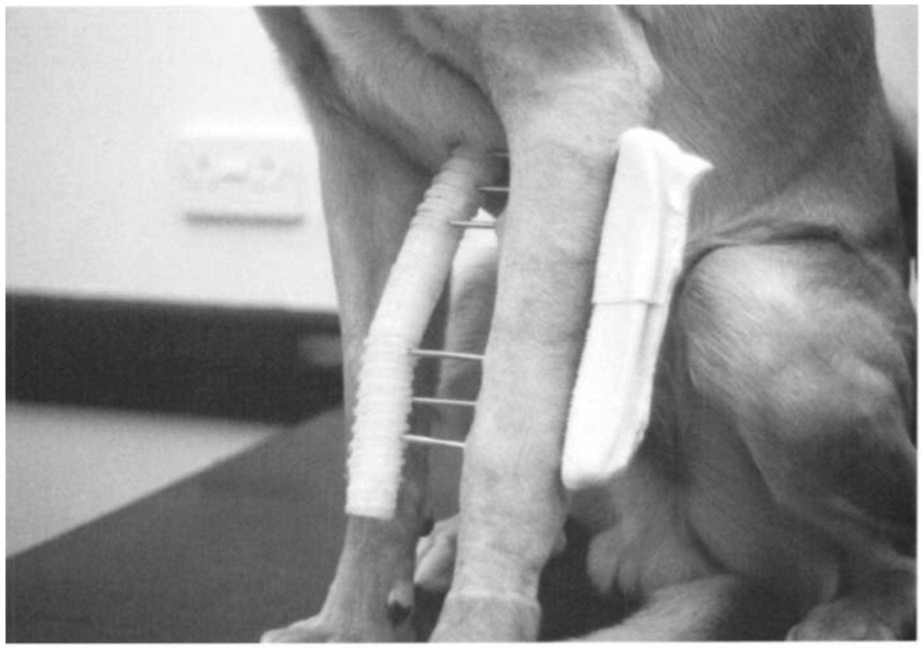


**Figure 8.10** Combining acrylic with other fixator systems. A fracture of the radius and ulna in a 35-kg cross-breed showing a modified type II (bilateral, uniplanar) fixator with an APEF column medially and a regular, steel connecting bar laterally.

**Figure 8.11** Tying in acrylics with intramedullary rods. A comminuted femoral fracture in a young cat was treated with an intramedullary pin and an APEF fixator. The proximal end of the intramedullary pin was left protruding from the proximal end of the bone; it was bent and "tied-in" to the same acrylic column that unites the two small fixator pins distally.

mold made from a length of the same flexible tube split longitudinally and arranged around the recently cut ends of the column. To ensure a strong repair, it is necessary to "key" the cut ends of the column prior to pouring the reparative acrylic by drilling several small holes into each recently cut surface using a drill or burr. An alternative technique is to drill and tap a single hole approximately 10 mm deep into the cut end of each column, into which is placed a single 15- to 20-mm bone screw – 2.7 or 3.5 mm in diameter according to the diameter of the column. The protruding screw provides excellent holding for the repair. Intraoperative realignment is a widely discussed advantage of the K–E and similar systems, but careful consideration of three-dimensional geometry reveals that, in truth, such frames are nonvariable and any potential for postapplication realignment is confined to that which might be achieved by reversing clamps or bending and stressing pins, etc.

Staged removal of external fixator constructs is discussed in Chapter 11. With APEF there is no potential to alter the mechanical properties of the connecting bar, as can be achieved using, for example, the Securos system. Nor is it easy to remove individual pins as facilitated by both the Securos and the IMEX systems. However, strategies have been developed to permit staging down of APEF frames. For example, where two or more connecting columns have been used, these can be removed individually at intervals (Figures 8.12 and 8.13). Although it is impossible to remove individual pins without destroying the acrylic column, this problem is avoided by cutting the pin between the acrylic and the skin. In so doing, that pin becomes mechanically incompetent and the fixator has been, effectively, staged down. Pin removal is completed subsequently at the time of final fixator removal.

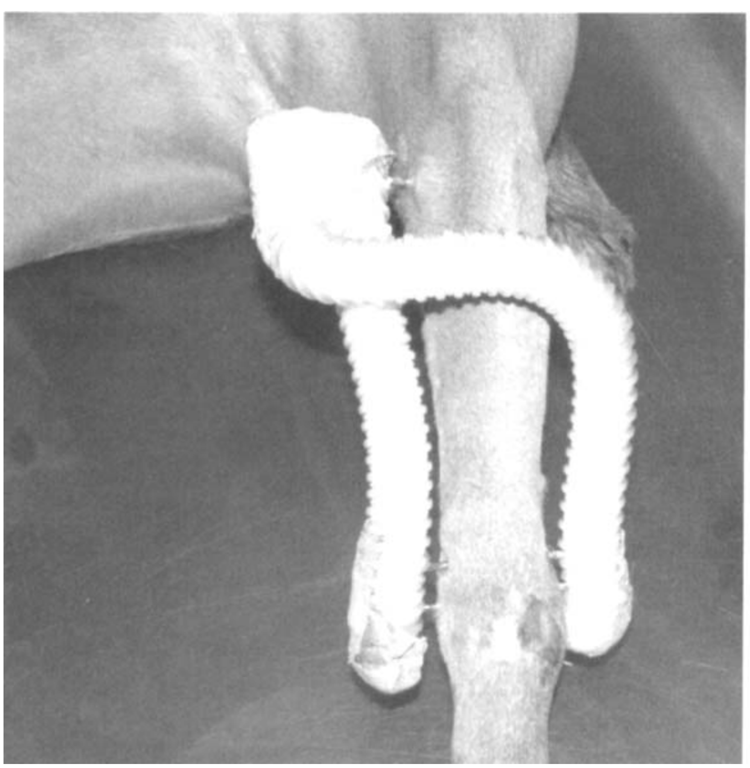


**Figure 8.12** Decreasing fixator stiffness. A tibial fracture in a 45-kg Weimaraner treated with a double-column APEF fixator.

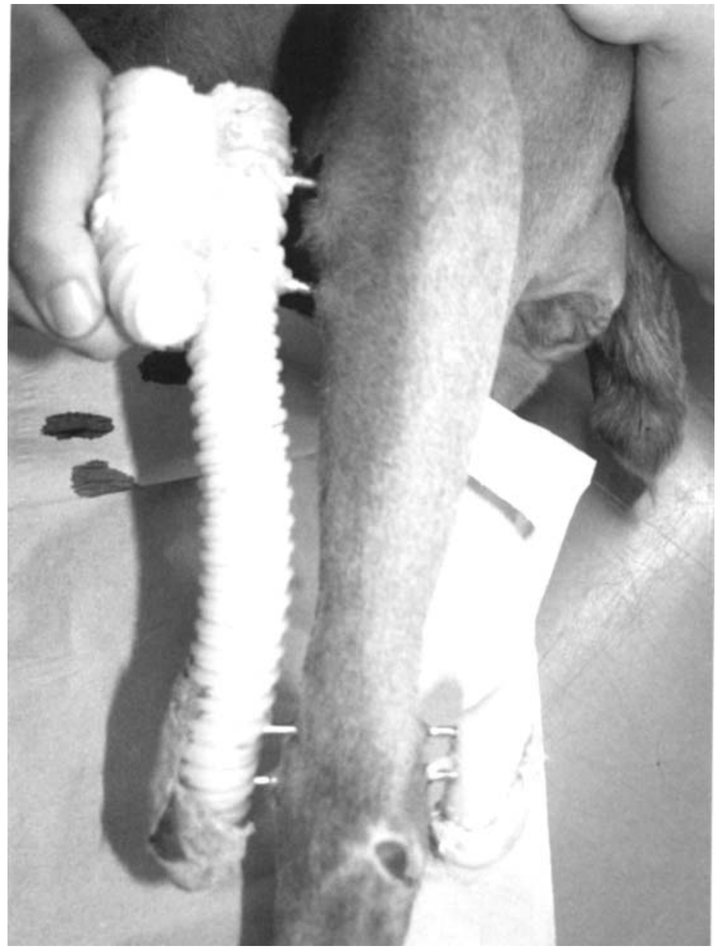


**Figure 8.13** Conversion to a type I, unilateral fixator. The same case as Figure 8.12. As bone healing has progressed, the fixator has been staged down by removing the central portion of the column that ran obliquely across the cranial aspect of the tibia, uniting the proximal pins medially to the distal pins laterally. The remaining fixator illustrated here is, in effect, a type I (unilateral, uniplanar) fixator.

# Chapter 9
# Evaluation of Postoperative Radiographs

Careful evaluation of properly exposed radiographs taken immediately after surgery and at appropriate time intervals thereafter is critical to optimal postoperative management of fracture patients. At each radiographic examination, a minimum of two orthogonal views should be taken, usually a lateral projection and a craniocaudal projection. The affected bone and the joints above and below it should be included in each film.

The AAAA scheme is a systematic method that encourages thorough evaluation of postoperative fracture fixation radiographs. The four As in this scheme are alignment, apposition, apparatus, and activity. Each of these factors should be assessed in the current set of radiographs and compared with previously taken films.

*Alignment* is evaluated relative to the normal shape of the bone prior to fracture. The evaluation should determine the degree to which this normal shape has been restored after surgery and whether or not this alignment is being maintained by the fixation as the bone heals. A set of radiographs of the patient's contralateral normal limb can provide a helpful comparison for assessment of alignment.

The craniocaudal projection radiograph is used to evaluate linear alignment in the mediolateral plane. Varus (inward) or valgus (outward) deviation of the bone segment below the fracture indicates improper alignment. The lateral projection radiograph is used to evaluate linear alignment in the craniocaudal plane. Cranial or caudal bowing in excess of what is normal for that bone indicates improper alignment. Either of the two radiographic projections can be used to assess rotational alignment. With proper alignment of the fractured bone, the joints above and below it should both be in either a true lateral position or a true craniocaudal position. If one joint is in true position and the other is in an oblique position, correct rotational alignment has not been achieved or maintained. When a current set of radiographs reveals a change in alignment compared with immediate postoperative radiographs, failure of the fixation technique is likely. This possibility should be critically evaluated and the fixation should be amended or revised if indicated.

Proper fracture alignment is important not only for cosmetic appearance but even more for normal postoperative function of the limb. Mild cranial or caudal bowing abnormalities result in functional shortening of the limb. Many patients can compensate for this by flexing the joints of the contralateral limb to "equalize" functional limb length. It is difficult, however, for animals to compensate for rotational or varus/valgus deviations. These abnormalities lead to abnormal forces on the joints above and below the deformity, predisposing to secondary ligamentous problems and arthritis.

*Apposition* is evaluated relative to the degree to which fracture fragments have been accurately reduced. Some fracture configurations are amenable to anatomic reconstruction that re-establishes a load-sharing bony column. With perfect apposition no significant fracture gaps are visible radiographically. When current radiographs are compared with previous ones, loss of apposition indicates inadequate fixation technique.

Perfect apposition is an impossible goal with highly comminuted fractures, especially those treated "biologically" (i.e. with closed alignment and fixation technique). In such cases, normal alignment, not anatomic reconstruction, is the goal. At the surgeon's discretion, an "open but do not touch" method may be used to improve apposition of intermediate fragments that are quite distant to the longitudinal axis of the bone. Encircling sutures of a monofilament absorbable material (e.g. polydioxanone) may be applied to pull such fragments closer to the bony axis. No mechanical expectation is placed on these sutures, and the fixation system must effectively function in buttress mode.

*Apparatus* is evaluated relative to established guidelines for proper application of the fixation system used. In immediate postoperative films of a fracture repaired with an external fixator, the following questions should be addressed: Are there adequate numbers of fixation pins in both the proximal and distal bone segments? Is fixation pin size appropriate (pin diameter should be approximately 25% of bone diameter)? Are the fixation pins properly centered in the bone and located a safe distance away from fracture lines and fissure lines? Relative to the fracture configuration (especially if the fixation must function in buttress mode), has an adequate frame configuration been used and is frame size properly matched with patient size?

Good orthopedic surgeons must be very critical of their fracture fixation technique in order to learn and improve for similar fracture cases in the future. Additionally, the best time to recognize a complication is before, not after, it has become a disaster. When postoperative films are evaluated, if the answer to many of the questions posed in the paragraph above is "no," reoperation of the patient or referral of the case to an orthopedic specialist should be considered.

In follow-up radiographic examinations, apparatus is evaluated for possible changes in position and integrity. Fixation pins and frame elements should be checked for evidence of loosening, bending, or breakage. With proper technique, the position of fixation components should remain constant throughout the healing process until they are no longer needed and can be removed.

*Activity* is evaluated relative to the expected biologic response of the bone during the various stages of healing. Factors that affect the speed and type of healing include the following: the age and general health status of the patient; the location (metaphyseal versus diaphyseal) and configuration of the fracture; the degree of injury to surrounding soft tissues; whether the fixation has been applied using open or closed technique; the degree of fragment apposition obtained; and the mechanical environment provided by the fixation technique.

Radiographic signs of primary bone healing are typical with a simple fracture that has been anatomically reduced and rigidly fixated. This appears as slowly increasing density of the fracture line without bridging periosteal and endosteal callus. The fracture line may be filled with bone density material by 6–8 weeks after surgery. Although staged disassembly (or dynamization) is often beneficial at this time, complete removal of the external fixator is usually delayed.

Comminuted fractures treated with minimal disruption of the fragments and rigid stabilization generally heal by secondary or indirect bone formation. Fracture fragments are progressively incorporated into a predominantly endosteal and uniting bone callus. Bone surfaces in the fracture region begin to appear fuzzy or indistinct coupled with a slight increase in radiodensity within the fracture gaps about 4–6 weeks after surgery. Staged disassembly or dynamization of the fixator can usually be initiated at about 6 weeks after surgery. As healing progresses over the next 6–12 weeks, fracture gaps are progressively filled with a cancellous bone material. The density of uniting callus is usually less than that of adjacent cortical bone. Callus formation is mainly the result of endosteal bone proliferation, but periosteal bone proliferation may be evident in areas where injury or surgery caused periosteal separation from the bone. Periosteal new bone is also a more prominent radiographic finding in skeletally immature patients.

The amount of external callus seen is inversely proportional to the rigidity of the fixation. Bridging periosteal callus would be expected in an anatomically reduced, simple, diaphyseal fracture of the tibia repaired with a four-pin type Ia fixator. If this same fracture was stabilized with a six-pin maximal type II fixator, excessive periosteal callus in a mature patient would be unusual.

The appearance of new bone in the fracture region should be carefully evaluated to determine if it is an expected sign of healing or evidence of a complication. Normal bridging callus has smooth, well-delineated margins, whereas new bone formation with a rough, irregular margin is suggestive of osteomyelitis. If aggressive changes in bone density (productive, lytic, or both) are observed, the possibility of a neoplastic lesion should be investigated.

Evidence of bone resorption should also be carefully evaluated. The external fixator depends upon secure pin–bone interfaces for maintenance of fracture alignment and stabilization. With careful predrilling and low-speed, high-torque power insertion of positive-profile threaded fixation pins, normal bone density is expected at the vast majority of the pin–bone interfaces throughout the healing period. A radiolucent area of 1 mm or more surrounding the threaded portion of a fixation pin strongly suggests that it is loose. This can be checked by temporarily loosening the fixation clamp and determining if the pin can be easily rotated within the bone. If so, the pin should be removed, especially if pin laxity is accompanied by pain and lameness.

Early focal bone resorption at the fracture line usually indicates high strain secondary to borderline fixation. With adequate blood supply, secondary bone healing may progress such that a bridging callus eventually consolidates the fracture. Resorption at the fracture line with subsequent failure to establish a bridging callus is predictive of delayed union or nonunion. For a delayed union, augmentation or revision of the fixation should be considered. For nonunion, re-exploration of the fracture, improved fixation, and cancellous bone grafting are necessary. Generalized loss of bone mineral density throughout the fracture region may be indicative of stress protection secondary to extremely rigid fixation that has been maintained for too long. Staged disassembly may stimulate recovery of bone mineral density, but if large gaps are present cancellous bone grafting may be indicated as well.

# Chapter 10
# Bandaging and Aftercare

## Bandaging

Following surgery, the fixator should be wrapped and, in the case of the distal limb, the entire limb should be bandaged as well. Bandaging the fixator helps prevent it from becoming caught on cages, furniture, fences, etc., which can lead to disruption of the fixator and fracture. The fixator can also harm an owner. Bandaging the fixator correctly helps prevent the skin from moving excessively around the fixator pin and therefore decreases the pin site wound. Skin and soft tissues tend to migrate out along the pin and can contact the fixator connector or column. In these cases, wounds can develop, the tissues swell, and the wounds become even larger. Some surgeons do not bandage the fixator after the limb swelling has abated as it can be argued that bandaging at this stage is not necessary and does not prevent pin site problems. The bandage may obscure observation and cleaning of the pin sites and, if saturated, may promote infection. However, wrapping the fixator is common practice with most surgeons.

A very practical method of wrapping the fixator is by using the sponge from a surgical scrub brush. The sponge is removed from the brush and rinsed thoroughly and wrung out (Figure 10.1). These sponges dry very quickly and can be autoclaved. The sponge is cut halfway through and placed around the fixation pin (Figures 10.2 and 10.3). The sponges

**Figure 10.1** Surgical scrub sponges. The sponge from a surgical scrub brush can be removed from the brush and used as an effective and economical bandage around the fixation pin.

**Figure 10.2** Placing sponges. Sponges are cut halfway through and placed around fixation pins, absorbing exudate and preventing the clamp from interfering with the adjacent skin.

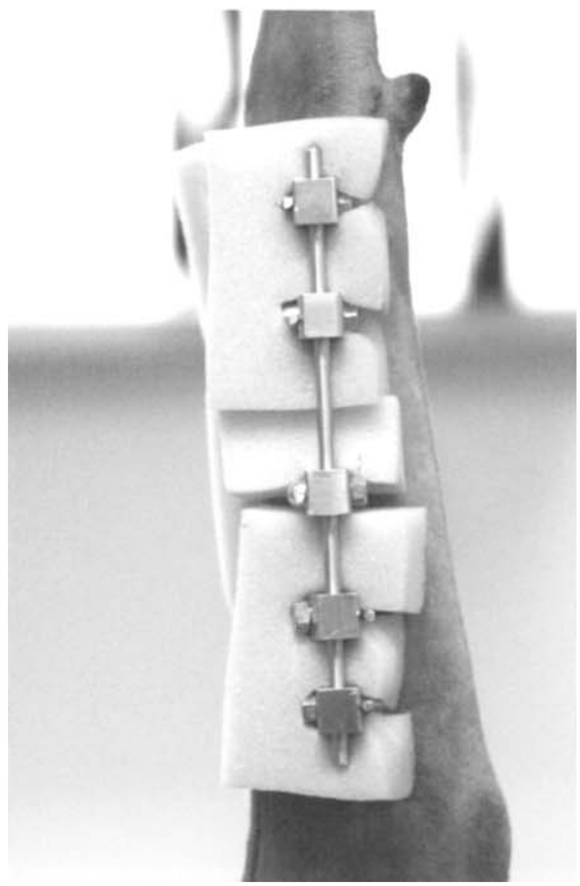


**Figure 10.3** Padding and bandaging the fixator. The surgical sponges also act to limit motion between the skin and fixation pin.

are a very effective and economical material for this purpose, but cast padding and cotton may also be used. After surgery for a distal limb fracture, the fixator and the entire limb are wrapped with a soft padded bandage (Figure 10.4). After limb swelling has abated, usually at 1 week to 10 days, when sutures, if present, are being removed, the fixator only is wrapped. In this case, only sponges and elastic tape are used (Figures 10.5 and 10.6).

## Discharge instructions

Discharge instructions include bandage care, orthopedic exercise restriction, and fixator care. These are best given as written orders. Examples of each are given below.

**Figure 10.4** Postoperative bandaging of a distal limb. After fixator placement, the entire limb is wrapped with a soft padded bandage. This limits distal limb edema, providing comfort and absorbing exudate.

**Figure 10.5** Subsequent bandaging of the limb. After 1 week to 10 days, only the fixator is wrapped. Besides the other benefits, this helps prevent the fixator from becoming entangled and injuring the animal and owner.

**Figure 10.6** Encircling the fixator with elastic tape. Elastic tape is used to encircle the fixator and surgical sponges.

### *Orthopedic exercise restriction*

Your pet is recovering from a major orthopedic problem that requires continued postoperative home nursing care in order to ensure a successful outcome. This care primarily entails restriction of your pet's activity. Your pet does not understand the nature of the injury and will become very active in a short period of time, unlike a person with the same injury; therefore, restriction of activity is of paramount importance. This means confinement indoors, no jumping, no running, no stairs, and no rough-housing. When taken outdoors to urinate and defecate, your pet must be confined to a leash, and once body eliminations are completed must immediately return indoors. If left alone, your pet must be confined to an area where it is not possible for him/her to come to any harm, e.g. a small room or cage. This degree of confinement is especially important during the first 3–4 weeks and should be continued for the entire 6- to 8-week convalescent period. Failure to heed these simple precautions may result in reinjury and/or complications and, ultimately, a need to repeat the surgical procedure; this leads to additional discomfort for your pet and additional costs, all of which are potentially avoidable.

### *Bandage care instructions*

Your pet is recovering from a fracture or other condition requiring a bandage or splint. The following instructions for his or her home care will aid recovery. All splints and bandages must be kept dry. Should the bandage become wet, a redressing is necessary as soon as possible. A wet bandage is dangerous.

When exercising a dog outdoors, a waterproof covering can be applied to the bandage to insure that it does not get wet. This is to be removed indoors. If the bandage should appear to have slipped, twisted, or otherwise become damaged, as by chewing etc., or if it gives off a bad odor, bring the animal to the clinic.

Remember that a splint is of value only as long as it is in proper adjustment. Even the most skillfully applied device cannot remain on an animal indefinitely. To avoid needless pain, possible damage to the skin or deeper tissues, or other serious consequence, return for a check-up at the indicated times; an appointment must be made for this visit except in emergencies.

### *External fixator care*

You pet has an external fixator. This is an orthopedic device in which pins pass through the skin, through bone, and are connected on the outside. The fixator is holding the bones in alignment while they heal. There are very special instructions for correct care of the fixator and things for you to watch for that might suggest trouble or complications.

The sites where the pins enter the skin need to be looked at every day. Usually, the fixator is wrapped, but you can gently lift the bandage material and observe the pin sites. Some redness and swelling is normal, but this is usually minimal after the first week. Some discharge is also normal. Discharge should be considered excessive if it saturates the bandage more than twice a week or drips off the limb. You can cleanse the pin sites using a warm, wet wash cloth. Do not use hydrogen peroxide or other antiseptic solutions as these may harm the tissues.

The wrapping on the fixator may occasionally need to be changed. You may have this done at our, or another, veterinary clinic, or we can show you how to do this.

The fixator, being on the outside of the limb, can scrape against you or get caught. Avoid circumstances in which this might occur. Do not allow your pet to stay unattended in an area bordered by chain-linked fence. Do not allow your pet to jump up on you. Read and follow the Orthopedic Exercise Restriction handout.

You must return immediately if:

1 Your pet was walking with the affected limb then suddenly is not.
2 There is excessive discharge as described above.
3 There is bleeding from the limb or pin site.
4 The fixator appears to have become damaged.
5 The paw swells so that the middle two toenails are spread apart.

Please return in 6–8 weeks. At that time your pet will be sedated and radiographs will be taken. If healing is complete, the fixator will be removed under a short-acting anesthetic. If the healing is not complete, a recheck examination will be scheduled for 3–4 weeks after that.

Remember that the external fixator is playing a very important role. Being outside the body, it can become damaged. Following these guidelines should prevent premature loosening of the device and help avoid complications and additional surgery.

# Chapter 11
# Recheck Examinations

## Physical examination

After discharge, a patient with an external fixator should be rechecked at 7–10 days, at 6–8 weeks, then every 3–4 weeks thereafter. In addition, the patient should be rechecked if he or she stops weight bearing, or if there is excessive bleeding or excessive discharge at the pin sites. The owner should be asked about the animal's general temperament, appetite, and level of activity. The recheck examination should include a brief general physical examination, including temperature, pulse, and respiratory rate. A very helpful observation is simply weight bearing. The owner should be asked about any change in weight-bearing ability, especially if the patient became acutely nonweight bearing at any time. Ask about the level of activity. This may be helpful in determining whether exercise restriction instructions have been faithfully followed.

All pin sites should be evaluated for pain by gentle palpation. Some discomfort is to be expected; however, if greater pain is elicited by palpating one pin site than others, more in-depth evaluation of that site is warranted. Some serosanguinous discharge is to be expected. This usually manifests as crust or mild wetness around the pin. Purulent discharge is abnormal. The amount of discharge should not be so great that the bandage becomes so saturated that it needs to be changed more often than twice per week or that discharge drips down an unbandaged limb.

The size of an external fixator pin tract varies depending on its location. It is also dependent on the amount of soft tissue between the skin and bone, and is even more dependent on the movement of the soft tissue around the pin. The primary example of this is an external fixator pin placed in the distal femur such that it involves the femoral patellar ligament (Figure 11.1). The normal motion of the soft tissues in this area against the fixed pin will result in a larger fixator pin wound. In most locations in the distal limb, however, the pin tract wound should not be expected to be much larger than the pin itself (Figures 11.2 and 11.3). Large inflamed wounds warrant further attention.

The first recheck should occur at 7–10 days. The patient should be partially weight bearing and toe touching while standing. At this time sutures, if any, should be removed. Some distal limb edema should be expected, but this should have decreased over the last few days and not be getting worse. Pitting edema of the distal limb is suggestive of infection, especially if the animal is not using the limb. Pin sites should look normal, although in many cases granulation around the pin tract is not fully developed; in these cases there will be some inflammation. Palpation of pin sites may elicit a pain response, but this should be very mild. In

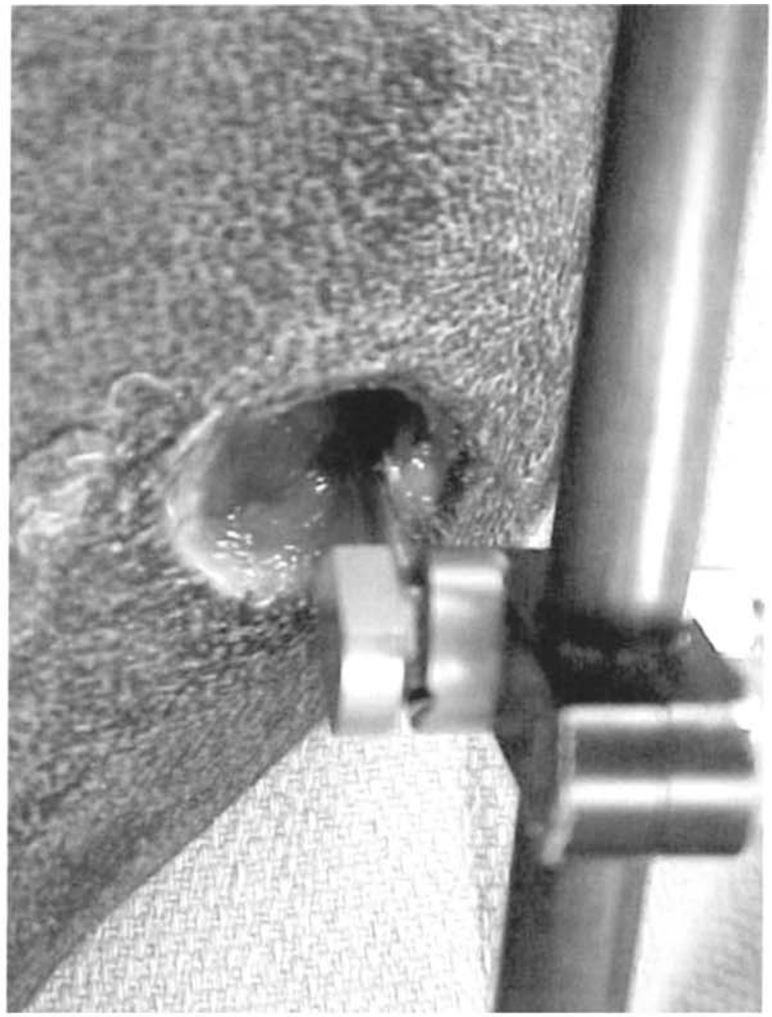


**Figure 11.1** Fixation pin wound. Large problematic fixation pin wounds occur in areas of deep soft tissues and motion between the soft tissues and pin. A problematic area is the distal femur if the pin invades the femoral patellar ligament.

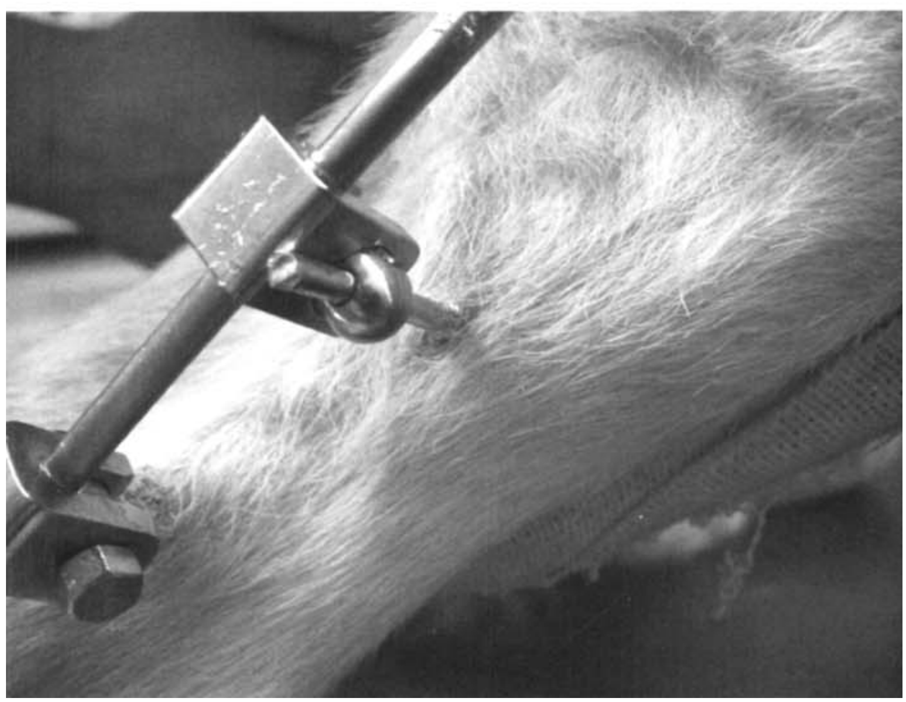


**Figure 11.2** Normal appearance of fixation pin sites. At 6 weeks the fixation pin site on the lateral aspect of this tibia is seen to be small without inflammation. A small amount of crust can be noted but is not abnormal.

**Figure 11.3** Normal appearance of fixation pin sites. These fixation pin sites on the lateral aspect of the tibia are seen immediately following fixator removal. The sites should be only slightly larger than the fixation pin.

some situations, the pin tract will become infected before granulation surrounds the pin. In this case, a rather large area surrounding the pin will be inflamed and there may be purulent discharge. These cases should be treated with antibiotics, specifically cefazolin at 10 mg/kg three times a day. Other beta-lactam antibiotics may also be chosen as the infective agent is usually coagulase-positive *Staphylococcus*.

Look for interference between the skin and external connecting apparatus. Occasionally, if the connecting apparatus is too close to the skin, wounds will start to develop. If this begins to occur, the swelling of the skin and soft tissues will exacerbate the interference and worsen the wound. Sponges, cotton, or cast padding can be placed to interpose between the skin and fixator and lessen the severity of the wound. Antimicrobial drain sponges containing polyhexamethylene biguanide (Figure 11.4) should be placed between the sponges and the skin to decrease microbial proliferation.

At dismissal of the patient, the owner should be instructed that the bandage should be replaced when soiled or malodorous (Chapter 10). The patient should be immediately brought back to the clinic if the limb becomes acutely nonweight bearing or there is hemorrhage or

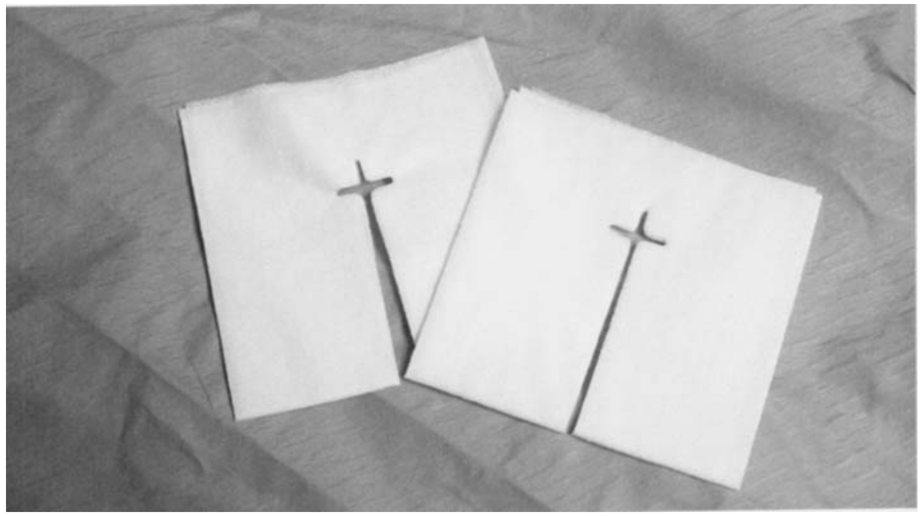


**Figure 11.4** Antiseptic drain sponges. Drain sponges containing the antimicrobial polyhexamethylene biguanide are efficacious in decreasing the bacterial load of pin sites that have become infected.

excessive discharge. Recheck evaluation in these cases should also include radiographic evaluation.

The second routine recheck examination should occur in 6–8 weeks. Many routine fractures will be healed by this time, but, even if a longer healing time than this is expected, it is important to evaluate the fracture to ensure that healing is progressing as expected. The patient should be weight bearing. A recent slow increase in lameness can be seen if pin loosening is occurring. Pin sites should be pain free with minimal discharge. The exception to this is areas of deep soft tissues and motion of skin around the pin as stated above. In this case, expect to see a larger wound that will require appropriate attention. Radiographs should always be taken and evaluated for the four As – alignment, apposition, apparatus, and activity (Chapter 9). This will dictate whether the fixator can be removed, more time is needed, decreasing fixator stiffness is warranted, or intervention is indicated. If the fixator is not removed, then the patient should be re-evaluated in 3–4 weeks. Evaluation at this interval assures that slow-healing fractures continue to progress and that problems can be addressed at an optimal time.

Careful radiographic interpretation is very important in deciding the future management of a case. In addition to interpretation of the four As, the results of the physical examination and weight-bearing ability must be taken into consideration. It is possible that a clinician will not be sure whether the fracture is healing slowly or progressing to nonunion even with careful radiographic interpretation at this time. However, there are specific radiographic findings that will dictate clinical direction, and these are based on the expected mechanism of bone healing.

## Fracture healing

Bone healing can occur via one of two basic methods, described as primary and secondary bone healing (Figure 11.5). Primary bony union occurs with rigid internal fixation and contact between fracture fragments or

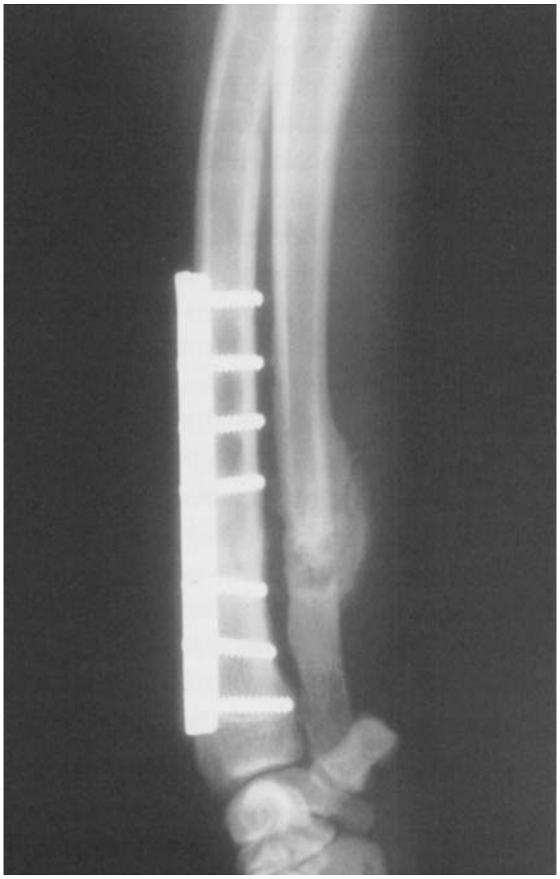


**Figure 11.5** Primary and secondary bone union. Primary bone union is occurring in the radius, where plate fixation has resulted in contact of the fracture gaps and rigid stabilization. Secondary bone union is occurring in the ulna, which has not been rigidly fixed, contains fracture gaps, and is subjected to some interfragmentary motion.

microscopic fracture gaps. In this case, Haversian systems cross directly across the fracture lines and the bone is remodeled without the formation of a fracture callus.

Secondary bone healing occurs with fracture gaps and some interfragmentary motion. As external fixators are often placed without interfragmentary compression, fracture gaps are most often present. Although fixators can be very rigid, they are not commonly applied with interfragmentary compression of fracture lines, as can be obtained with cerclage and bone plates. Thus, with the presence of fracture gaps and interfragmentary motion, secondary bone union is most common in the healing of fractures repaired with external fixators. Fortunately, external fixators are also very well suited to support secondary bony union. This is because preservation of vascular supply and enhancement of the local biologic and mechanical environment needed for secondary bone union are supported.

Breaking of bone releases many cytokines that recruit pluripotent mesenchymal stem cells that multiply in the area of a fracture. Most stem cells originate from the cambium layer of the periosteum, which is generally not disturbed during application of an external fixator. Other cytokines and local influences result in the ingrowth of blood vessels needed to support the multiplication and differentiation of these cells to osteoblasts. The local proliferation of stem cells results in callus formation, the hallmark of secondary bone healing. The size of a callus is influenced by many factors, including age and location, and there is a direct relationship between the size of a callus and local interfragmentary motion. The callus stem cells follow an osteoblastic, chondroblastic, or fibroblastic lineage depending on the local biologic and mechanical environment. Small amounts of interfragmentary strain and a high-oxygen environment will result in the formation of more osteoblasts. More strain and a lower-oxygen environment will result in formation of chondroblasts. Large amounts of strain, motion, and low oxygen will cause fibrous tissue to form. These different conditions occur within the same callus. Because the outside of a callus, like the outside of a cylinder, is most capable of opposing bending force, it is subject to less strain. In addition, as the blood supply to a healing callus is to a great degree periosteal, the outside of a callus has a high oxygen tension. Therefore, the outside of a callus has both the best mechanical and biologic environment, resulting in stem cells being prompted to preferentially form osteoblasts. The fracture ends of the original bone, in contrast, are under high interfragmentary strain and low oxygen tension. Here, the environment favors stem cells following a fibroblastic or chondroblastic lineage. Therefore, when evaluating a fracture that is healing through secondary callus formation, the outer edge of the callus will yield the most information on whether or not the fracture has been bridged by bone.

As stated above, more motion at a fracture callus generally results in a larger callus. However, too much motion across a fracture gap will not allow proper osteocyte formation. Rather, only fibroblasts and chondroblasts will form in an unstable fracture, and with a low oxygen tension environment the end result is likely to be nonunion. In general, the amount of motion a fracture can tolerate is approximately 2% of the area of fracture. For example, a 2-mm fracture gap in a transverse fracture will tolerate motion of 0.04 mm of motion. In contrast, a 10-mm area of comminution can tolerate 0.2 mm of motion.

Some strain across a fracture gap is needed to encourage bone to become strong. It has been shown that, if a very stiff fixator is placed on an intact tibia, bone will start losing mineral content, progressing toward osteopenia, within only a few weeks. A healing callus will become stronger faster if strain across the fracture is present yet does not reach the motion limit for bone union. Forces that travel along the long axis of the bone, called axial forces, as are normally present in weight bearing, are best at promoting callus maturation. Bending, twisting, and shearing forces are more detrimental than beneficial. In a situation in which there is a complete lack of axial forces transmitted across a fracture, such as can occur with a very stiff fixator, a small initial callus will form, but, rather than increasing in mineral content and radiodensity, it will progressively lose mineral content and become increasingly radiolucent.

## Assessment of fracture healing

Recheck examination and radiographs should direct one of four courses of action, namely fixator removal; allowing more time for healing; intervention; or decreasing the fixator stiffness by staged removal or dynamization. Based on the understanding of the mechanism of bone healing and the radiographic appearance of healing bone, some criteria on which to base clinical choices can be laid down. Two radiographic views are usually taken: a craniocaudal view and a lateral view. The patient is usually sedated and the bandage material, if any, should be removed so as not to obscure the fracture site. Radiographic technique and developing should be sufficient to evaluate new bone formation.

The fixator can be removed if there is sufficient bony callus bridging the fracture gap (Figure 11.6). The edge of the callus should be continuous along the cranial and caudal aspects in the lateral view and the medial and lateral edges in the craniocaudal view. The fracture callus should contain sufficiently radiodense bone. This is the case when the density of the fracture callus approaches that of the adjacent host bone. If a complete bridging callus of adequate radiodensity can be seen and the patient is weight bearing, then the fixator can be removed. If the patient

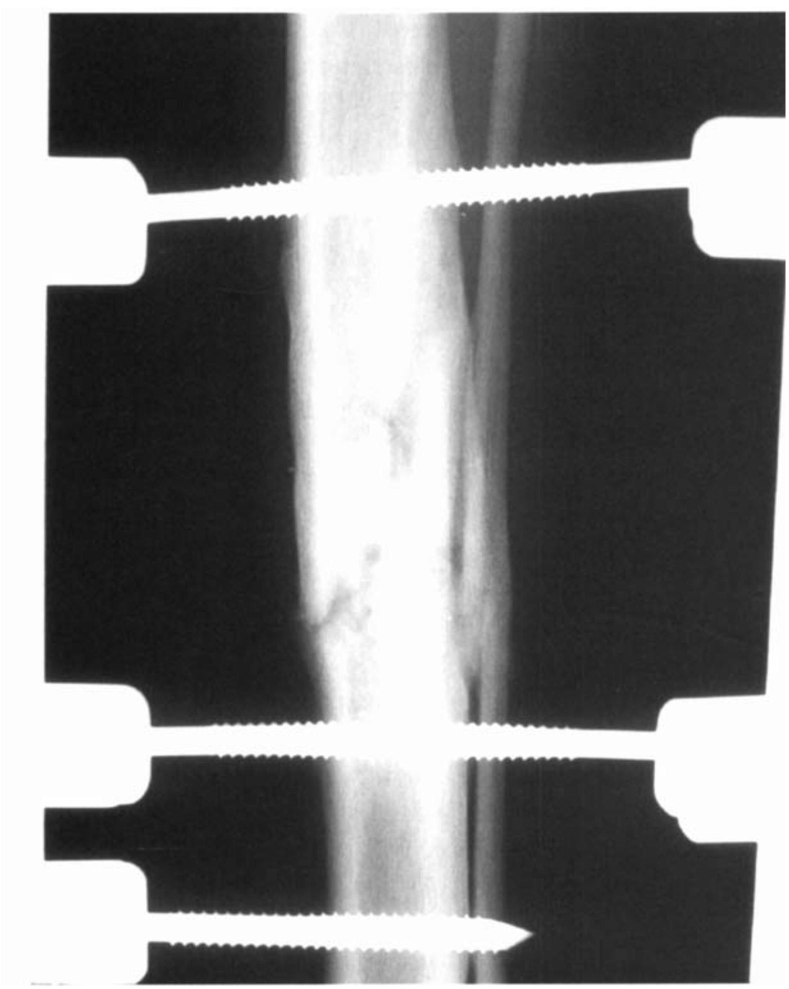


**Figure 11.6** Appearance of a healed fracture. A fixator can be removed if there is a continuous callus of sufficient radiographic mineral content.

is not weight bearing, the reason for this must be determined. Loose pins can cause severe lameness even though the fracture is sufficiently healed. In this case, removing the fixator will remove the cause of lameness. However, sufficient healing of the fracture must be more rigorously scrutinized. If possible, the fixator should be loosened and the fracture checked for stability in addition to critical radiographic evaluation. There need not be continuity of the original bone cortices before a fixator can be removed. Long before remodeling of bone cortices, large calluses can be very stiff and strong . Although leaving a fixator in place is not necessarily contraindicated, remodeling of some fractures can take months and can subject the patient and owner to longer periods of discomfort and care. The fixator is removed by cutting or disassembling the connecting column, then unscrewing the pins from the bone with a pin chuck or small battery-powered electric drill. Full pins are cut flush with the skin on one side before unscrewing them from the other. This must be done under general anesthesia. Short-acting thiobarbiturates or propofol are very effective.

The fracture should be given more time to heal if the animal is weight bearing and: (1) there is a callus but it is not completely bridged, (2) there is a bridging callus of insufficient radiodensity where the fixator is not deemed too stiff, and (3) the bone–pin interface is intact for all pins (Figure 11.7). If the patient is not weight bearing then the reason for this must be determined and corrected. The patient is discharged with instructions for continued exercise restriction and recheck examination with radiographs in 3–4 weeks.

Intervention in the form of removing or replacing fixation pins is indicated if there is pin loosening prior to complete healing of the fracture. Loose pins do not aid fracture stabilization and they promote pain and infection, and therefore they should be removed. A single loose pin can be removed if two secure pins remain in a segment and the fracture will remain stable. Otherwise, loose pins should be replaced.

An external fixator can be so rigid that it will carry the majority of weight bearing. This can result in the fracture callus not being exposed to sufficient load to remodel into strong bone. This usually occurs with bilateral type II fixators with three or more pins per segment. At the first radiographic recheck at 6–8 weeks, the callus, although often bridged, is not exuberant and appears more radiopaque than adjacent bone (Figure 11.8). The bone–pin interfaces are intact and the patient is weight bearing. There are several simple strategies that can be pursued. If the fixator is a type Ib, one connecting bar with its pins can be removed. If a unilateral fixator is applied with augmentation bars, these can be removed. Securos type II fixators have the unique feature of axial dynamization. Replacing the bolts of the clamps with square bolts will allow the clamp to slide on the connecting rod. The fracture is held stable in bending, torsion, and translation, but weight-bearing force will be transferred along the axis of the fracture (Chapter 6).

**Figure 11.7** Appearance of a healing fracture. A fixator should be left in place if there is a callus that is not completely bridged, the fixator pins are tight, and the patient is weight bearing.

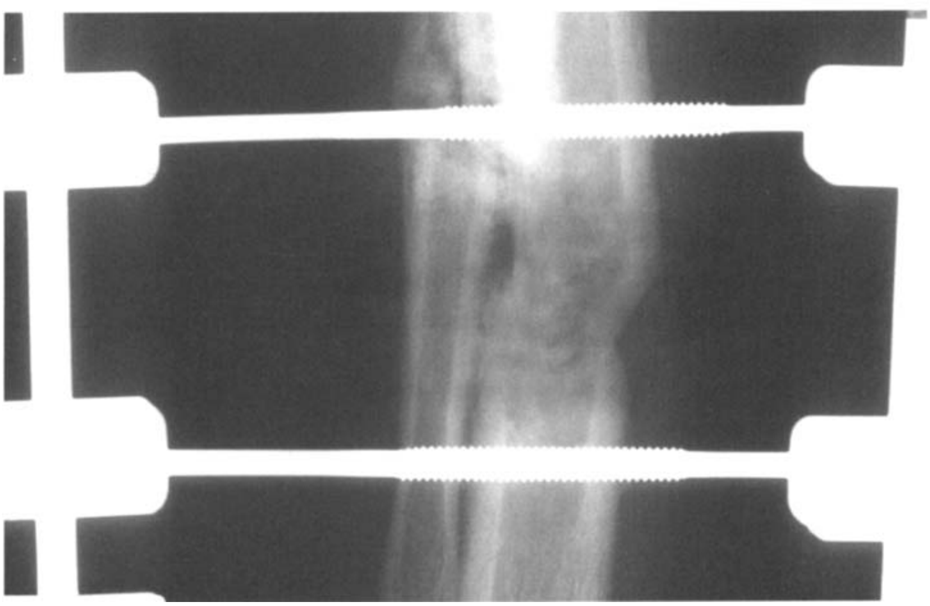


**Figure 11.8** Appearance of a stress-protected callus. A fixator should be made less stiff or dynamized if there is a small callus that appears radiographically to be less radiodense than adjacent bone.

# Chapter 12
# Complications

The use of external fixation in fracture repair has a checkered history. Some of the earliest reports of external fixation came from human orthopedic surgeons working at the end of the nineteenth century and, although some results were promising, their techniques failed to gain widespread popularity and apparently fell from use. Fixators enjoyed something of a renaissance during World War II, when their utility in battlefield casualty surgery was recognized and exploited. However, this era, too, was remarkably brief and brought to an abrupt end when the US Surgeon General effectively banned the use of ESF because of concerns about the very high complication rate.

In recent years, there has been a realization that many of the "complications" were in fact the inevitable consequence of technical errors made by the surgeon when applying the fixator. This realization was of key importance because, by recognizing that errors of technique were the cause of subsequent complications and then modifying their technique, orthopedic surgeons have been able to substantially reduce the incidence of complications. Although external fixation is wonderfully simple in concept, it remains annoyingly susceptible to apparently minor technical variations or errors.

This theme of complication arising from earlier, apparently minor, technical error is one that will recur in any discussion of ESF complications. A range of fixator-associated complications are recognized, and these can be categorized as shown in Table 12.1.

This classification will form the basis for the organization of this chapter. However, a complex inter-relationship exists between the various components of the fixator (including the injured limb!), and the potential for several, apparently minor, biologic or mechanical factors to act in concert to produce, for example, a loose and infected fixator pin should not be overlooked.

**Table 12.1** Complications associated with external fixation

| Soft-tissue impalement | Failure to maintain stability | Infection |
|---|---|---|
| Muscles | Catastrophic frame failure | Osteomyelitis |
| Nerves | Pin breakage | Sequestration |
| Tendons | Pin pullout | Major pin tract infection |
| Vessels | Premature pin loosening | Minor pin tract infection |

## Soft-tissue impingement

Impalement of tendons, vessels, or nerves during pin placement must be avoided. Safe, hazardous, and unsafe corridors have been defined by Marti and Miller. This knowledge of surface and "landmark" anatomy, as well as an understanding of cross-sectional limb anatomy, is essential if the surgeon is to avoid damaging essential soft-tissue structures (Chapter 5).

Tendons impaled by inappropriately placed fixator pins do not normally sustain significant permanent functional damage, although a degree of discomfort and disability inevitably results. Following removal of the offending pin, the tendon should be inspected, but only rarely will it be necessary to suture the tendon.

Damage to peripheral nerves, although not frequently seen, is a serious complication. Significant nerve damage may occur as the result of nerves becoming "wound up" around pins during placement. The use of drill guides and tissue protectors, plus a sound knowledge of neural anatomy, will minimize the risk of peripheral nerve injury. Such lesions will be very severe, being a combined crushing and stretching injury involving a significant length of the nerve. These lesions rarely have any potential for recovery or restoration of neurologic function and, although the prognosis with respect to limb function will vary with the specific nerve involved, consideration should be given to early salvage surgery.

Impalement of muscles during ESF pin placement is unavoidable – the anatomy of the distal limb is such that there are too few regions with directly subcutaneous bone to permit ESF application if pin placement were to be confined to these areas alone. Significant functional problems may occur if muscles are pinned through their midsection, or if a normally mobile muscle is fixed to the underlying bone. However, pins placed through muscles near their origins or insertions are associated with remarkably little morbidity. The consequence of muscle impalement is discussed in more detail in "Major pin tract infection" and "Minor pin tract infection" (below).

### *Acute hemorrhage*

Major blood vessels should be encountered only if pins are placed in an inappropriate location. However, occasionally a brisk hemorrhage will occur either during drilling or at pin placement. In these cases, the pin should be withdrawn at once and hemorrhage controlled by direct and continuous digital pressure that is maintained for 90–120 seconds. The offending pin is then repositioned some way distant from the bleed. Very occasionally it may be necessary to abandon surgery and control hemorrhage using pressure bandages etc. before resuming the ESF procedure 24–48 hours later.

### *Late hemorrhage*

This is seen typically 7 days to 6 weeks after an otherwise uneventful pin placement. Late hemorrhage is most often associated with the medial exit of full pins placed through the proximal radius. Hemorrhage is almost certainly due to erosion through a branch of the median artery against the fixator pin. Bleeding can be quite brisk and may persist for many hours, resulting in a significant, even life-threatening, blood loss. Treatment demands immediate removal of the pin and application of a pressure bandage, which should remain in place for several hours – less aggressive treatment will give, at best, only temporary respite. It is rarely, if ever, necessary to dissect and ligate the blood vessel but, as previously implied, any attempt to control this late hemorrhage without pin removal is destined to fail.

## Failure to maintain adequate stability

The term "adequate stability" can be defined as the effective control of forces which might disrupt fracture healing. Adequate stability does not imply absolute stability – indeed, a small degree of micromovement is not only well tolerated by healing bone but has been shown to be beneficial. Equally, "adequate stability" is neither finite nor predetermined. It will vary depending on whether the reduced fracture shares some of the weight-bearing forces (Figure 12.1) or the fixator must support the entire weight-bearing force because of comminution (Figure 12.2). It will also vary as the fracture heals and the repairing bone becomes increasingly mechanically competent and therefore less reliant upon the fixator. As this process proceeds, the amount of stability required to be adequate will diminish. Ideally, the surgeon should retain control of the fixator throughout the entire bone-healing process, and failure to maintain adequate stability for any reason at any stage must be considered a complication. However, it is recognized that a good clinical result can sometimes be achieved in spite of a rapidly loosening and failing fixator.

## Catastrophic frame failure

Frame failure is almost always the result of technical error. The construction of a frame that was either too small or not sufficiently stiff and strong to withstand the forces to which it will be exposed during fracture healing will inevitably lead to problems and complications (Figures 12.3 and 12.4). To prevent frame failure, surgeons have evolved stronger, more rigid, external fixator constructs that will not fail prematurely (Figures 12.5 and 12.6).

Recent developments in ESF instrumentation are described in Chapters 6–8, and this newer instrumentation has the advantage of being stiffer and

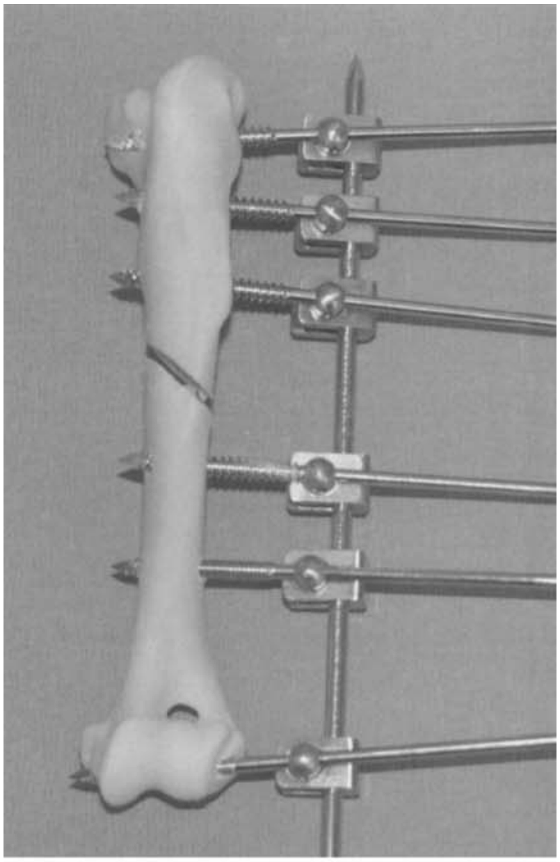


**Figure 12.1** Load sharing. In this humeral fracture, accurate reconstruction of the two-piece fracture is possible such that the rebuilt bone can be expected to bear some load. The external fixator is therefore *load sharing*.

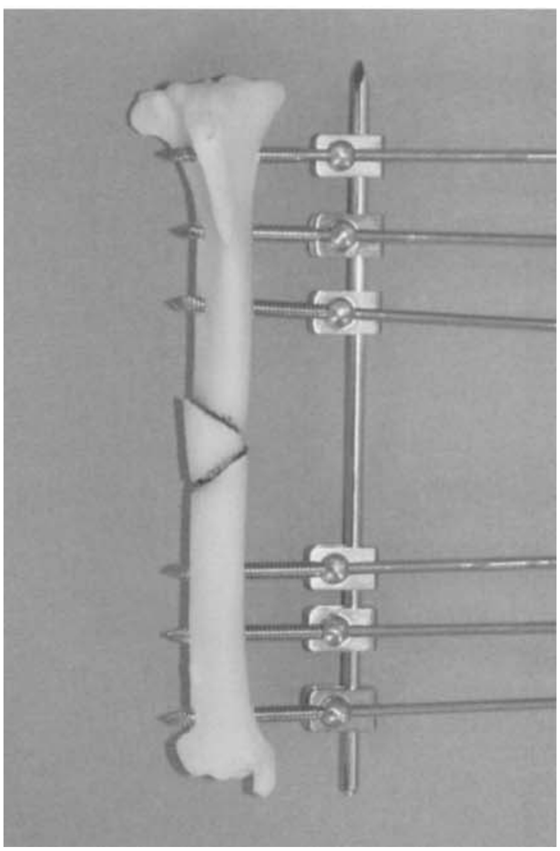


**Figure 12.2** Load bearing. This fracture is comminuted, and no matter how accurately the fragments are reconstructed the bone will be mechanically incompetent. The fixator will therefore be *load bearing* and must be sufficiently robust to resist all the forces generated when the patient ambulates.

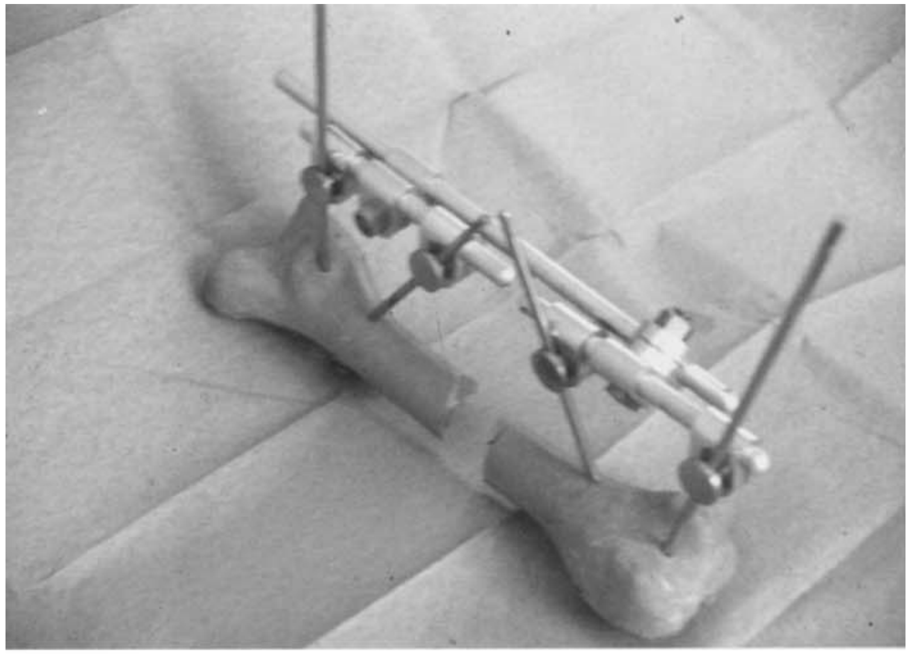


**Figure 12.3** Double clamps. Double clamps are inherently weak and should not be used in the primary supporting column.

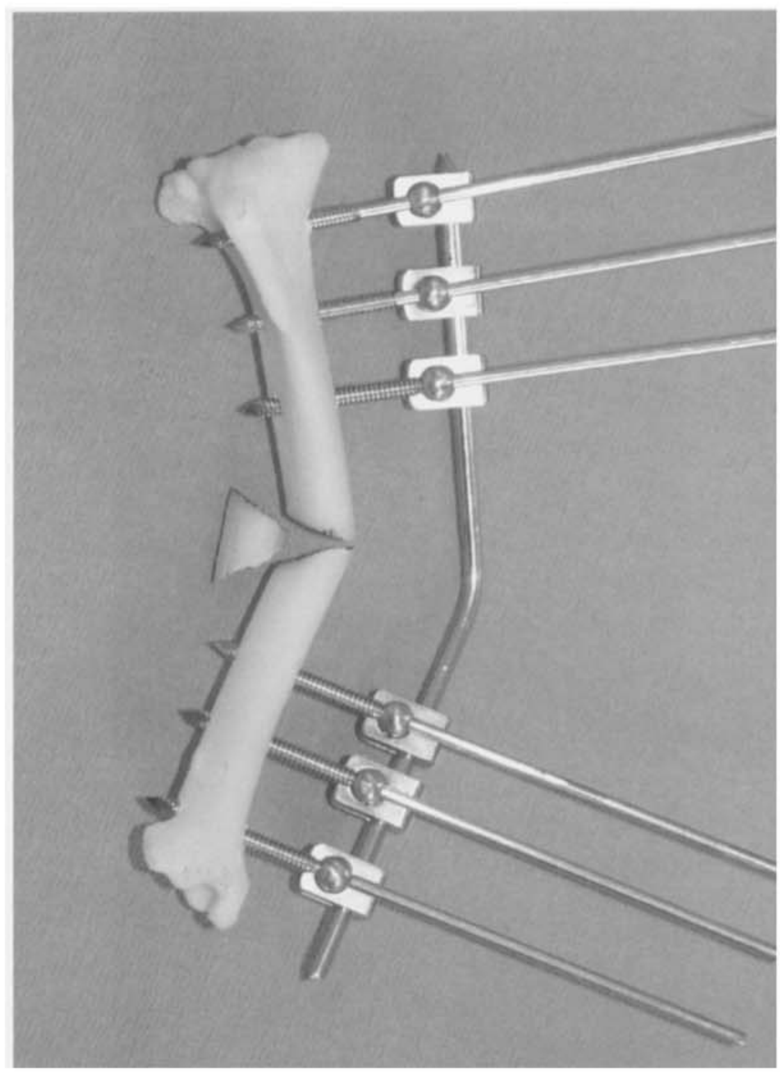


**Figure 12.4** Inadequate fixator frame. The inevitable result of building an inadequate fixator is frame failure. If this unilateral fixator using a single 4.8-mm connecting rod were applied to a comminuted tibial fracture in a 50-kg dog, it could not support weight bearing and would fail.

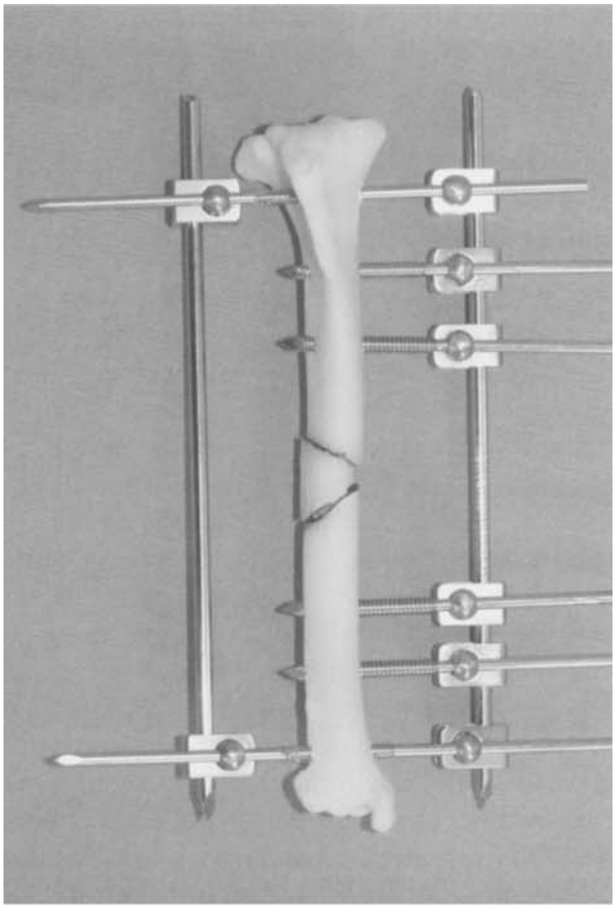


**Figure 12.5** Increasing fixator frame strength. The addition of a second contralateral connecting bar significantly increases the strength and stiffness of the construct.

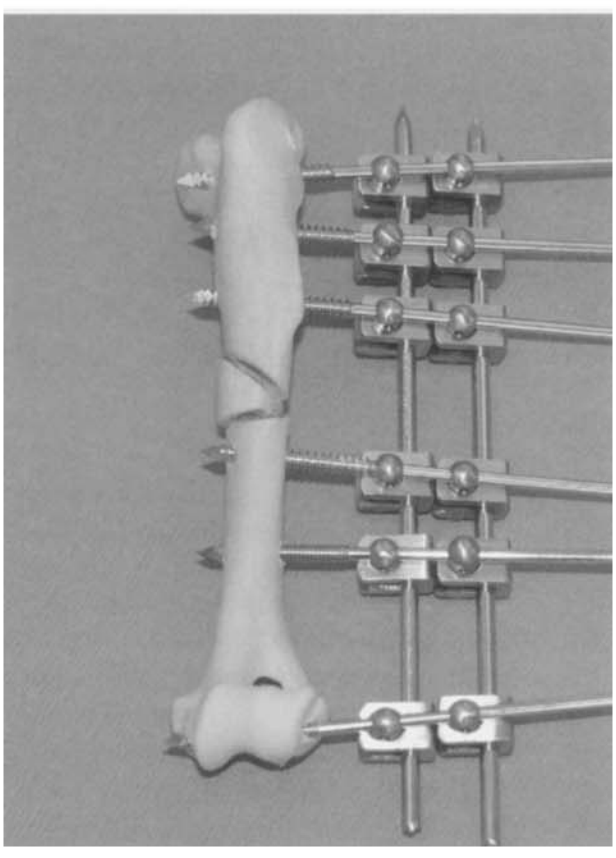


**Figure 12.6** Double connecting bars. In the proximal limb (humerus and femur) it is not possible to use bilateral connecting bars. A second unilateral connecting bar will enhance stiffness and strength. These double bar constructs are intermediate in strength and stiffness between the fixators shown in Figures 12.4 and 12.5.

stronger than its predecessors, giving the surgeon the potential to achieve stiff, strong frames with fewer components. Alternatively, the surgeon may choose to use a complex frame with the benefit of an increased safety margin and the expectation of fewer complications.

## Pin breakage

Providing sufficient appropriately sized pins are used, then breakage of fixator pins is a rare occurrence. However, pins featuring negative or "cut-in" threads appear to be particularly prone to failure by breakage through the junction between threaded and nonthreaded portions. The negative thread results in a small area of stress concentration at the end of the threaded portion, which leaves the pin at risk of fatigue failure. One design of negative-thread pin – the Ellis pin – features a very short length of thread such that the stress-riser comes to rest inside the medullary canal, effectively in a mechanically protected environment. Positive-threaded pins have none of the shortcomings of Ellis or other negative-threaded pins and, with the advent of these implants, negative-threaded fixator pins have become obsolete. A degree of controversy remains about the use of Ellis pins in veterinary orthopedics, as some surgeons use Ellis pins routinely and without problems. It is obvious that additional factors, such as the use of too few pins or pins that are too small, significantly influence whether or not pins break, and the surgeons who use Ellis pins successfully have evolved effective strategies to overcome the mechanical shortcomings of the implant.

Managing a case with a broken fixator pin involves an attempt to remove the pin, but because pins usually break flush with the cortex removal of the tip is often difficult, if not impossible. In such cases, the pin tip can be left *in situ* without expectation of further complications. Subsequently, the surgeon should review the strength and stiffness of the fixator to assess why the pin failed. It might be necessary to place additional pins and perhaps add further connecting bars to enhance the strength and rigidity of the construct. The surgeon should be aware that duplication of the original frame design (which has already failed once) would be an error.

## Pin pullout

Pin pullout will occur if smooth fixator pins are placed parallel or near-parallel to one another. Correct technique dictates that smooth fixator pins are placed at divergent or convergent angles, and ignoring this well-established principle will inevitably lead to failure. The use of threaded fixator pins came about in an attempt to prevent pin pullout without the compromise imposed by angled pin placement (Figure 12.7).

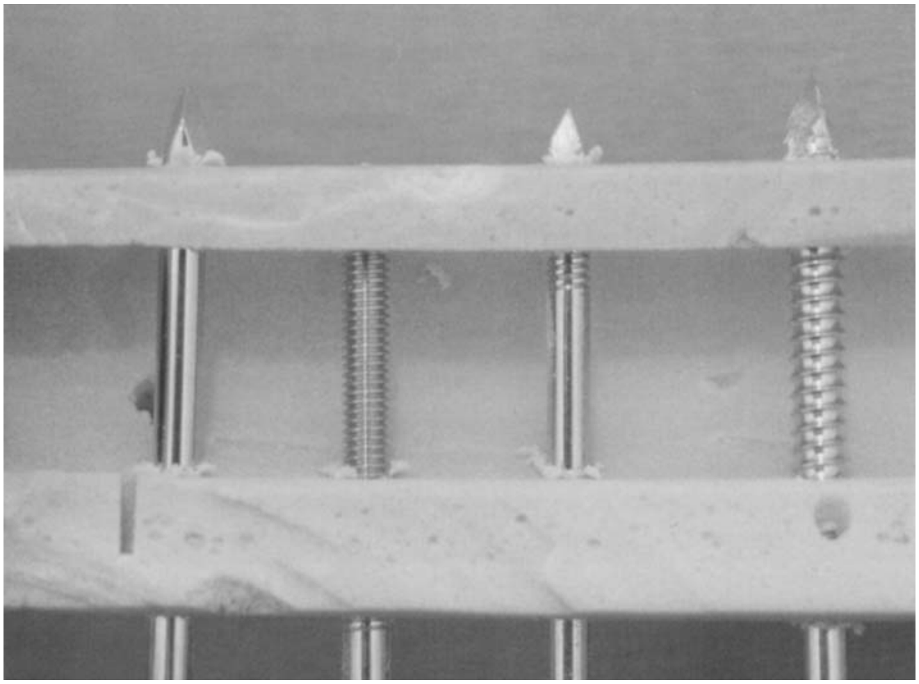



**Figure 12.7** Fixator pin types. Four different types of ESF pins placed in a cutaway section of bone. (A) Smooth, trocar pointed pins are cheap to produce but have minimal resistance to pullout. (B) Negative-thread pins are somewhat resistant to pullout but have a weakness at the end of the threaded portion. Frequently, this "stress-riser" comes to lie adjacent to the near cortex – the very place where strain is greatest. (C) Ellis pins have a short length of negative thread so that the stress-riser at the end of the thread lies within the medullary cavity, where, hopefully, it is mechanically protected. (D) Positive-threaded pins are very resistant to pullout and are much less prone to breakage than negative-threaded pins. Many surgeons use nothing but positive-threaded pins in their fixators.

## Premature pin loosening

A fixator pin should remain firm in the bone until such time as the surgeon chooses to remove it – any pin that has loosened prior to elective removal should be defined as loosening prematurely. Premature pin loosening is an extremely common complication of external fixation, and many fractures will proceed to union *despite* premature loosening of one or more pins; thus, there is a tendency among some fixator surgeons to downplay premature pin loosening as a complication. The factors that contribute to pin loosening have a complex inter-relationship and are summarized in Figure 12.8. Poor pin placement technique is usually the initiating factor for this cascade.

Treatment of premature pin loosening varies greatly depending upon the specifics of each particular case. When only one or two pins are loose and bone union is well progressed, it may be possible merely to remove the offending pins without further action – in effect, to stage-down the fixator. When the loosened pin(s) result in a frame that is no longer adequately stable, a more aggressive approach is required. In such cases, all loose pins should be removed and the design of the failing external fixator construct reviewed. Typically, it is necessary to supplement the remaining fixator either with additional pins placed along existing connecting bars or, more often, by the addition of an extra connecting bar and pins. Infection is frequently seen in association with prematurely loosened pins, and it is important to appreciate that such infection will *not* resolve while the pin remains *in situ*. Similarly, it is never possible to control infection in the hope that the pin will "firm up." Loose and infected pins need to be removed.

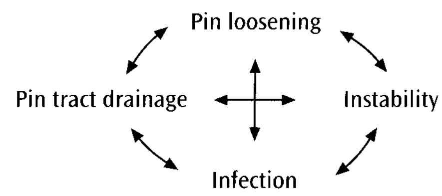



**Figure 12.8** The complex inter-relationship of factors contributing to premature pin loosening.

## Complications related to infection

### *Osteomyelitis*

True osteomyelitis as a complication of external fixation is remarkably uncommon; indeed, external fixation offers one of the more effective ways of stabilizing bones during the ongoing management of osteomyelitis which has arisen from, for example, complications following intramedullary pin or plate fixations of a fracture.

### *Bone sequestra*

Sequestrum formation is an infrequently encountered complication and, again, external fixation has proved useful in managing established bone sequestra which have arisen as complications of, for example, pin or plate fixation of open and infected fractures.

Ring sequestra have been reported as a specific complication of external fixation. These arise as the result of significant thermal necrosis of bone during pin placement. The damaging thermal necrosis is entirely the result of poor technique – usually drilling hard, cortical bone at excessively high speed using a trocar point fixator pin (Figure 12.9). Correct pin placement is described in some detail in Chapter 5, and surgeons encountering a ring sequestrum as a complication should urgently review their technique. The calcaneus is perhaps the most common location for ring sequestra, and this probably reflects the fact that calcaneal bone is particularly hard and dense.

Treatment of ring sequestra involves removal of the affected pin (which will inevitably be loose) followed by curettage of the pin tract – this is most easily done by drilling out the tract with an oversized drill. Skin wounds are not sutured – the pin tract is allowed to drain freely and heal by secondary wound healing. Occasionally, worryingly large holes remain in the bone, and these might warrant treatment with an autogenous cancellous bone graft. Bone grafting should be performed 4–7 days after curettage to permit control of infection and establishment of healthy granulation tissue.

### *Major pin tract infection*

Major pin tract infection is a relatively common complication of ESF and is invariably associated with premature pin loosening (Figure 12.10). Major pin tract infection is characterized by:

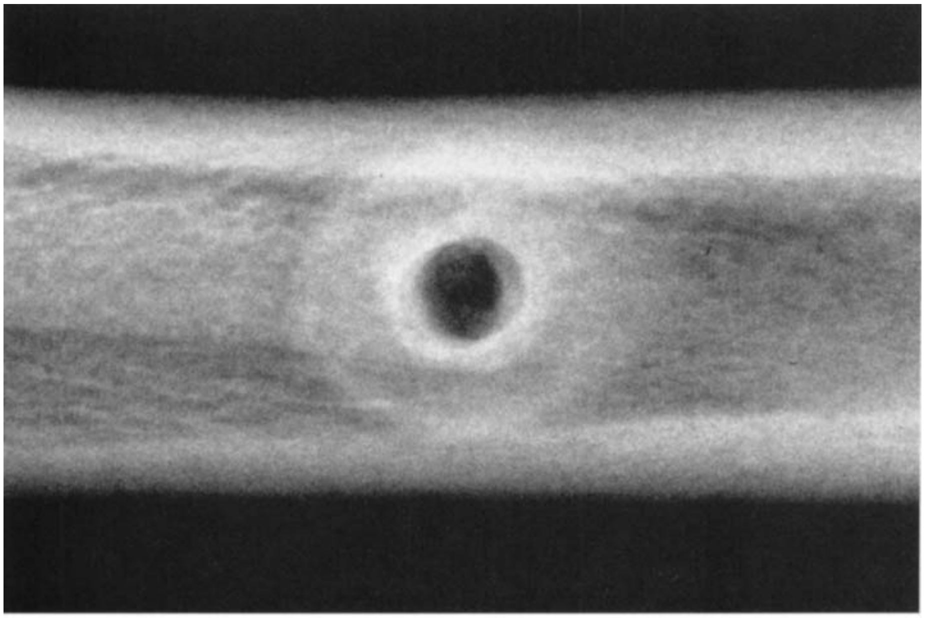


**Figure 12.9** Ring sequestrum. This pin tract through the tibia was made using a trocar pointed Steinmann pin. Although not a mature ring sequestrum, changes have occurred as a result of thermal injury to the bone.

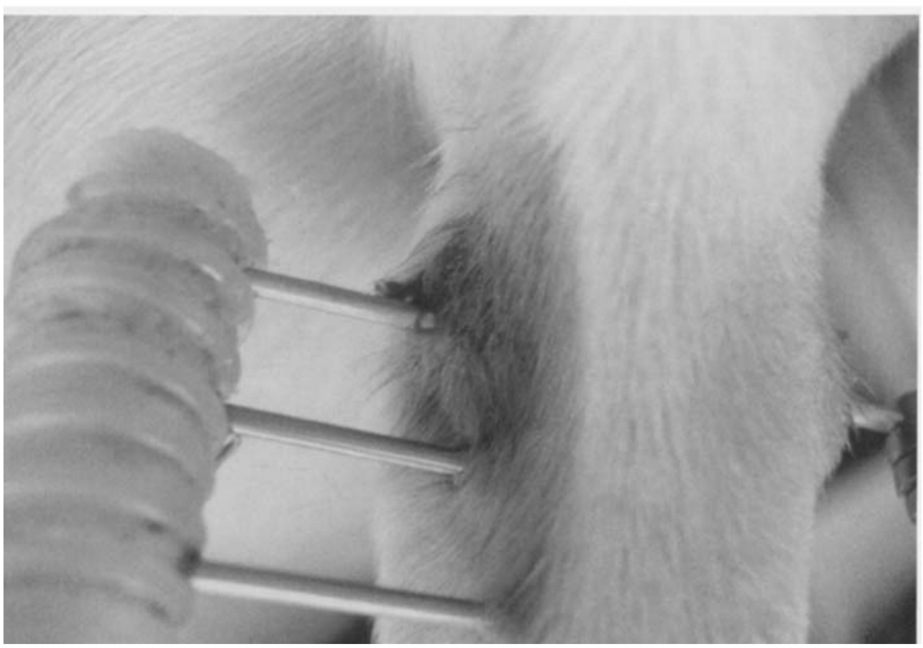


**Figure 12.10** Major pin tract infection. Soft-tissue swelling is evident around both ends of this proximal full pin in a radius. The dog had become increasingly lame, and palpation near the pin caused pain. There is significant purulent discharge causing wetness and discoloration around the pin. Radiographs showed an area of bone lysis around the pin. Removal of this single pin was curative.

- bacterial colonization of pin–skin interface;
- pain;
- purulent discharge around pin;
- pin loosening.

Major pin tract infections occur most frequently when a number of apparently minor technical errors have been made, leading ultimately to infection and premature pin loosening. The inter-relationship between pin tract infection and other problems is summarized in Figure 12.8, which shows that, for example, an unstable frame design will encourage pin loosening and infection, which in time allows infection to become established with further pin loosening and yet more instability.

Treatment of major pin tract infection involves early removal of the affected pins and medication with antibiotics. Pin tracts are left open and encouraged to drain freely. A key step in the management of major pin tract infection is to review the strength and stiffness of the ESF construct. It may be necessary to add further components to increase stiffness and strength if further pin tract infection and/or loosening is to be avoided.

### *Minor pin tract infection*

It is important to distinguish between major pin tract infection, as described above, and minor pin tract infection. Minor pin tract infection will be seen, to some degree, in almost all fixator cases, and it is most noticeable where fixator pins pierce a significant thickness of soft tissue (Figure 12.11). When fixator pins are placed directly into subcutaneous bone (that is without penetrating any muscle etc.), the pin–skin interface seals itself without any sign of ongoing inflammation, infection, granulation, or discharge (Figure 12.12). However, if a thickness of muscle or other subcutaneous soft tissue is penetrated then a minor pin tract infection is the inevitable consequence. Minor pin tract infection is characterized by:

- bacterial contamination of the pin–skin surface;
- limited granulation tissue formation;
- light serous discharge;
- lack of pain;
- no pin loosening.

The severity of these lesions appears to be proportional to the depth of soft tissue penetrated and the mobility of these soft tissues – minor pin tract infections are not true complications, rather the inevitable and self-limiting consequence of transfixing soft tissues. No specific treatment, other than routine wound hygiene, is indicated.

In conclusion, the majority of complications associated with external fixation are the consequence of earlier technical error. Attention to technical detail will be rewarded by enhanced clinical outcome. The surgeon should be aware of the complex inter-relationship of apparently minor problems, summarized in Figure 12.8, which can work almost synergistically to produce complication and failure.

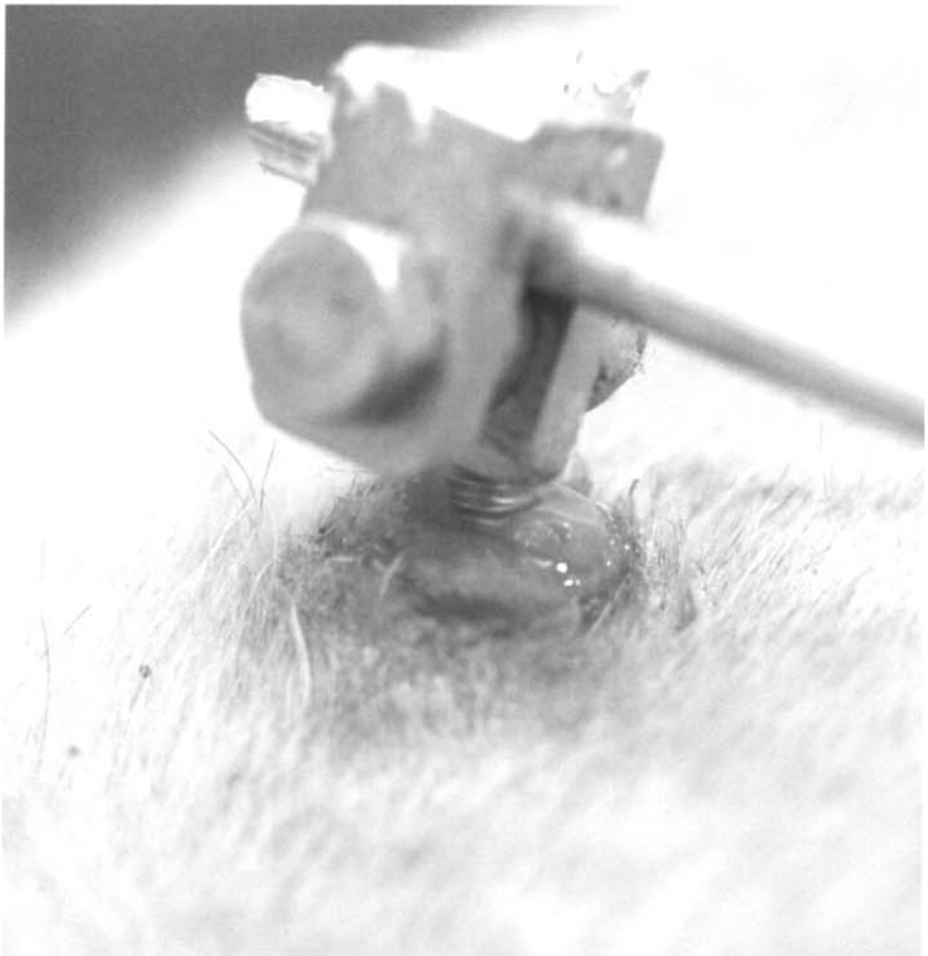


**Figure 12.11** Minor pin tract infection. A positive-threaded pin placed in the distal femoral diaphysis of a cat. The pin has been *in situ* for 8 weeks and, although there is some granulation tissue, there is little if any discharge. The pin remains firm and there is no pain. This is a "minor pin tract infection." In reality, this is not a complication but merely the inevitable consequence of placing a fixator pin through a thickness of mobile soft tissue.

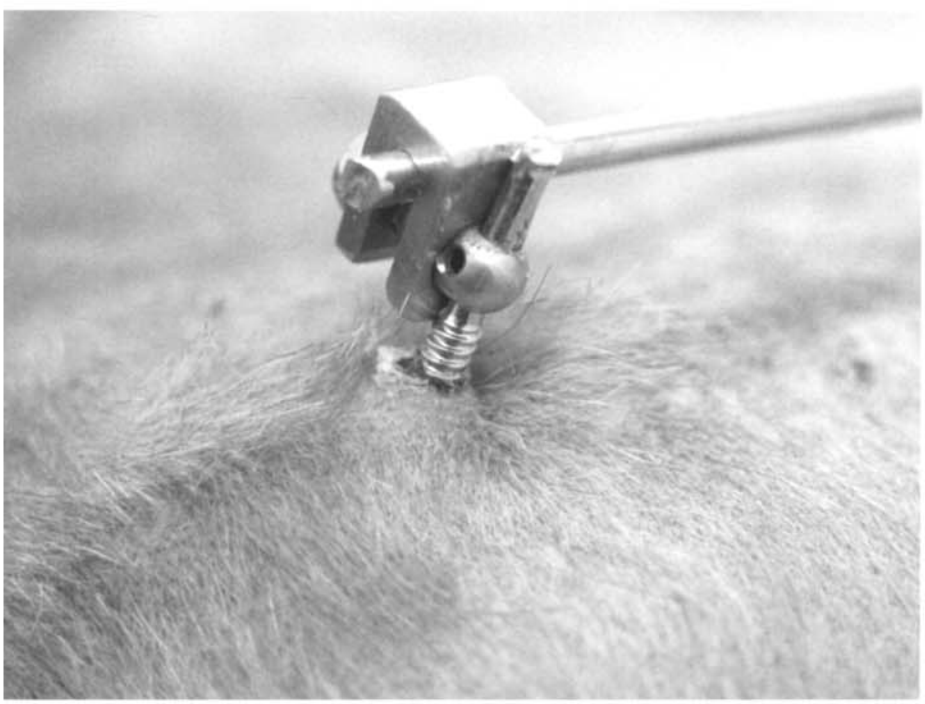


**Figure 12.12** Normal pin tract. The proximal end of the same cat's femur illustrated in Figure 12.11. This fixator pin penetrates subcutaneous bone without involving any significant soft tissue. There is neither pain nor discharge and the pin–skin interface is completely dry, benign, and nonreactive.

# Part II
# CASE STUDIES

# Radius/ulna

# Case study 1

## Clinical presentation, history, and fracture

A 5-year-old, 35-kg, intact, female German Shepherd sustained open fractures of the right radius after being missing for several hours. Thoracic and abdominal radiographs were within normal limits. The wound was clipped and lavaged and placed in a Robert Jones bandage. The fracture was a grade I open fracture of the midshaft radius and ulna. There were several large comminuted fragments. A longitudinal fissure extended 5 cm into the cranial and caudal distal diaphyseal segment. The distal fragment was displaced caudally and was overriding by 1 cm.

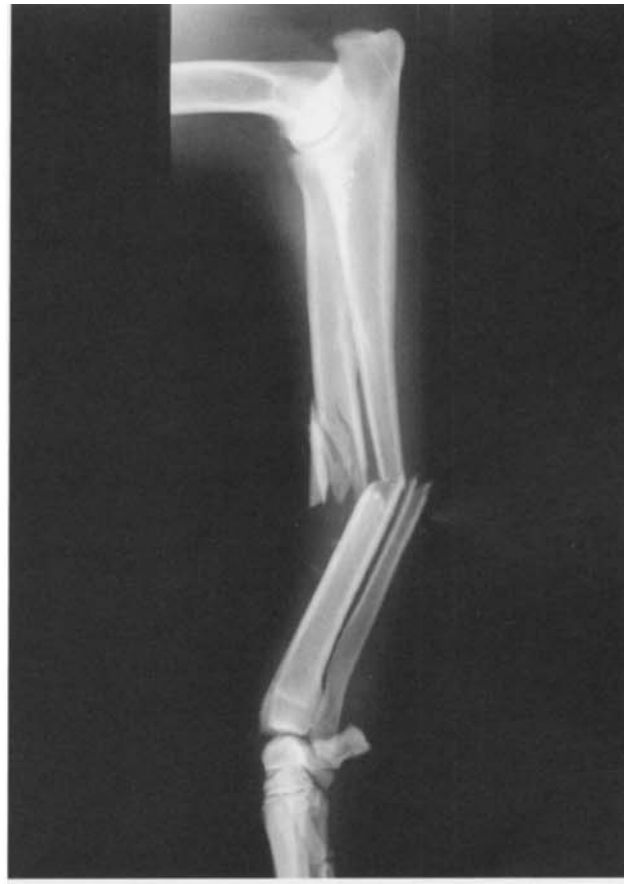
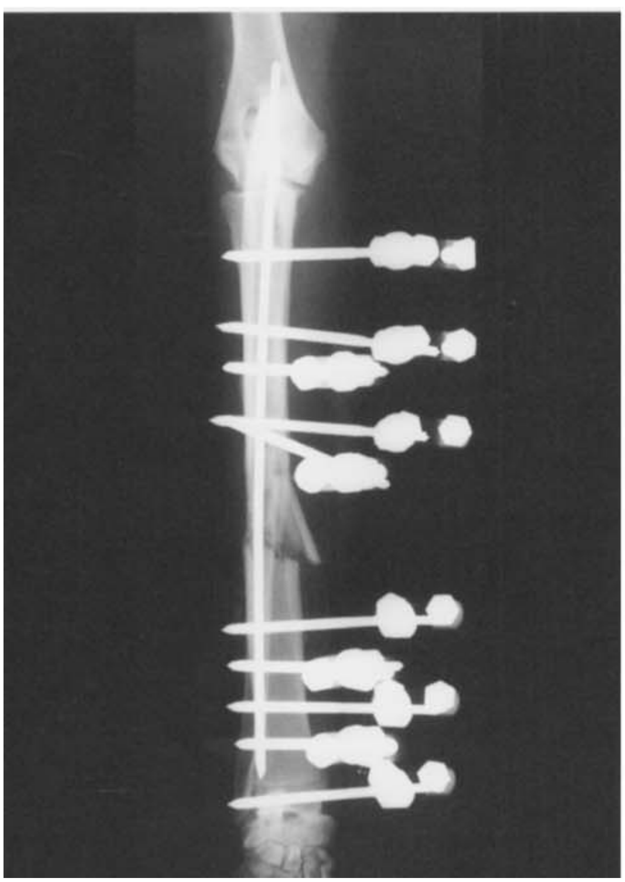
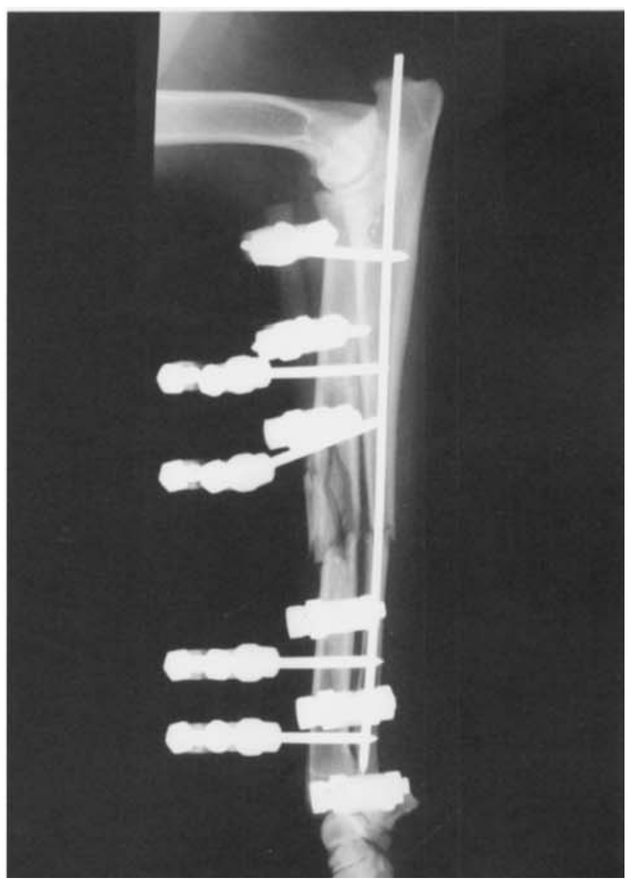
## Surgical planning

Surgery was performed the day after the accident. Casting should not be considered. The options for surgical repair could include open reduction and bone plate fixation of the radius. As the fissures were cranial and caudal, a medial or craniomedial plate location would be best. However, the number of comminuted fragments does not allow complete reconstruction of the fracture. External fixation with a limited approach should be considered. The dog was large at 35 kg. Because of the comminution, meaningful load sharing is unlikely. A fixator of adequate strength and stiffness for load bearing should be chosen. If an external fixator is used, a type II (bilateral) or type Ib (unilateral biplanar) construct should be considered to compensate for lack of load sharing by the bone.

## Fracture repair and evaluation

The fracture was repaired with an intramedullary pin in the ulna. A 5-cm approach was made to the ulna and an intramedullary pin normograded across the ulnar fracture. This not only aligned the ulna but also served to reduce the radius. A type Ib (unilateral, biplanar) fixator was applied to the radius without a surgical approach. Positive-profile half-pins were placed in the proximal and distal radius and the connecting bar applied. Four additional half-pins were applied to this connecting rod. A second connecting rod with four positive-profile half-pins was applied to the craniomedial aspect of the antebrachium. Care was taken to try to avoid the fissures in the distal radius.

Postoperative radiographs showed good alignment. Fracture apposition was adequate. The type Ib fixator was adequate for load bearing in this dog.

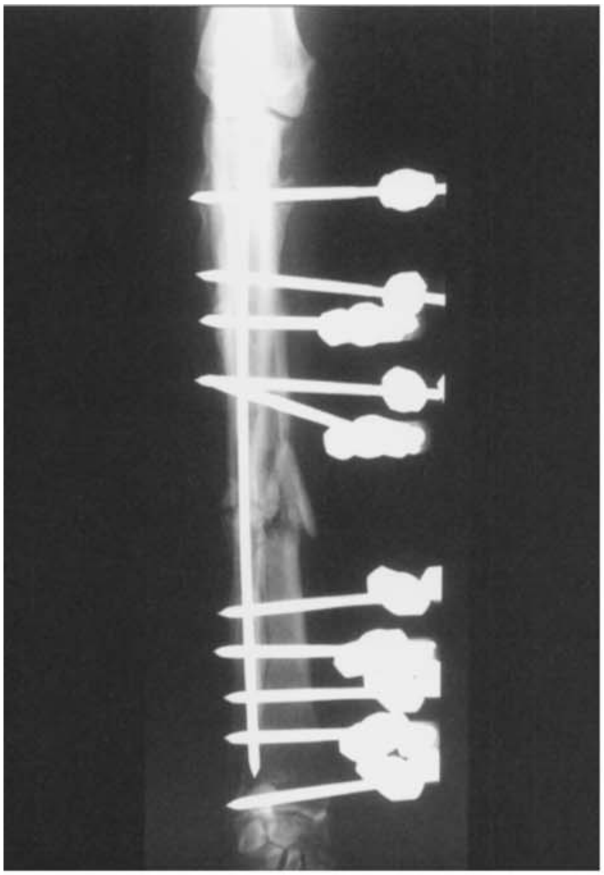





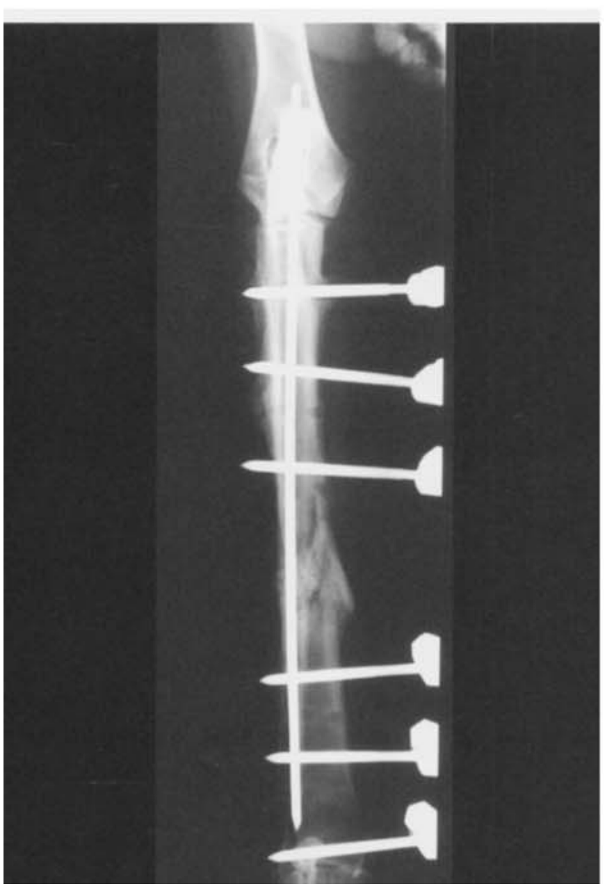
## Follow-up evaluation

At 9 weeks the dog was re-evaluated, and radiographs of the right antebrachium were taken. The dog had been using the limb well. There was persistent discharge around the proximal two fixator pins and 2-cm-diameter granulation wounds. Radiographs showed that alignment and apposition were maintained. There was early pin loosening of the most proximal fixation pin. There was a small amount of bridging callus of both the radius and ulna, although deficits of the radius were noted. The fixator cranial connecting bar with its four half-pins was removed and the patient restricted to leash walks for an additional 4 weeks. The most proximal loose fixation pin should also have been removed.

## Second follow-up evaluation

At 13 weeks the dog was presented for radiographs and re-evaluation. The dog was weight bearing with lameness, and would hold the limb up while standing. There was persistent drainage and a granulation wound around the most proximal pin. Radiographs demonstrated unchanged limb alignment and apposition. The most proximal fixation pin was loose. The intramedullary pin in the ulna had not migrated. The fracture had healed with bridging callus of both the radius and ulna. The remaining fixator was removed and the dog discharged with instructions to slowly return to normal function.






# Case study 2

## Clinical presentation, history, and fracture

A 4-year-old, 22-kg, intact, male Weimaraner sustained fractures of the left radius and ulna when hit by a car 1 day before presentation. No abnormalities were seen on thoracic and abdominal radiographs. Closed, short oblique fractures of the midshaft radius and ulna with comminution (numerous small intermediate fragments) were seen on radiographs of the left antebrachium. The distal radial segment was overriding by about 2 cm and its proximal end was displaced cranially and laterally.

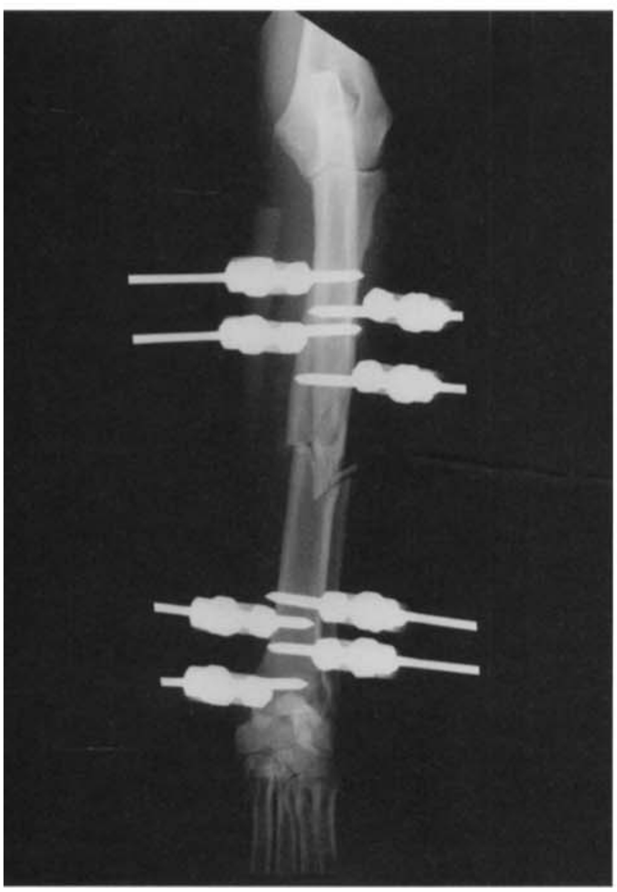
## Surgical planning

The limb was placed in a Robert Jones bandage to stabilize the fractures temporarily and to reduce swelling prior to surgery. The options for surgical repair would include bone plate fixation of the radius alone or in combination with intramedullary pinning of the ulna. The intermediate fragments are too small to attempt fixation with cerclage wires or lag screws. External fixation with a limited approach or closed manipulation is an attractive option in this case.

The dog is of moderate size at 22 kg. Owing to the obliquity of the fracture lines and the comminuted fracture pattern, meaningful load sharing is unlikely. The bone plate or fixator will, therefore, have to function in buttress mode. There is ample intact bone in both the proximal and distal fracture segments to enable placement of an adequate number of bone screws or transfixation pins. If an external fixator is used, a biplanar construct should be considered to compensate for lack of load sharing by the bone. If the fracture is opened, a cancellous bone graft should be seriously considered.

## Fracture repair and evaluation

The fracture was repaired with a unilateral, biplanar (type Ib) external fixator using large SK clamps and radiolucent carbon-fiber composite connecting rods. Approximate alignment of the fractures was obtained using the hanging limb technique with the dog positioned in dorsal recumbency. A "mini-approach" was made to adjust alignment if necessary and to enable cancellous bone grafting. One proximal and one distal half-pin were placed craniomedially and connected with two single clamps and a rod. Fracture alignment was adjusted slightly, and these clamps were tightened to maintain alignment. Two additional pins were placed through clamps added to the rod to complete a four-pin craniomedial frame. A four-pin craniolateral frame was applied to complete the type Ib construct. Cancellous bone harvested from the proximal metaphyseal region of the left humerus were applied to the fracture region prior to closure. Articulations were not applied.



Postoperative radiographs showed adequate limb alignment. The most distal craniolaterally placed pin in the proximal segment is near the fracture region but does not violate it. The most proximal craniolaterally placed pin in the distal segment is too far away from the fracture region and ideally should have been placed further proximally (nearer to the fracture region) to reduce frame working length. Placement of four transfixation pins per segment and the biplanar construct should provide adequate stabilization of this fracture. If additional construct stiffness was desired, double diagonal articulations could have been applied.

## Follow-up evaluation

At 7 weeks the dog was re-evaluated and radiographs of the left antebrachium were taken. The dog had been crate confined when the owner was away from home and had used the limb well throughout this period when taken for leash walks. The pin sites were clean and dry and the owner had been doing a good job of maintaining a protective bumper bandage on the fixator. Radiographs showed no change in fracture alignment and the expected amount of early callus deposition throughout the fracture region. At this time, staged disassembly was initiated in the following manner. The large SK single clamps and 9.5-mm carbon-fiber composite connecting rod of the craniolateral frame were removed and replaced with small SK single clamps and a 6.3-mm titanium rod. Similar replacement of the craniomedial frame was carried out, exchanging large components for small components. This resulted in a fourfold reduction in frame stiffness but still provided biplanar neutralization of bending forces.

## Second follow-up evaluation

At 12 weeks the dog was presented for re-evaluation and radiographs. Normal functional use of the limb had been maintained since the previous visit. Progressive healing of the fracture was evident radiographically. Staged disassembly was continued by removal of the four-pin craniolateral frame, thus converting the fixator to a type Ia construct.

## Third follow-up evaluation

At 16 weeks the dog was again presented for re-evaluation. Radiographs demonstrated good healing with adequate callus bridging the fracture region. The clamps were loosened to palpate the fracture. Clinical union was evident, enabling removal of the fixator at this time. More aggressive staged disassembly at earlier time intervals would probably have reduced the time to fixator removal in this patient. The dog was restricted to leash walking for an additional 6 weeks following removal of the fixator.

# Case study 3

## Clinical presentation, history, and fracture

A 2-year-old, 26-kg, spayed, female golden retriever disappeared from home for 3 days and returned carrying the left forelimb. The referring veterinarian diagnosed fractures of the left radius and ulna, treated the dog for a mild pneumothorax and moderate dehydration, and placed a Robert Jones bandage to immobilize the injured limb. The dog was in a stable condition on presentation. Radiographs of the left antebrachium revealed closed, short oblique fractures of the distal diaphyseal regions of the radius and ulna with moderate comminution and about 2 cm of overriding. The distal radial segment was about 5.5 cm in length. The distal end of the proximal radial segment had a fissure line and was displaced caudally and medially.

On the craniocaudal projection, a small ossified density with smooth edges was seen medial to the elbow joint. This was felt to represent previous pathology unrelated to the recent traumatic incident. Because neither pain nor instability could be demonstrated on palpation of the elbow joint, this ossified mass was felt to be clinically insignificant.

## Surgical planning

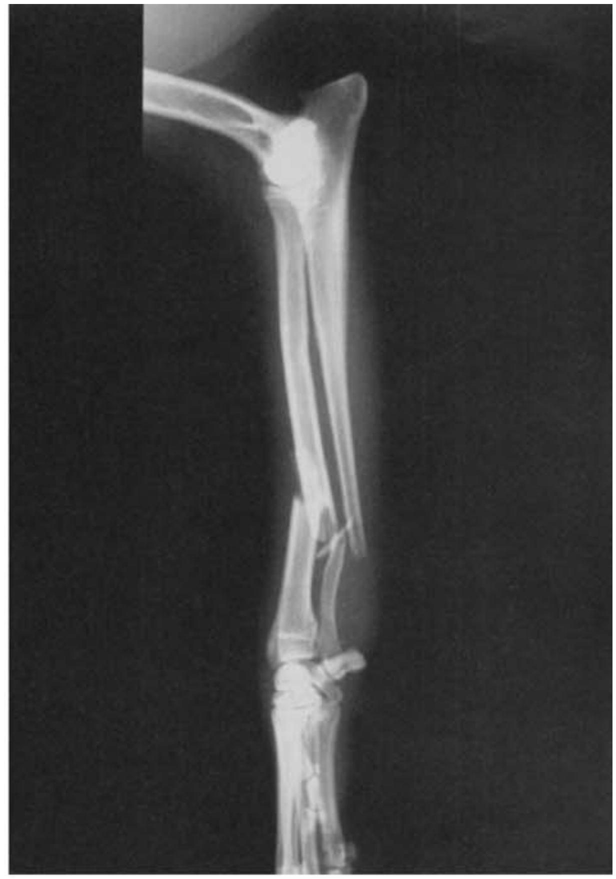
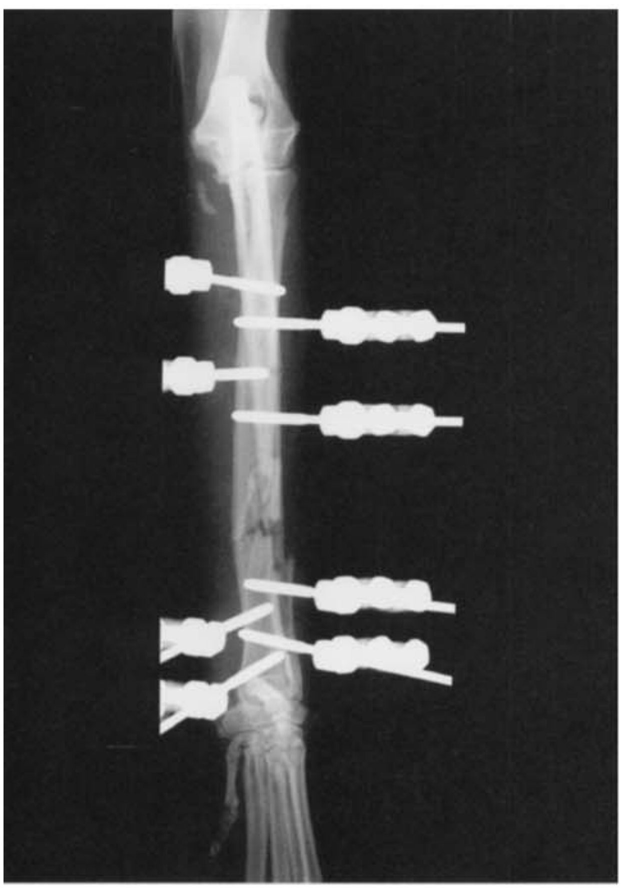
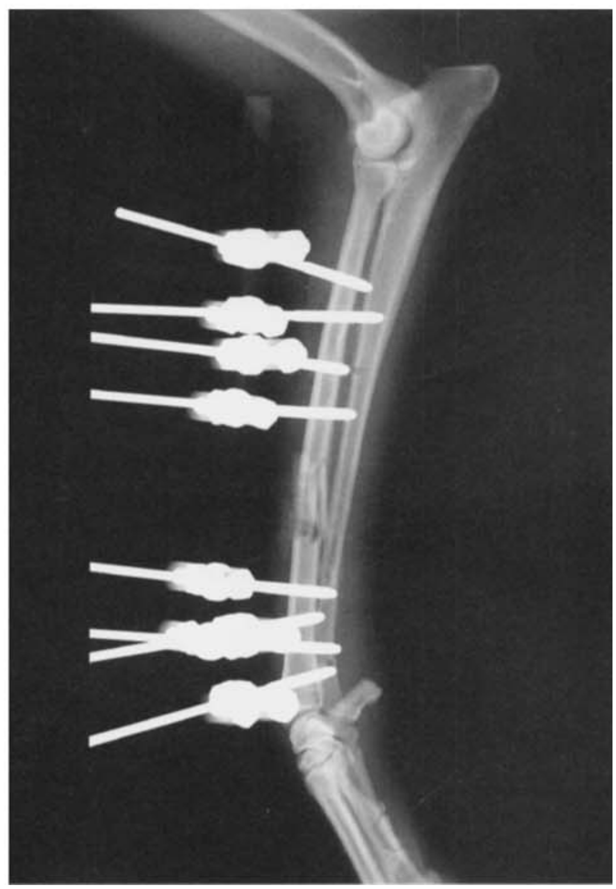
The best options for treatment would include bone plate fixation or application of an external fixator to the radius. The intermediate fragments are too small to attempt fixation with cerclage wires or lag screws. Obtaining good load sharing is unlikely because of the obliquity of the fracture lines and the comminuted fracture pattern. The fixation technique chosen should be capable of functioning in buttress mode.

## Fracture repair and evaluation

The dog was placed in dorsal recumbency and the right forelimb pulled caudally and secured to improve access to the proximal metaphyseal region of the humerus for obtaining a cancellous bone graft. The hanging limb technique was used to achieve approximate alignment of the fractured bones. A "mini-approach" was made to enable adjustment of fracture alignment and cancellous bone graft application.

The fracture was repaired with an eight-pin, unilateral, biplanar (type Ib) external fixator. Large SK clamps, carbon-fiber composite connecting rods, and "no-point" (rounded end) positive-profile fixation pins were used. Although it is strongly suggested that a predrilling technique be used with all positive-profile fixation pins, it is essential with the pins used in this case because they have no cutting point. The theoretical advantage of such pins is that they are less likely to damage soft tissues overlying the far cortex of the bone.

One proximal and one distal half-pin were placed craniolaterally and connected with two single clamps and a rod. Fracture alignment was

adjusted, and the clamps were tightened to maintain alignment. Two additional pins were placed through clamps added to the rod to complete a four-pin craniolateral frame. A four-pin craniomedial frame was applied to complete the type Ib construct. A cancellous bone graft was applied to the fracture region prior to closure. Articulations were not applied to this biplanar fixator.

Postoperative radiographs were made and good alignment of the radius and ulna were noted on both projections. A fissure line was evident in the distal segment of the radius (see craniocaudal projection) that was not apparent in the preoperative radiographs. Fixation pins were placed in a far–near–near–far pattern relative to the fracture region, and all were a safe distance from it (see lateral projection). A biplanar construct with 9.5-mm connecting rods and four transfixation pins per segment was expected to provide adequate stabilization of these fractures. Articulations could have been applied to increase fixator stiffness, if desired.

## Follow-up evaluation

The dog was re-evaluated and radiographs of the left antebrachium were made 7 weeks after surgery. Physical activity had been confined to leash walking, and the dog's functional use of the leg had progressively improved throughout this period. The owner had done a good job with bandaging of the fixator, and the majority of pin sites were clean and dry. There was some discharge from the proximal pin site in the craniolateral frame. Radiographs showed good alignment of the fracture and early deposition of smooth callus throughout the fracture region, especially along the cranial aspect of the radius, where the cancellous bone graft had been applied. There were no problems seen in the distal segment, where the fissure line had been previously noted and it was no longer apparent radiographically.

Staged disassembly was achieved in the following manner. The large SK clamps and carbon-fiber connecting rod were removed from the craniomedial frame and replaced with small SK clamps and a titanium connecting rod. The craniolateral frame and its four pins were removed. This converted the fixator from a type Ib with large components to a type Ia with small components. This resulted in a much greater reduction in frame stiffness than with the initial disassembly in case study 2.

## Second follow-up evaluation

At 11 weeks the dog was presented for re-evaluation and radiographs. Good functional use of the left forelimb was evident and the pin sites were clean and dry. Radiographs revealed smooth, mature callus bridging the fracture region. Fixation clamps were loosened to enable palpation of the fracture and clinical union was evident. The fixator was removed. The dog was placed in a modified Robert Jones bandage for 1 week and confined to leash walking for 6 weeks following fixator removal.




# Case study 4

## Clinical presentation, history, and fracture

A 3-year-old, 38-kg, male golden retriever sustained a fracture of the left ulna and radius by trapping the limb in the bars of a gate over which he was jumping. Clinical examination confirmed that abnormalities were confined to the injured limb. The fracture was open, with a 1-cm wound over the fractured radius medially and involved the mid-diaphyseal portion of the ulna and radius. Essentially a transverse fracture of each bone, there was an additional small ulnar fragment; the radius was more comminuted, with a larger "butterfly" fragment plus several smaller fragments laterally.

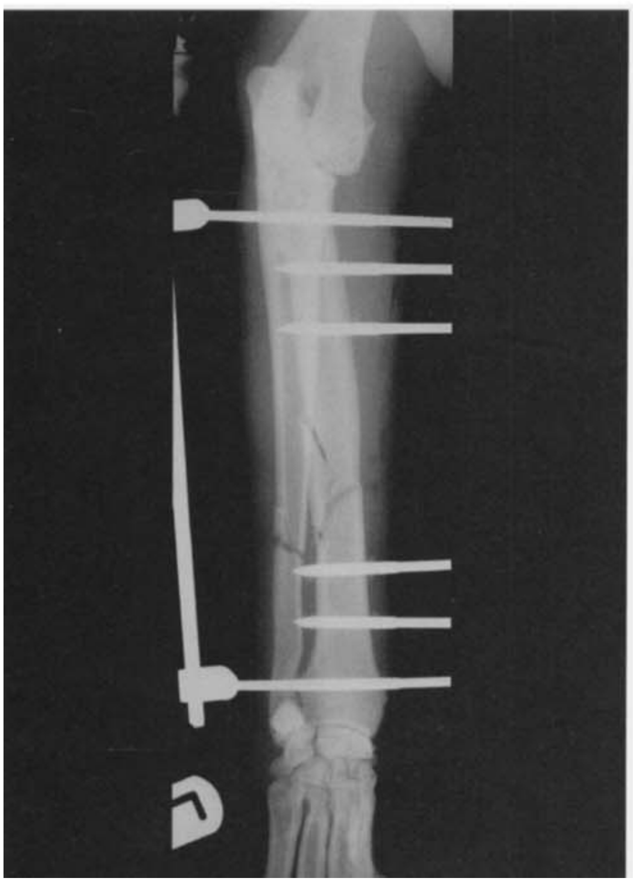
## Surgical planning

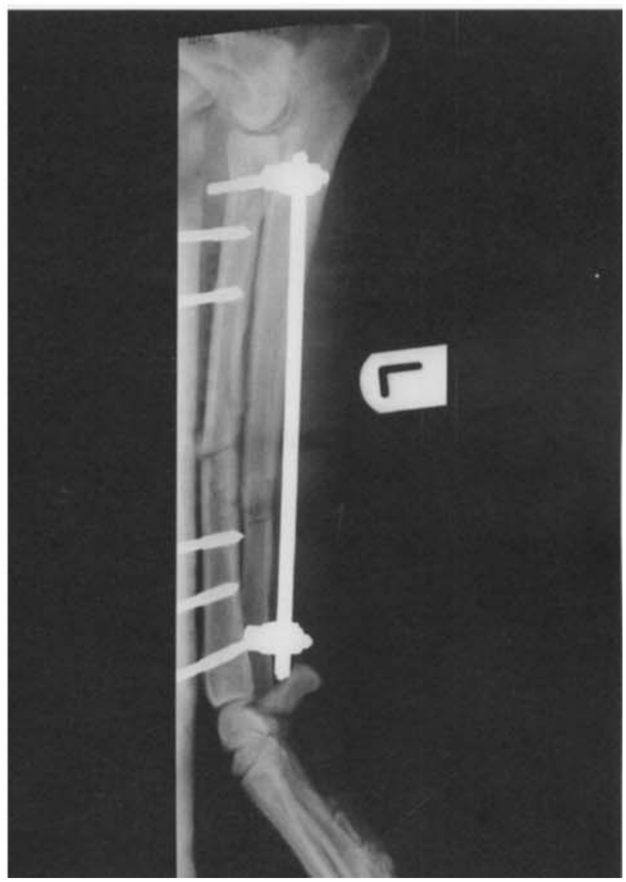
External coaptation could be considered. However, in this mature patient, bone healing will be relatively slow and the risks of cast-related complication and fracture disease are considerable. Intramedullary pinning of the radius cannot be effectively performed on patients without iatrogenic damage to the adjacent joints. Pinning of this fracture would be contraindicated. Open reduction and plating fixation of this fracture would be eminently suitable. The presence of small fragments would prevent perfect anatomic reconstruction and, being an open fracture, plating would involve placing implants into a contaminated wound. However, a well-applied plate could be expected to produce an excellent outcome in this case.

External skeletal fixation should be chosen because the prognosis equals or exceeds that of other options, and external fixation, in this case, has many advantages, including economy, technical simplicity, and speed of application.

## Fracture repair and evaluation

The fracture was treated using a bilateral, uniplanar (modified type II) external fixator featuring an APEF bar medially. Using the hanging limb technique, the limb was realigned. Reduction was evaluated by palpation of the fracture fragments through the intact skin and reference to external anatomical landmarks. A single full pin was placed proximally and a second full pin distally; four half-pins were placed – two in each major fragment – all on the medial side. All pins were placed into the radius and positive-profile threaded pins were used throughout. A single steel connecting bar was attached to the two full pins laterally and limb





alignment checked once more prior to placing a flexible tube mold over all six medial pins then pouring the acrylic. The wound was lavaged then dressed for 5 days to allow secondary wound healing; no sutures were placed.

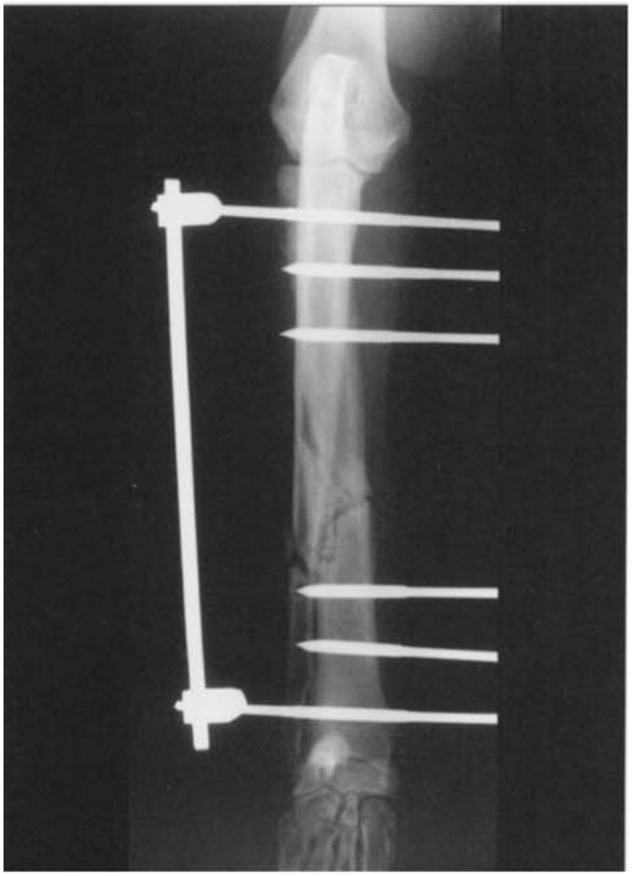
Radiographs showed excellent limb alignment with near anatomic reduction of the small fragments. All pins were well located and of suitable size.

## Follow-up evaluation

The dog was weight bearing confidently on the operated limb the day after surgery. Six weeks later, the dog was walking with only minor lameness. Pin sites were clean and dry except for the proximal pin, which showed a degree of inflammation and slight serous discharge both medially and laterally. Radiographs showed only very modest callus formation but already well-established interfragmentary new bone; there was no evidence of pin loosening, although a degree of sclerosis and bony reaction was seen around the proximal full pin. At this stage the fixator was staged down by removing the lateral connecting bar along with both the proximal and distal full pins to leave a four-pin type I (unilateral, uniplanar) frame.

## Second follow-up evaluation

Four weeks later – 10 weeks after surgery – the dog was re-examined. Lameness was minimal even during free running exercise. Pin sites were all clean and dry. A single lateral radiograph was taken, which showed good healing of both bones; there was minimal callus formation and some evidence of bony remodeling. The fixator was removed.




VETS


VETS

# Case study 5

## Clinical presentation, history, and fracture

A 9-year-old, 38-kg German Shepherd cross sustained an open, comminuted fracture of the radius and a segmental fracture of the ulna in a road accident 3 hours prior to presentation. Clinical examination supported with thoracic radiography confirmed that significant abnormalities were confined to the fractured limb. The dog had undergone bilateral tibial plateau leveling osteotomy procedures to treat cranial cruciate ligament failure 2 years earlier but was judged to have made a full recovery from those operations. The fracture was an open, comminuted, distal third radius and ulna fracture. There was one 2 × 3 cm comminuted fragment and several small fragments. The distal fragment was displaced laterally and was overriding by 1 cm.

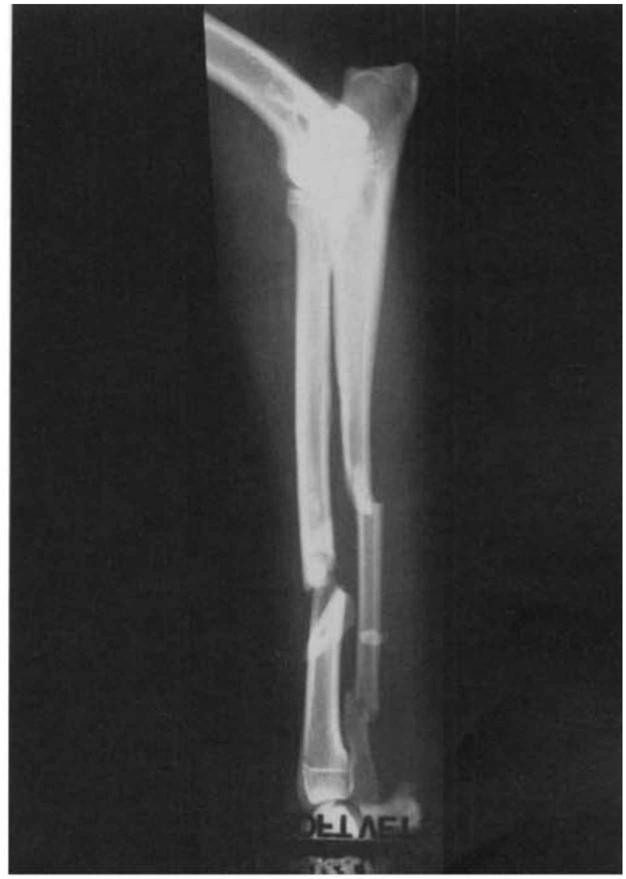
## Surgical planning

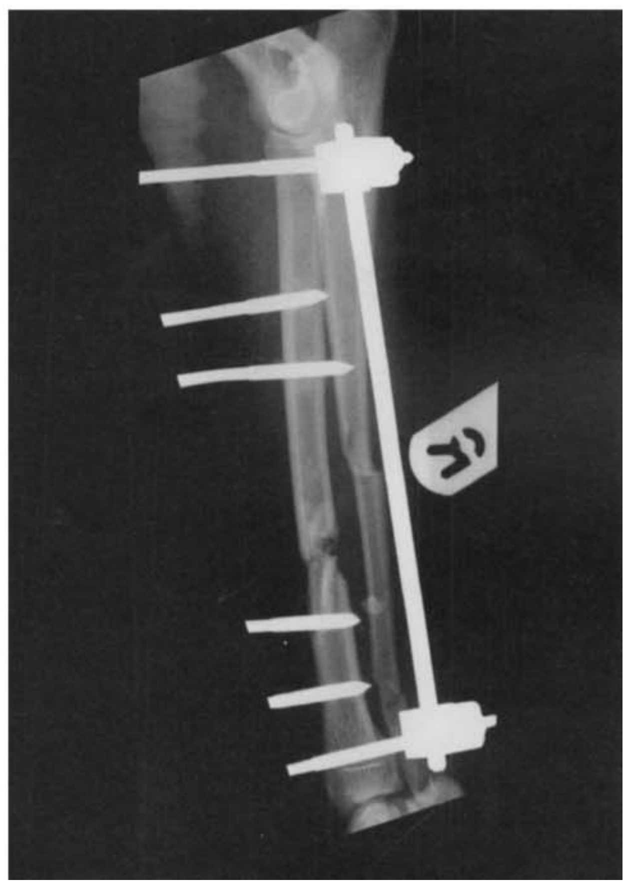
Options for management of this fracture might include external coaptation. However, as this is an inherently unstable and open fracture in an older dog, this is not a suitable case for treating with a cast or splint. The canine radius is not amenable to intramedullary pinning. This fracture is suitable for plate fixation. However, anatomic reconstruction of the radius will not be possible so the plate would be a "buttress." Because this is an open fracture, plating is a less than ideal option, although this is mitigated by the fact that the case has presented during the short "golden period" before *contaminated* open fractures are thought to become *infected.* With careful attention to the details of appropriate technique, plate fixation of this fracture would give good results. Open fractures like this are best treated by external fixation whenever possible, as this provides stabilization without having implants placed in the contaminated fracture site.

## Fracture repair and evaluation

The hanging limb technique was used. The small wound over the fracture site was debrided, but no surgical approach was made to the fracture; nor was this wound sutured. A single, threaded, full pin was placed proximally near the elbow and a second full pin distally near the carpus. Four threaded half-pins – two in each major fragment – were placed into the medial aspect of the radius. A steel connecting bar was placed to unite the two full pins laterally, and limb alignment was then rechecked prior to formation of an APEF column to unite all six pins medially.

Radiographs showed excellent limb alignment although there was some lack of fragment apposition. Pin placement was considered acceptable. The proximal full pin was perhaps a little too proximal and one of the half-pins was poorly placed, engaging only one cortex and impinging upon the fracture. Neither of these shortcomings was considered sufficiently



serious to warrant revision of the surgery. The dog was seen to be weight bearing consistently on the limb on the day after surgery.

## Follow-up evaluation

After 6 weeks the dog was walking well with remarkably little lameness. The skin wound had healed without incident. All pin–skin interfaces were clean and dry. Radiographs showed limb alignment and fragment apposition were unchanged. The fixator was in place and the bone–pin interface was intact. Bone healing was progressing as there was evidence of modest bridging callus uniting the fractures. The fixator was staged down by removing the lateral (steel) connecting bar as well as the proximal and distal full pins, which were cut from the acrylic column and withdrawn laterally.

## Second follow-up

Four weeks later (10 weeks after surgery) the dog was re-examined. The owners reported that the dog had become significantly more lame 2 days after the fixator was staged down. Lameness had then improved steadily, but by the 10-week check the dog remained markedly more lame than at the 6-week check. Radiographs showed excellent healing and early remodeling of the original fractures, but there was an iatrogenic fracture associated with the most proximal half-pin. Abundant and mature bony callus was formed about this fracture. There was no instability associated with this fracture and other pins appeared firm. All remaining implants were removed.

Lameness resolved slowly over a period of 6 weeks or so. At final evaluation 6 months after surgery, the dog was fully active and without discernible lameness.

## Discussion

Fracture through a pin tract like this is an unusual complication. The radiographic appearance and clinical history indicate that the fracture occurred 2 days after staging down of the fixator at the 6-week check. Although not excessively large, these pins are at the upper size limit (30% bone diameter), and this may have contributed to the failure. Similarly, it might have been advisable to stage down this fixator more gradually – perhaps removing only the lateral bar initially. At the time of second follow-up, the pathological fracture was already healing well and the dog was improving clinically so a decision was taken to manage conservatively. That decision was vindicated by the subsequent prompt return to full athletic activity and soundness.

# Case study 6

## Clinical presentation, history, and fracture

A 5-year-old, 37-kg intact, female German Shepherd sustained fractures of the right radius after being missing for several hours. Thoracic and abdominal radiographs were within normal limits. Grade I open, comminuted transverse fractures of the midshaft radius and ulna were seen on radiographs of the left antebrachium. There were several longitudinal fissures in the proximal radius. The distal radial segment was minimally displaced. The wound was debrided and lavaged and closed with skin sutures. The limb was placed in a Robert Jones bandage to temporarily stabilize the fractures and to reduce swelling prior to surgery.

## Surgical planning

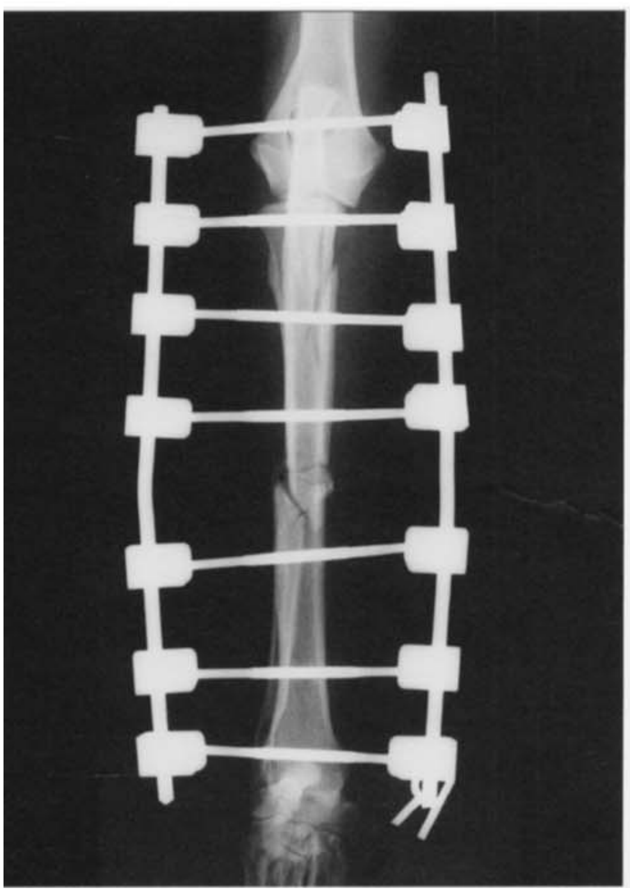
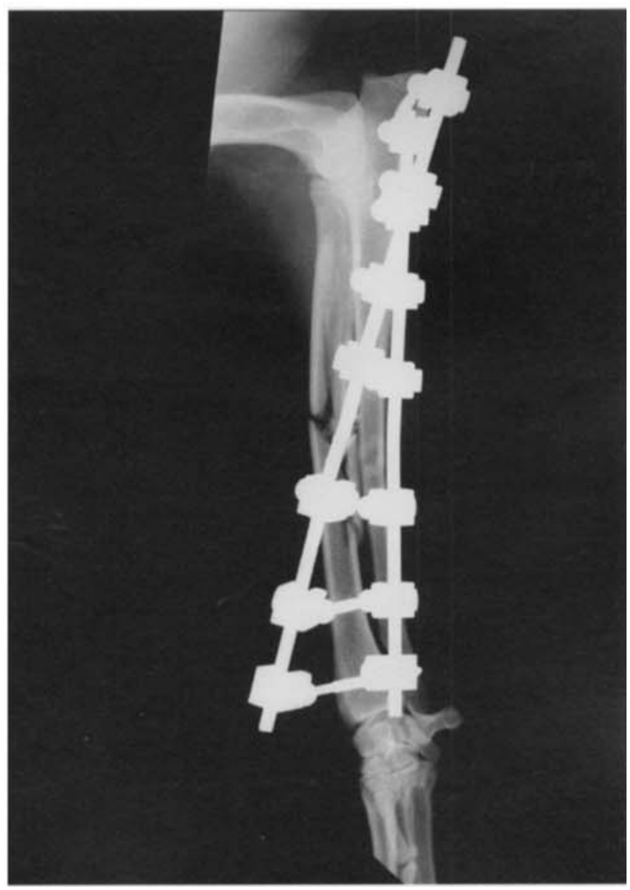
Surgery was performed the day after the accident. Casting should not be considered. The options for surgical repair should not include bone plate fixation of the radius because of the fissures of the proximal radius. External fixation with a limited approach should be considered. The interosseous ligament between the proximal radius and ulna could be utilized to stabilize the combined proximal radius and ulna. By stabilizing the distal radius and the proximal ulna, the fracture could be sufficiently stabilized for osteosynthesis. The dog was large at 37 kg. Owing to the comminution, meaningful load sharing is unlikely. A fixator of adequate strength and stiffness for load bearing should be chosen. If an external fixator is used, a type II (bilateral) or type Ib (unilateral biplanar) construct should be considered to compensate for lack of load sharing by the bone.

## Fracture repair and evaluation

The fracture was repaired with a type II (bilateral) external fixator. Approximate alignment of the fractures was obtained using the hanging limb technique and a small surgical approach. One proximal full pin in the olecranon and one distal full pin in the distal radius were placed, joined by connecting rods. Fracture alignment was adjusted, and connecting bars placed. Three additional full pins were placed in the proximal ulna and two in the distal radius fragment using an aiming tool.

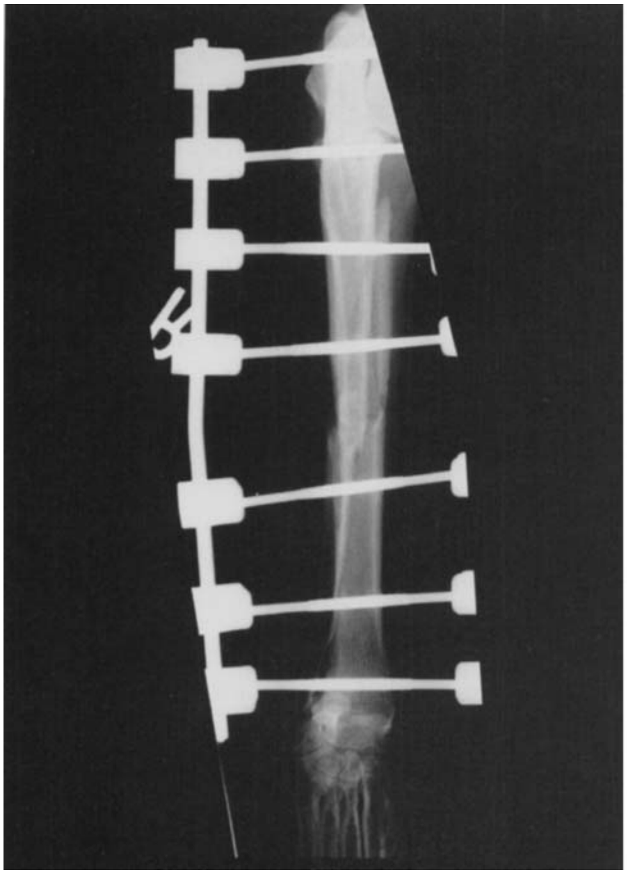
Postoperative radiographs showed limb good alignment. The most proximal fixation pin in the distal radius fragment may have invaded a fissure line.

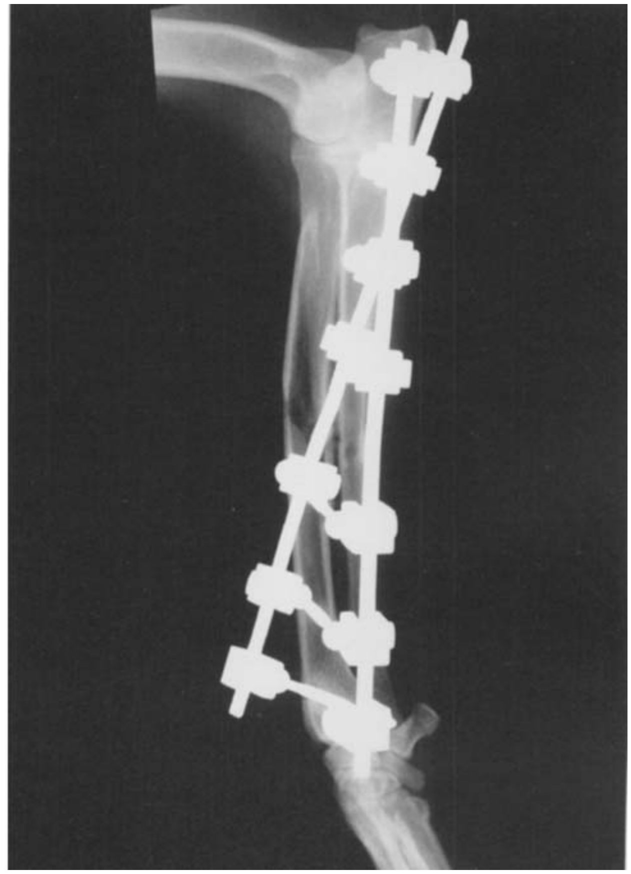


## Follow-up evaluation

At 10 weeks the dog was re-evaluated, its owner having neglected a recommended 8-week evaluation, and radiographs of the right antebrachium were taken. The dog had been using the limb normally. There were no complications at the pin sites. Radiographs showed that alignment and apposition were maintained. There was no pin loosening. There was bridging callus of both the radius and ulna. The fixator was removed and the patient restricted to leash walks for an additional 3 weeks.





# Case study 7

## Clinical presentation, history, and fracture

A 3-year-old, 45-kg, castrated, male golden retriever sustained fractures of the left radius and ulna from a motor vehicle accident. Severe pulmonary contusions were noted on thoracic radiographs. Grade I open, comminuted, transverse fractures of the midshaft radius and ulna were seen on radiographs of the left antebrachium. The distal radial segment was displaced cranially and was overriding by 2 cm.

## Surgical planning

The wound was debrided and lavaged and closed with skin sutures. The limb was placed in a Robert Jones bandage to temporarily stabilize the fractures and to reduce swelling prior to surgery. Surgery was delayed for 2 days to allow resolution of the pulmonary contusions. Casting should not be considered. The options for surgical repair would include bone plate fixation of the radius alone or in combination with intramedullary pinning of the ulna. The intermediate fragments were too small to attempt fixation with cerclage wires or lag screws. External fixation with a limited approach should be considered. The dog was large at 45 kg. Owing to the comminution, meaningful load sharing is unlikely. A fixator of adequate strength and stiffness for load bearing should be chosen. If an external fixator is used, a type II (bilateral) or type Ib (unilateral, biplanar) construct should be considered to compensate for lack of load sharing by the bone.

## Fracture repair and evaluation

The fracture was repaired with a type II (bilateral) external fixator. Approximate alignment of the fractures was obtained using the hanging limb technique and a small surgical approach. One proximal and one distal full pin were placed, joined by connecting rods. Fracture alignment was adjusted slightly and the clamps were tightened to maintain alignment. Three additional full pins were placed in the proximal fragment and two in the distal fragment using an aiming tool.

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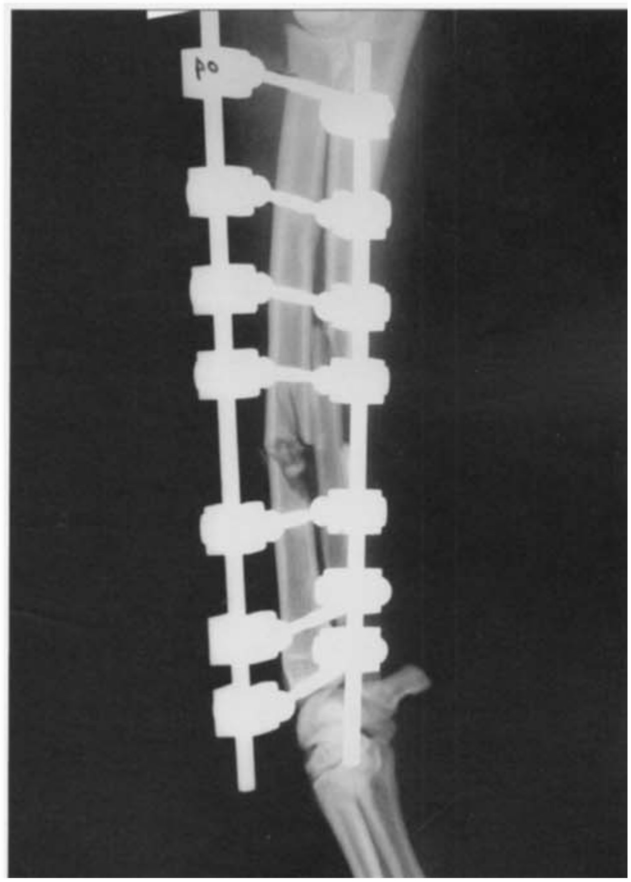
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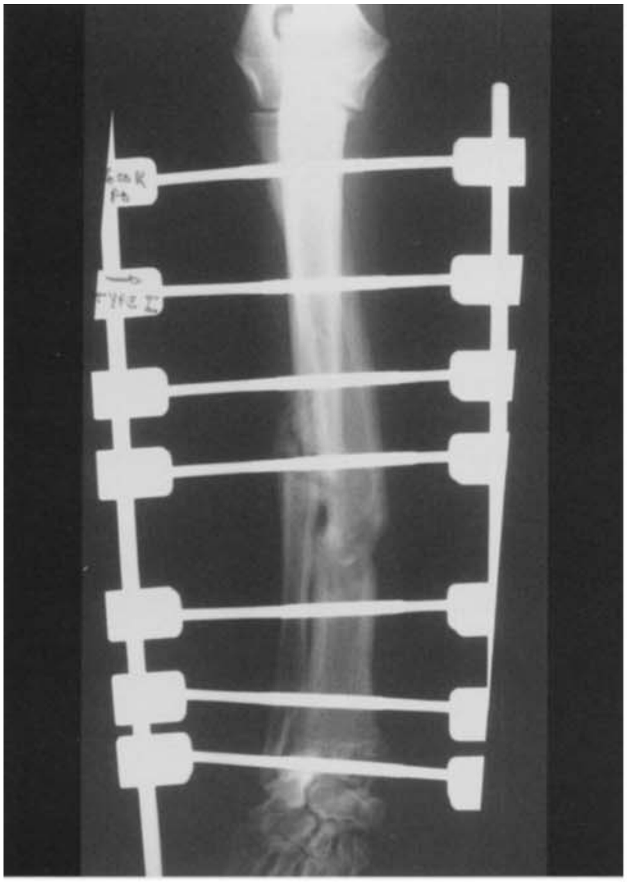
Postoperative radiographs showed 5° of lateral angular malalignment. The most proximal fixation pin was noted to have caused a fracture of the cranial radial cortex. The distal pin appeared to be very close to the radiocarpal joint.

## Follow-up evaluation

At 6 weeks the dog was re-evaluated and radiographs of the left antebrachium were made. The dog had been using the limb normally. There were no complications at the pin sites. Radiographs showed that alignment and apposition were maintained. The most proximal fixation pin was loose. There was bridging of the fracture with a small amount of callus, although there were deficits at the caudal cortex of the radius. The proximal fixation pin was removed and the bilateral fixator was converted to a unilateral fixator by removing the lateral connecting bar and shortening the fixation pins.

## Second follow-up evaluation

At 9 weeks the dog was presented for re-evaluation and radiographs. Normal functional use of the limb had been maintained since the previous visit. Radiographs showed progressive healing of the radial fracture and bridging callus of the ulnar fracture. Deficits of the caudal radial fracture remained. The fixator was removed and the dog restricted to leash walks for an additional 3 weeks.

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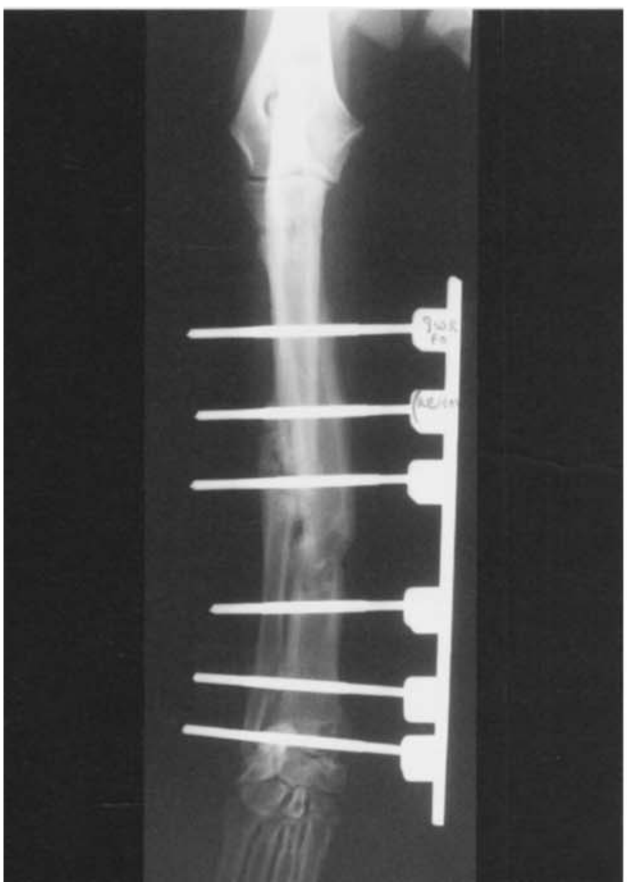


# Case study 8

## Clinical presentation, history, and fracture

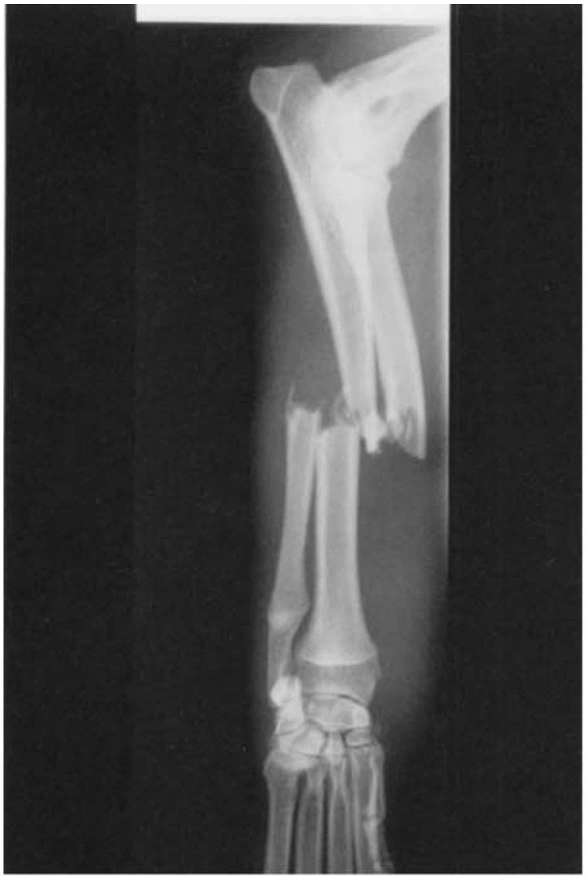
An 18-month-old, 20-kg, intact, male Chow sustained trauma to the right antebrachium. The dog had been seen fighting another dog the previous night and was nonweight bearing that morning. Physical examination revealed a moderate amount of dried blood on its fur and puncture wounds in its right antebrachium. Radiographs revealed comminuted midshaft radius and ulna fractures displaced caudally and overriding by 1 cm. There were several small, comminuted pieces and fissures extending up the proximal bone section. The fracture was very unstable, as evidenced by the craniocaudal preoperative radiograph, which shows a lateral view of the elbow and cranial to caudal view of the distal limb. There was no radiographic evidence of gas within the soft tissues.

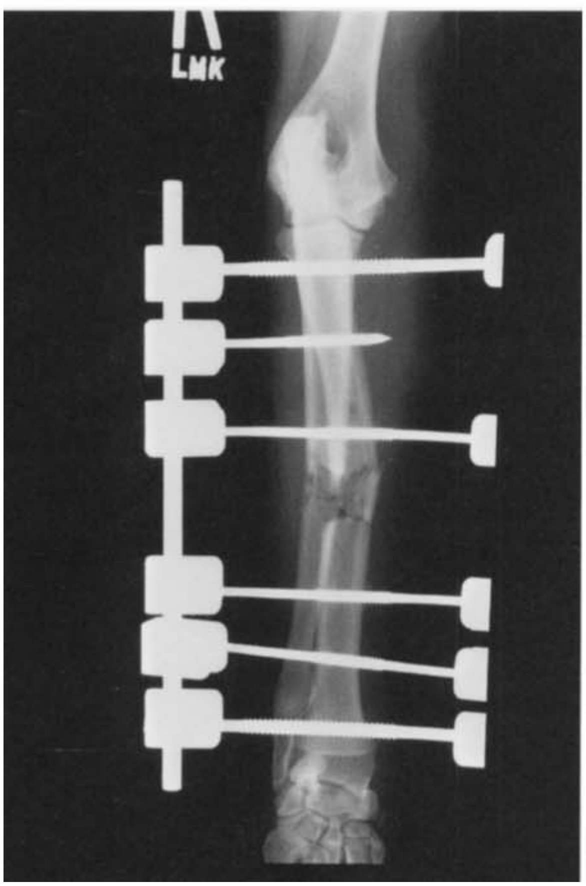
## Surgical planning

Although radiographically there was no evidence of this being an open fracture, it is very probable that it was. This would require special and prompt attention, including clipping and cleansing, exploration, debridement, and lavage. Casting should not be considered. Intramedullary pin and wire fixation is usually not considered in radius fractures, but especially in this fracture. Plate fixation could be considered, although propagation of the potentially infected fracture site to the area of exposure for placement of the plate is likely. External fixation is an ideal method of fixation. A limited-approach reduction would allow exploration of the fracture, debridement, and lavage, while allowing assurance that the fracture was aligned. A type II (bilateral), type Ib (unilateral, biplanar), or type III (multiplanar) fixator should be chosen and stiffer fixators should be chosen as there would be limited load sharing with the degree of comminution. In addition, the wound should be left open if the fracture appears infected and treated with wet-to-dry bandages and delayed primary closure.

## Fracture repair and evaluation

The fracture was repaired with a type II (bilateral) external fixator. The limb was reduced using the hanging limb technique. A limited approach was made over the fracture area, and the area was debrided of dead tissue and blood clot. The wound was then copiously lavaged. Two 3.2-mm positive-profile threaded full pins were placed, one in the proximal radius and one in the distal radius. Connecting rods were attached to these and

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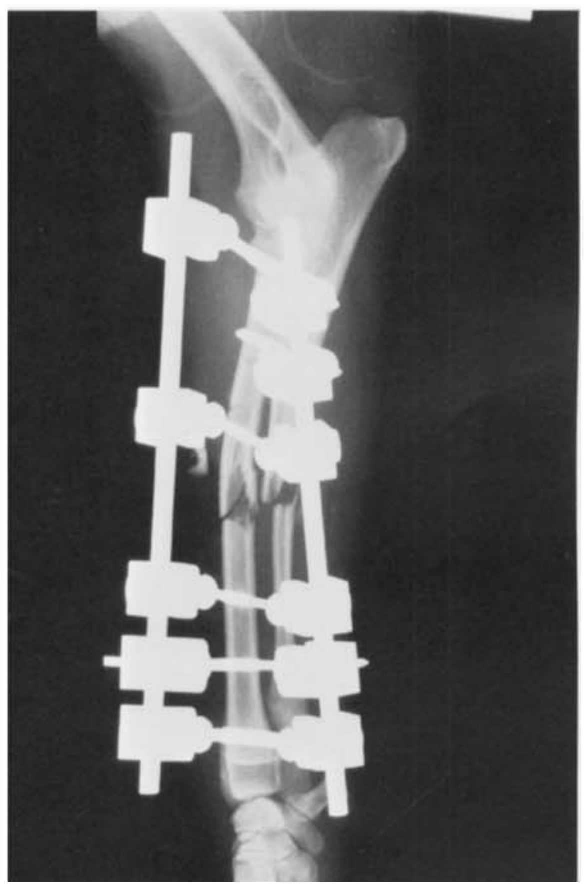
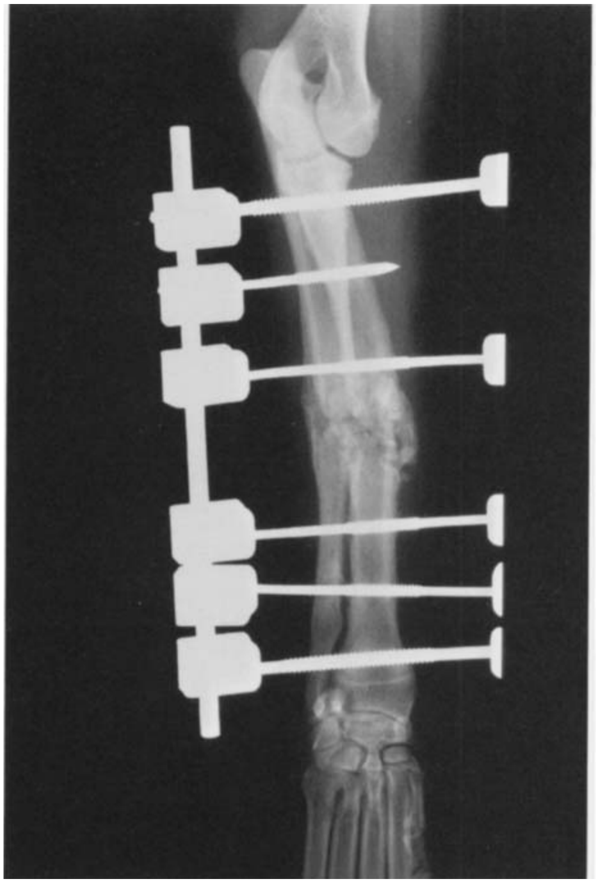


the fracture reduced. The fracture could be visualized to assure adequate reduction. Consecutive 2.4-mm positive-profile threaded pins were added. The smaller pins were added because the radius in this dog was so small that 3.2 mm would be larger than 20% of the diameter of the bone in a lateral radiographic view. A second half-pin was placed in the the proximal segment, because a more rigid full pin could not adequately engage the radius and still be attached to the opposite connecting rod.

The alignment of the fracture was adequate, although radiographically there seemed to be a small amount of medial bowing at the fracture site. Apposition of the fracture fragments was adequate. The apparatus was properly applied close to the ends of the radius and close to the fracture without invading it. It is of at least sufficient stiffness for this weight of dog. The amount of contamination was not considered significant and the wound was closed. The dog was discharged the following day with instructions for fixator care and a prescription for cephalexin.

## Follow-up evaluation

The dog had been ambulatory since 1 week post surgery. At 6 weeks radiographs revealed that the alignment and apposition of fracture fragments were unchanged. The position of the fixator was also unchanged and there was no sign of radiographic loosening of fixation pins. The fracture was bridged as seen from both radiographic views. The fixator was removed.




# Case study 9

## Clinical presentation, history, and fracture

A 6-year-old, 35-kg, intact, male Husky sustained a right radius and ulna fracture while fighting with another large dog. On presentation the antebrachium had several puncture wounds. The dog was otherwise in a stable condition. Radiographs revealed gas within the facial planes of the antebrachium and diffuse swelling. The fracture was an open, transverse, midshaft radius fracture, displaced caudally and medially, and was overriding by 1 cm.

## Surgical planning

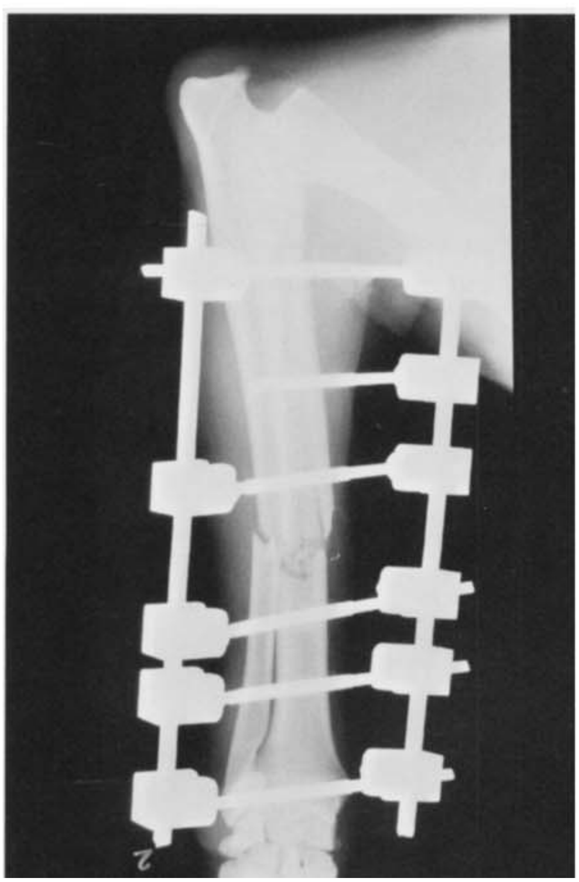
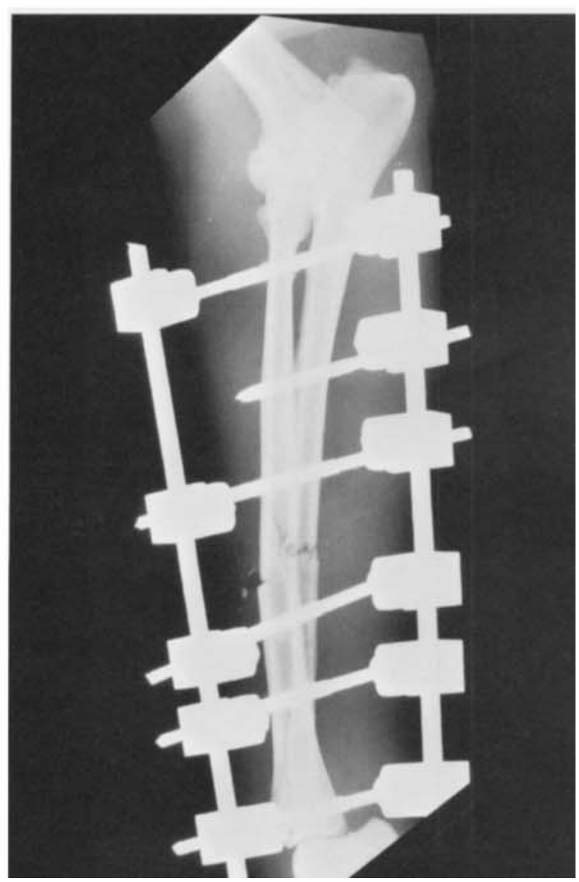
Bite wounds require specific treatment and consideration. As soon as the patient is stable, the wounds should be clipped and debrided. In many cases, the wound should be surgically explored, debrided, lavaged, and stabilized as soon as possible. With most bite wounds, there is considerable soft-tissue injury as well as fracture, and injection of bacteria into the wound. Delay in treatment can result in colonization of the tissues and bone. Fractures associated with bite wounds and gunshot wounds are best treated with external fixation. The exposure is minimal and implants are avoided at the contaminated site. Casting or pinning would be contraindicated. The fracture could be plated if the tissues were reasonably viable. Even then, the exposure needed for plate fixation and presence of implant at the fracture may increase the incidence of infection.

The dog is large at 35 kg. The fracture is transverse and may allow load sharing if the fissures in the proximal segment of the radius do not propagate. A bilateral (type II) fixator with three full pins per segment or unilateral, biplanar (type Ib) with 4–6 half-pins per segment should be considered. A bilateral fixator would provide sufficient stiffness with fewer pins. This may decrease the morbidity in this situation, in which contamination and crushing of soft tissues is known to have occurred.

## Fracture repair and evaluation

The fracture was repaired with a bilateral (type II) external fixator. The limb was reduced using the hanging limb technique. A 7-cm incision was made at the fracture site to explore for soft-tissue damage, for debridement and lavage, and to visualize fracture reduction. There was mild tissue trauma. Only minimal debridement was needed and the area was copiously lavaged with several liters of saline. Full pins were placed in



the proximal and distal radius and the fracture was reduced. Connecting bars were placed. The surgical plan was to apply three full pins in the proximal and distal segments of the radius. Although an aiming device that allows placement of full fixation pins in several orientations to the fracture was used (see Chapter 6), the second fixation pin could not be placed as a full pin and a half-pin was used instead. The wound was cultured and the dog placed on antibiotics for 3 weeks.

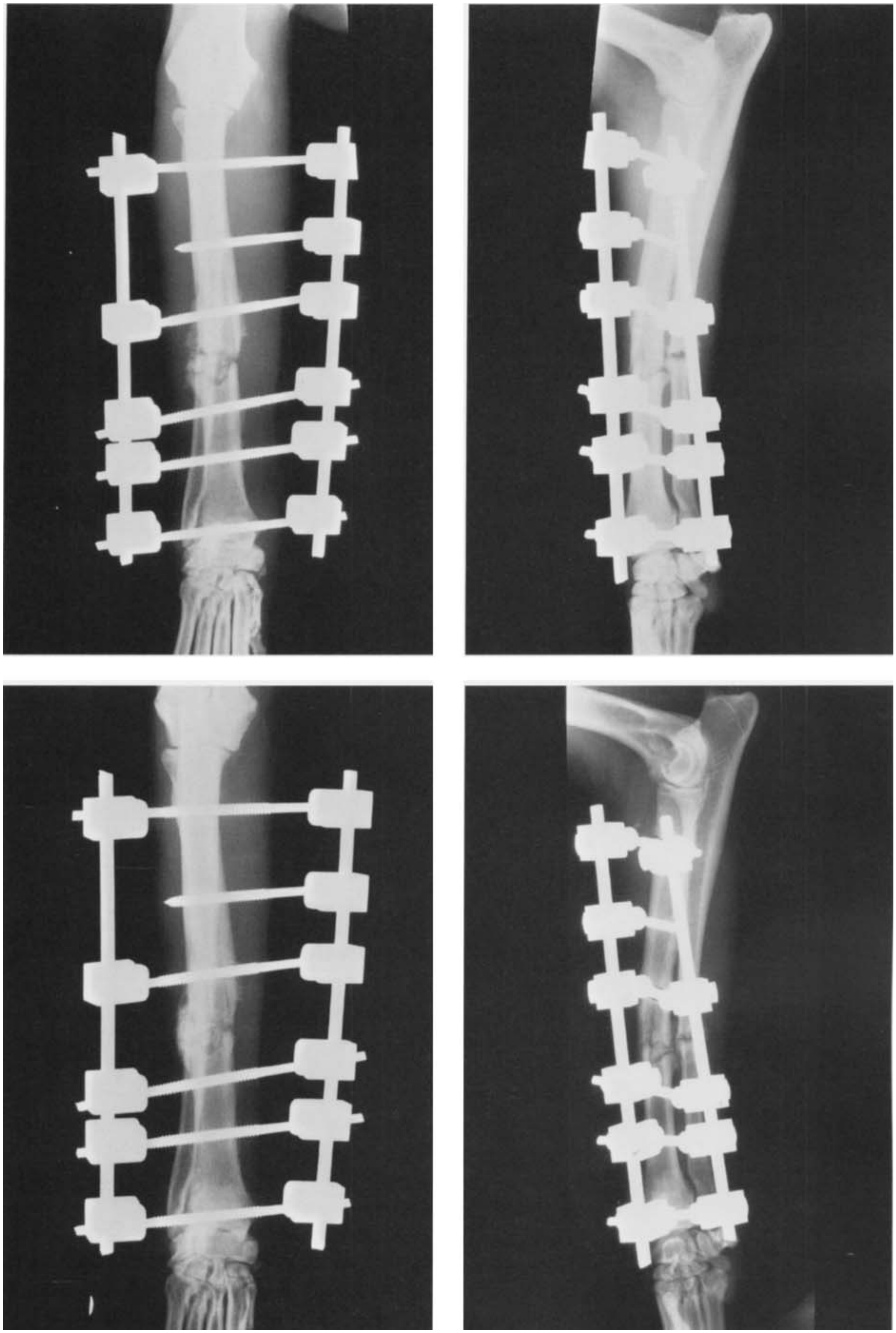
Postoperative radiographs demonstrated adequate alignment and apposition. The external fixator is of substantial stiffness for this size of dog and may lead to stress protection. Placement of the first fixation pin may be questionable. The radius is oblong in this area and, although there is sufficient medial to lateral width, it can, as in this case, be narrow in the cranial to caudal dimension. The fixation pin may need to be directed obliquely for adequate bone purchase without compromise to the structure of the bone.

## Follow-up evaluation

The patient was re-presented for radiographs at 6 weeks postoperatively. He walked with a modest lameness and occasionally lifted the leg while standing or sitting. There was mild discharge from the proximal and third fixation pins on the medial aspect. Radiographs demonstrated good callus formation that appeared to bridge the fracture site, but insufficient radiodensity of the callus. There was lucency around the first fixation pin at the medial cortex. There was a suggestion of lucency around the third fixation pin at the medial cortex. As the dog was using the limb and there was radiographic appearance of bridging callus, the fixator was left in place and the fracture given more time to heal. If there had not been radiographic evidence of bridging or the dog was not using the leg, suggesting instability of the fracture, the fracture should have been assumed to be unstable and the first and third fixation pins should have been replaced.

## Second follow-up evaluation

The patient was re-presented 9 weeks postoperatively. He was walking well but would hold the limb up when running. There was mild discharge from the medial aspect of the proximal and third pins. Radiographs demonstrated lucency around the first and third fixation pins, but, interestingly, not the second. There was smooth bridging callus across the fracture as seen from the medial to lateral as well as the cranial to caudal radiographic views. The fixator was removed and the dog limited to leash walks for an additional 3 weeks.



# Case study 10

## Clinical presentation, history, and fracture

A 4-year-old, 48-kg German Shepherd sustained a right radius and ulna fracture from a motor vehicle accident. Thoracic radiographs were within normal limits. The fracture was a closed transverse to short, oblique, distal fourth diaphyseal radial fracture displaced caudally and medially and overriding by 1 cm. A large medial fragment was present originating from the proximal diaphyseal segment.

## Surgical planning

The limb was placed in a Robert Jones bandage to temporarily stabilize the fracture and reduce swelling prior to surgery. The options for surgical repair would include plating. Either a straight plate or "T" plate could be used, but the small distal segment and large missing segment may make screw placement difficult. Pinning and cerclage would not be indicated. External fixation with a limited or no approach could be considered.

The dog is large at 48 kg. Although the fracture is transverse, the large segment would not allow a large amount of load sharing and axial load would result in shear at this fracture line. The distal segment is small and would accommodate, at most, two full pins or four half-pins in a biplanar configuration. A bilateral fixator with two distal full pins or a unilateral, biplanar fixator with four distal pins could be considered. However, this dog's weight would be at the upper limit of support for these configurations if the fixator were to buttress the limb fully. A multiplanar configuration should also be considered.

## Fracture repair and evaluation

The fracture was repaired with a bilateral (type II) external fixator. The limb was reduced using the hanging limb technique and a limited surgical approach to assure fragment apposition. One proximal and one distal full pin were placed and the fracture reduced. The bolts were tightened and the remaining fixator pins were placed. In the proximal fragment, a full pin was placed close to the fracture, then another halfway between that and the proximal pin. In the distal fragment, an additional full pin was placed so as not to encroach on the fracture.

Postoperative radiographs showed adequate limb alignment. There were fracture gaps as a result of the large fragment not being apposed. The fixator was adequately applied, although there was some concern as

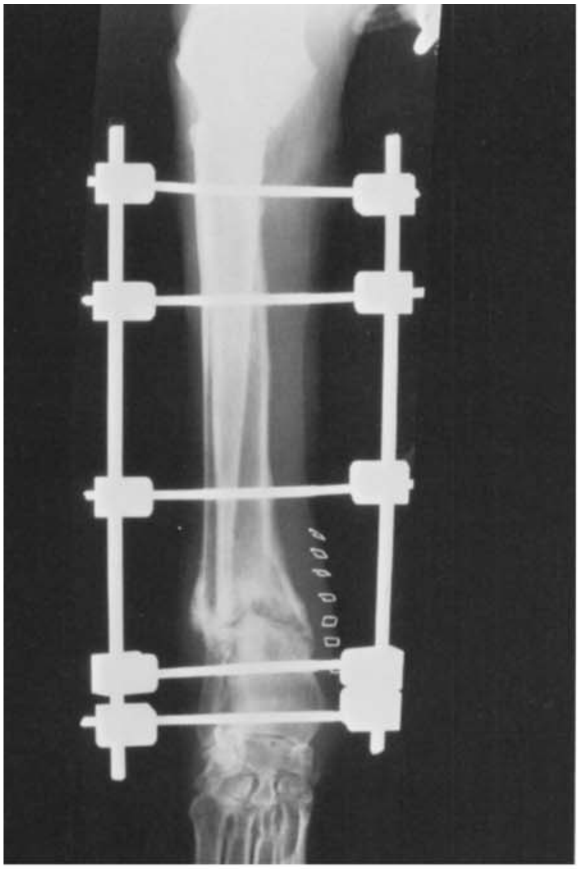
to the stiffness of only two distal full pins if complete buttress support of the limb were needed.

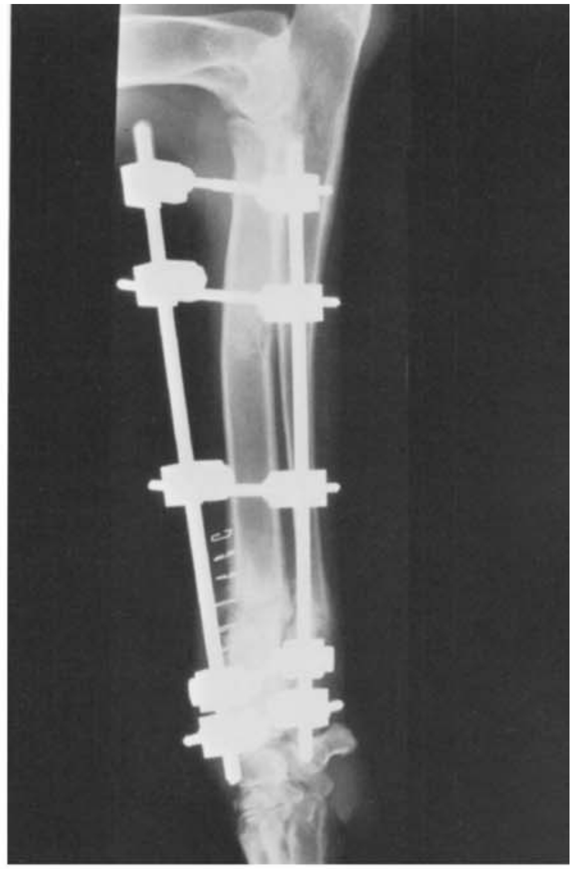
## Follow-up evaluation

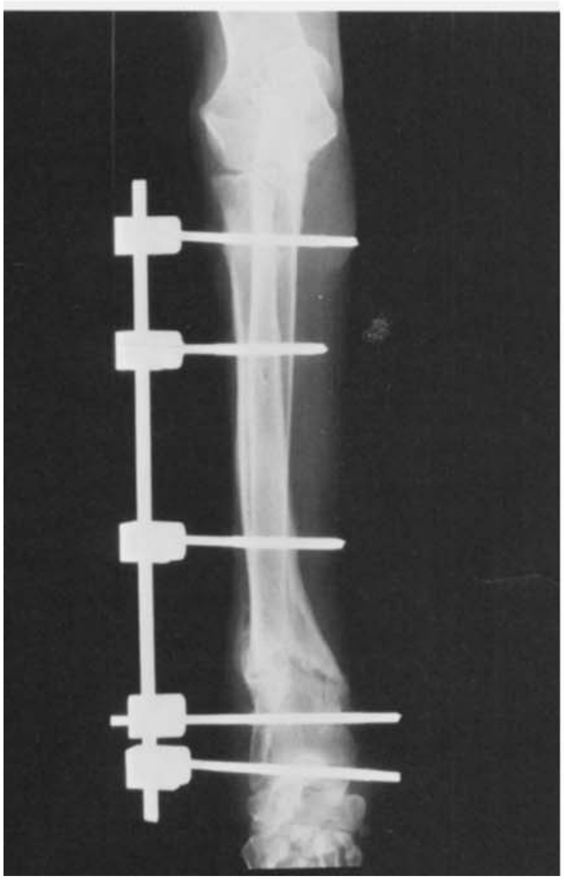
At 6 weeks the dog was re-evaluated and radiographs were obtained. The dog had been using the limb well, with only a slight limp. The pin sites were clean and dry. Radiographs showed a moderate amount of bridging callus and early remodeling. At this time the fixator was converted into a unilateral fixator by removing the medial connecting bar. The original fixator was not of sufficient stiffness to load protect the limb in this dog. In addition, the stiffness of a unilateral fixator with a 4.8-mm connecting rod is very low. Converting the fixator to a unilateral fixator was a questionable choice. Leash walks and giving the fracture more time to heal would have been a better choice.

## Second follow-up evaluation

At 9 weeks postoperatively the patient was presented for re-evaluation and radiographs. The dog had been using the limb without noticeable lameness. There was no discharge from the fixator pins. Radiographs demonstrated good healing with a bridging callus on all aspects of the fracture line. The fixator was removed.







# Tibia

# Case study 1

## Clinical presentation, history, and fracture

A 7-year-old, 30-kg, spayed, female greyhound sustained an open fracture after being away from her owner for less than 1 hour. The dog was treated for shock, the limb was bandaged, and the animal was transported to a surgical hospital. On presentation, the dog was in a stable condition. Despite extensive soft-tissue trauma, the distal limb was vascular and had pain sensation to the medial and lateral digits. A grade III open, segmental, comminuted tibia fracture was diagnosed. The proximal fracture was a short oblique fracture with several comminutions, was displaced caudally, and was overriding by 1 cm. This aspect of the fracture did not appear to be open. The distal fracture was transverse with several comminutions and loss of bony fragments. This aspect of the fracture was open with substantial soft-tissue loss and exposure of several centimeters of bone on both the segmental and distal diaphyseal segments.

## Surgical planning

This fracture should be considered a surgical emergency because it is a grade II open fracture with extensive exposed bone and soft-tissue loss. Once stabilized, the wound should be debrided and the fracture stabilized. This type of fracture should not be stabilized with casting, pins and wires, or bone plate. External fixation should be used. The fixator must span a large fracture gap because of the segmental section, which may not accommodate fixation pins as a result of longitudinal fissures. A sufficient number of fixation pins must engage the relatively small proximal and distal epiphyseal segments. Also, the fixator must be sufficiently stiff and strong to accommodate load bearing and must remain stable for a long time because of the expected delay in bone healing. For this 30-kg dog a type III (bilateral, biplanar) configuration should be chosen. Reduction of the proximal segmental fracture should be closed to preserve vascular supply to this aspect of the fracture and limb and prevent extension of contamination. The tissue loss would allow visualization of fracture reduction of the distal segmental fracture but will complicate the preservation of viability of the large area of exposed bone.

## Fracture repair and evaluation

The limb was operated on an emergency basis once the patient was sufficiently stable for anesthesia. The wound was debrided and copiously lavaged. Using the hanging limb technique, proximal and distal positive-

profile full pins were applied. An unsuccessful attempt was made at applying a second full pin to the proximal epiphysis. Two additional full pins were placed in the segment, with the most distal of these two placed with direct visualization to avoid fissures. A cranial connecting bar was applied with two positive-profile half-pins in both the proximal and distal epiphyses. This third connecting rod was attached to the first two with angled connecting rods at the area of the proximal and distal segmental fractures. Soft tissues were advanced to cover most of the exposed fracture, but a $2 \times 5$ cm area of exposed medial tibia was treated with a wet-to-dry bandage.

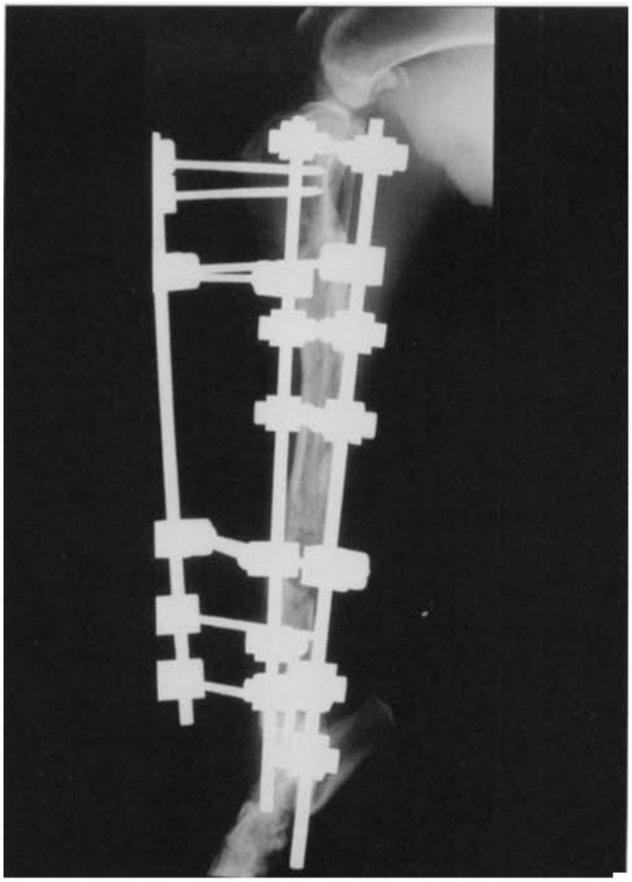
Limb and fracture alignment was adequate, although there was some caudal and medial translation of the proximal segmental fracture. There was a long distance between the fixation pins in the segmental section and the distal pins, and concerns that these two pins could propagate the numerous fissures in their proximity.

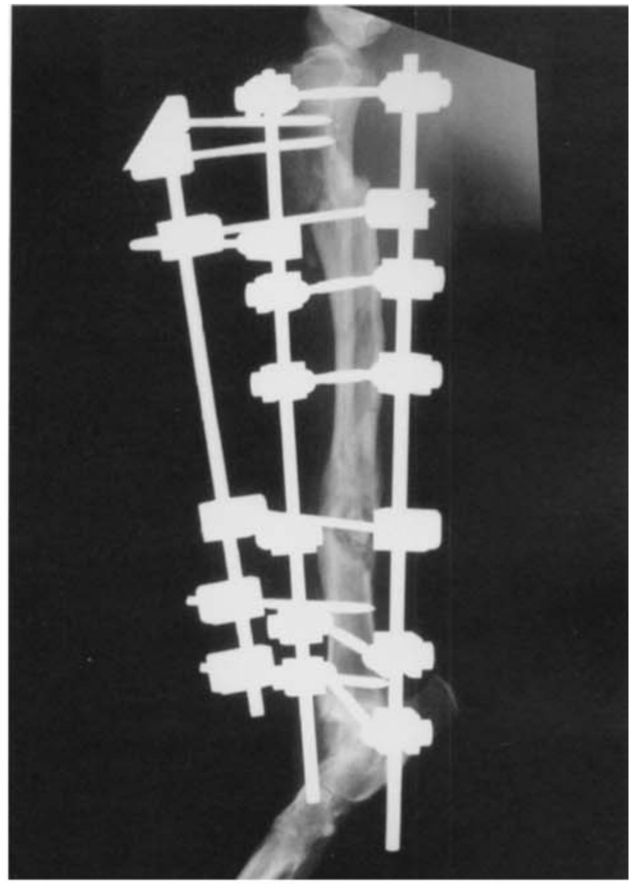
## Follow-up evaluation

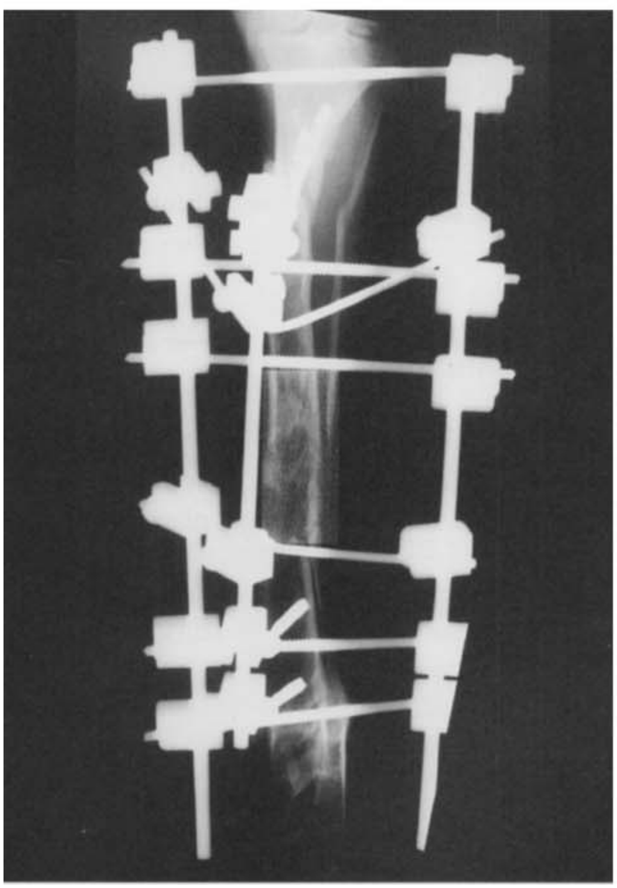
The wound was treated with wet-to-dry bandages until granulated, then with nonadherent bandages thereafter. A $2 \times 2$ cm area of granulation persisted with modest amount of discharge. The dog was using the limb well starting about 4 weeks postoperatively. Radiographs taken 12 weeks postoperatively demonstrated maintenance of limb alignment and apposition of the fracture. The fixator was stable, with early loosening of the most proximal full pin. A sequestrum was discernible at the distal segmental fracture. At this time, the dog was reoperated, the sequestrum removed, and the affected area debrided and cultured. The defect was filled with a cancellous bone graft.

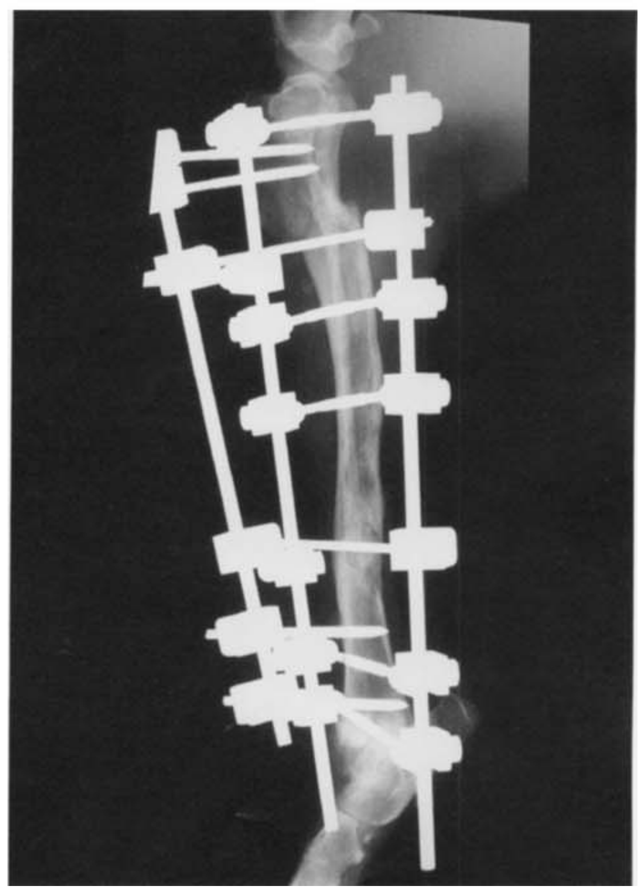
## Second follow-up evaluation

Radiographs were obtained 17 weeks postoperatively. The dog had been using the limb well and the wounds had contracted and epithelialized. There was no discharge from the previous site of the sequestrum. There was discharge from the proximal fixation pin, primarily on the lateral aspect. Radiographs demonstrated that alignment and apposition had been maintained. The fixator was stable, though the most proximal full pin was seen to be loose. The fracture was healed with no sign of residual osteomyelitis. The fixator was removed.









# Case study 2

## Clinical presentation, history, and fracture

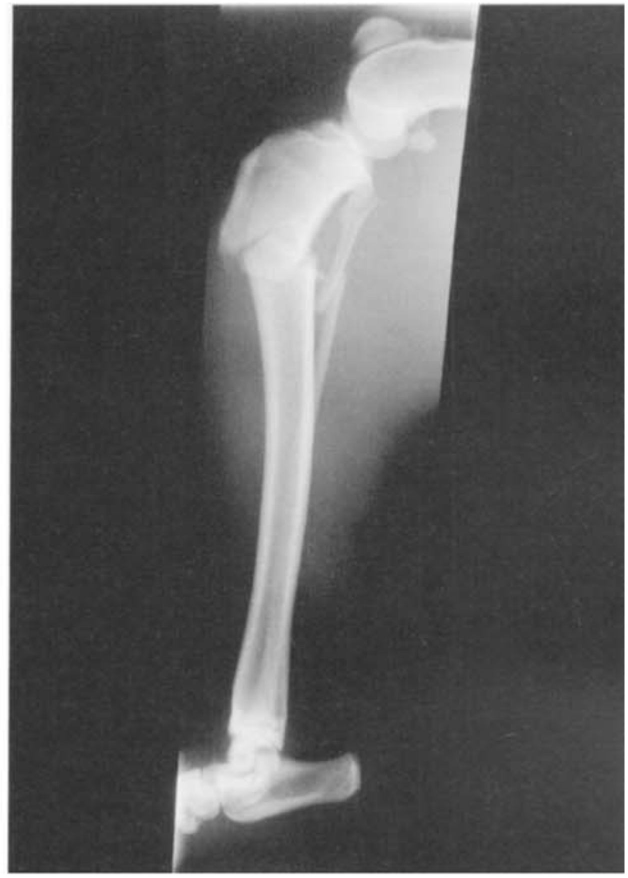
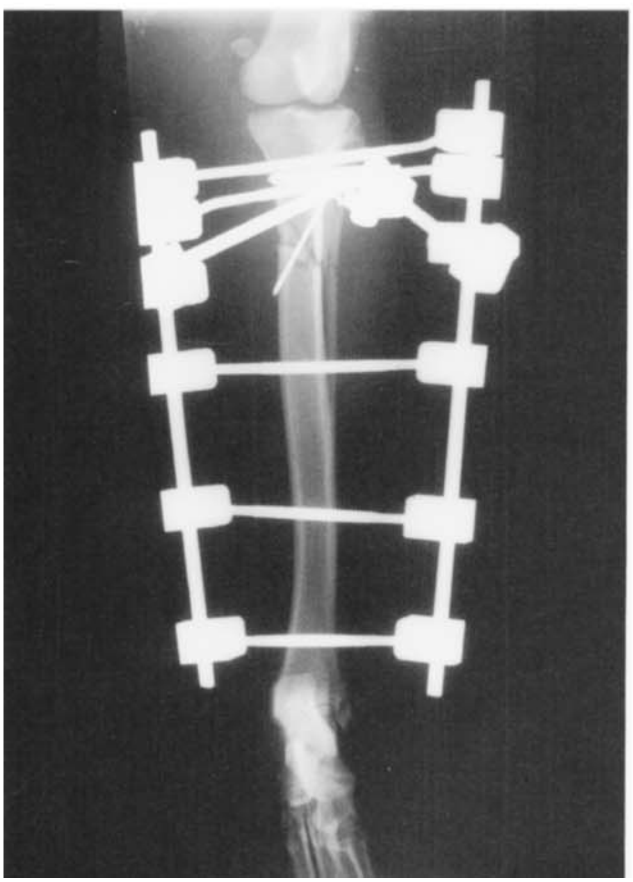
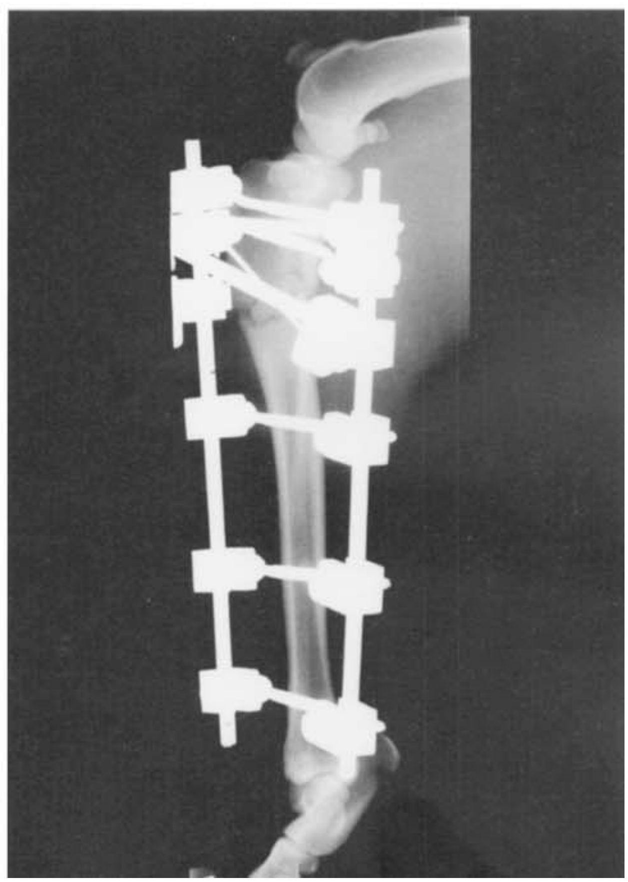
A 3-year-old, 21-kg, female Boxer sustained a right tibia fracture in a motor vehicle accident. The dog was treated for shock and the limb placed in a Robert Jones bandage. The fracture was a proximal, short, oblique tibia fracture with two or more small comminutions, was displaced laterally and caudally, and was overriding by 1 cm.

## Surgical planning

The fracture was proximal on the tibia and, although a Robert Jones bandage should be indicated, it is important that it sufficiently immobilizes the stifle. Casting this fracture is not advisable because it is close to the stifle and rotational stability would be difficult. The obliquity of the fracture would not allow full cerclage wires and the small comminutions may complicate reduction. The fracture is very proximal and angular forces may not be counteracted with intramedullary pinning. Open reduction and internal fixation with plates and screws should be considered as there is sufficient proximal tibia for screw placement. External fixation should be considered, although the proximal segment is small, making application of adequate pins difficult. Fixator configurations would include type II (bilateral), type Ib (unilateral, biplanar), and type III (bilateral, multiplanar) fixators. As the fracture is rather simple, a limited approach should be considered to achieve reduction and load sharing. If small comminutions preclude load sharing, a load-bearing fixator may be needed.

## Fracture repair and evaluation

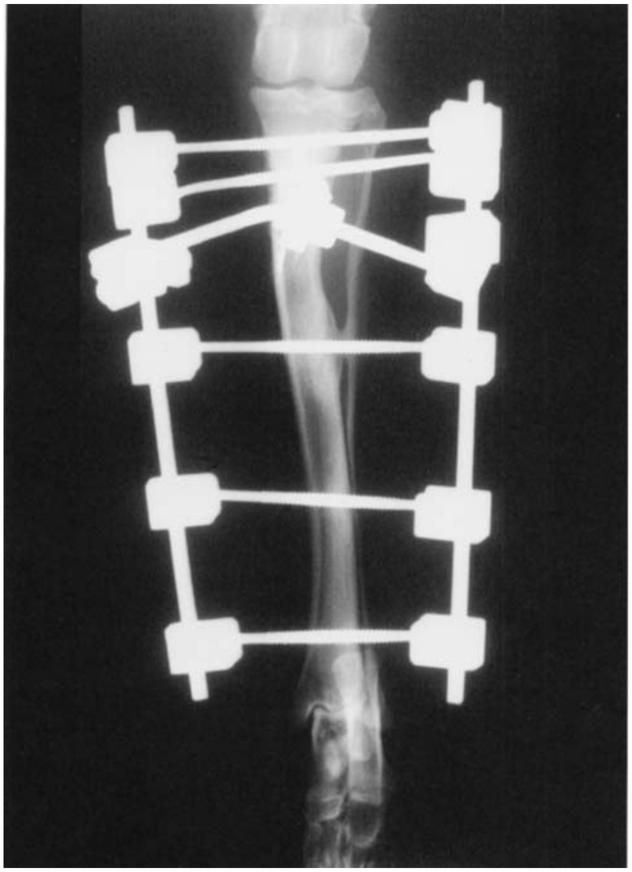
The limb was operated using a hanging limb technique and a limited approach. The fracture was reduced and a Kirschner wire placed across the fracture. A positive-profile threaded pin was placed in the proximal fragment and at the metaphysis of the distal fragment. Additional positive-profile threaded full pins were placed, one in the proximal fragment and two in the distal fragment close to, but not invading, the fracture. The two proximal full pins were considered close so they may not counter cranial and caudal bending forces. For this reason, the type II fixator was converted to a type III. An additional angled connecting rod was applied to the proximal fragment and a positive profile half-pin placed from a cranial direction.

Fracture alignment and apposition were adequate, though there was 2–3 mm of caudal translation. The Kirschner wire was left in place as it was stable; however, this could have been removed.

## Follow-up evaluation

The dog was presented 10 weeks following surgery. She had used the limb well soon after surgery. There had been no complications with the fixator until 3 weeks after a missed 6-week recheck examination. The week before the 10-week recheck evaluation, the proximal pin sites had begun to exhibit purulent discharge that increased in volume and lameness had developed. Radiographs showed that alignment and apposition had been maintained. The fracture had healed. The proximal three fixation pins were seen to be loose. The fixator was removed and the limb placed in a soft padded bandage for 7 days.




# Case study 3

## Clinical presentation, history, and fracture

A 7-year-old, 45-kg, male Weimaraner sustained a closed fracture of the left tibia and fibula in a road accident. Injuries were confined to the fractured limb. Radiographs showed a long spiral fracture of the tibia involving the middle and distal thirds of the tibial diaphysis with numerous fissures extending longitudinally beyond the fracture line. The fracture was displaced laterally and was overriding by 2 cm.

## Surgical planning

Options for management of this fracture would include external coaptation. However, long spiral fractures are not effectively immobilized by casts and, also, bone healing in this mature dog will be slow – there is a significant risk of malunion, delayed union, cast complication, and fracture disease. Intramedullary pinning or interlocking nail and cerclage wires would be a good surgical option if the tubular shape of the bone could be reconstructed. Pins and cerclage wiring might not be sufficiently robust for a patient as large as this. Open reduction and internal fixation with plates and screws would be a reasonable alternative. A long, heavy plate would be needed and prior lag screw fixation would be an essential part of the repair. The relatively small amount of good bone distally and the extensive cracking would provide technical challenges for screw placement. External fixation is an alternative, although the small distal fracture segment and numerous fissures could complicate stabilization.

## Fracture repair and evaluation

The hanging limb technique was used. The fracture was exposed via a limited medial skin incision then reduced and fixed using three Kirschner wires. By applying multiple cerclage wires around the long spiral fracture it was possible not only to control the propagation cracks but also to provide a degree of mechanical competence to the repair by reconstructing osseous anatomy. This repair was neutralized using an external fixator. The wound was closed prior to placement of four large positive-threaded fixator pins: two half-pins proximally and two full pins distally. To minimize soft-tissue problems due to transfixion of muscles on the lateral aspect of the proximal tibia, the proximal pins were placed medially. Two APEF columns were formed; the first connected all four pins medially and the second engaged both proximal pins on the medial side before passing obliquely in front of the tibia to fix both of the distal




full pins on the lateral side. Postoperative radiographs showed excellent reduction of the fracture and revealed all implants to be well located. The patient was seen to be weight bearing on the operated limb the day after surgery.

## Follow-up evaluation

After 5 weeks the dog was walking and weight bearing confidently. The owner had found it difficult to control the dog, which had, consequently, exercised freely since shortly after the operation. All pin sites were clean and dry. Radiographs showed the fracture to be healing well and with minimal callus formation. Two of the three Kirschner wires placed with the cerclage wires had been lost – this loss had not been noticed by the owner. The fixator was staged down by removing the center section of the second acrylic column – that which crossed the front of the tibia to join the proximal medial pins to the distal lateral pins – leaving, in effect, a unilateral, uniplanar (type I) fixator.

## Second follow-up

Three weeks later – 8 weeks after the operation – the dog was re-examined. There was some discomfort and slight serous discharge at the proximal pin. Radiographs showed further progress of bone healing and there was an area of lucency around the proximal pin, indicating that this pin had loosened. All remaining fixator components were removed.

The patient quickly returned to full athletic activity.

# Case study 4

## Clinical presentation, history, and fracture

A 2-year old, 30-kg, spayed, female German Shepherd was presented with a right tibia fracture immediately after a motor vehicle accident. The automobile was reported to have been traveling at 80 km/h. The dog was treated for shock and the limb placed in a Robert Jones bandage. A mild pneumothorax was noted on thoracic radiographs. The fracture was a midshaft comminuted tibia fracture, displaced medially and cranially and was overriding by 2 cm. A 4-cm fissure could be seen propagating into the proximal segment from the lateral radiographic view.

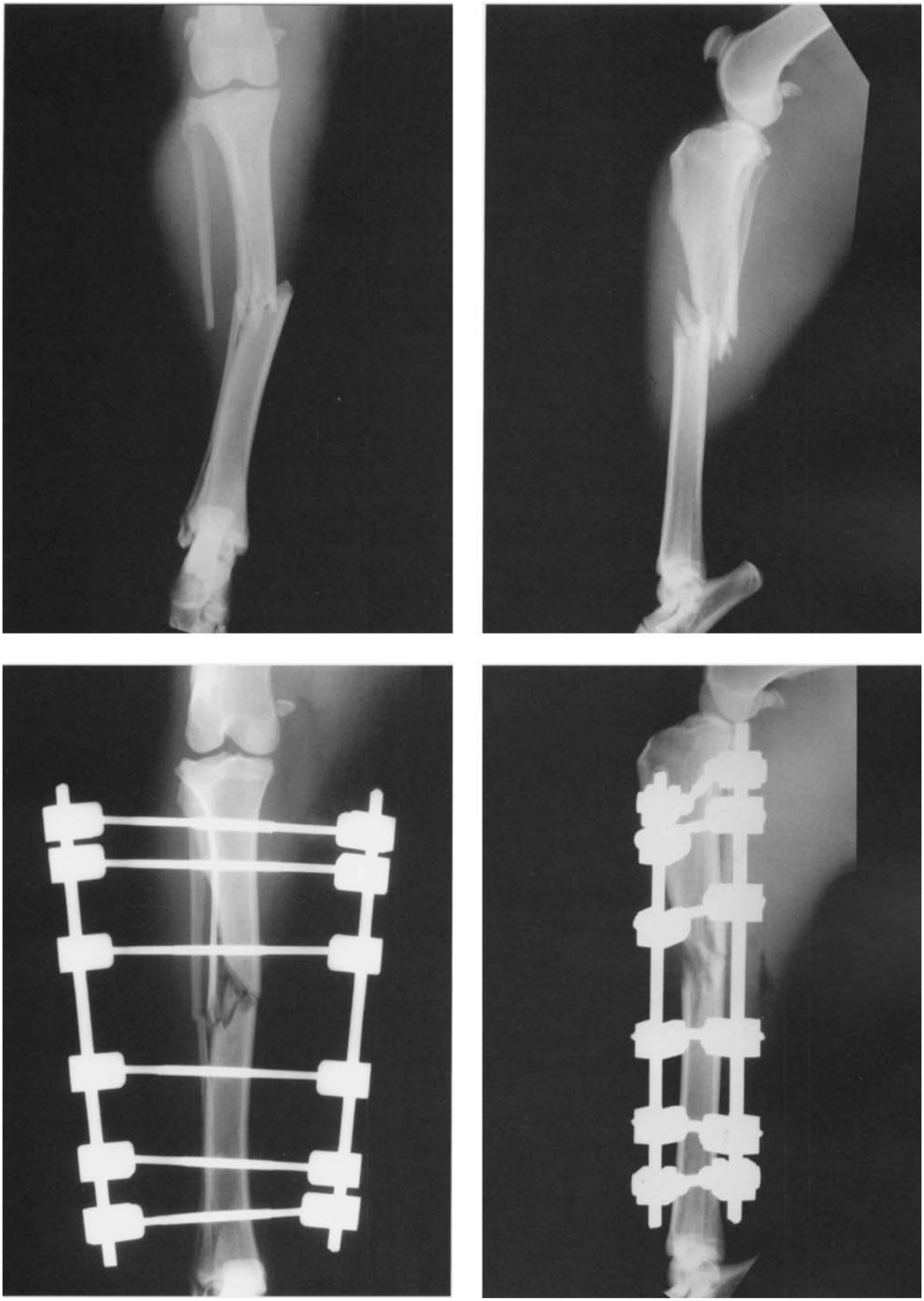
## Surgical planning

The mild pneumothorax did not result in impaired respiratory ability. However, this could worsen with time or pulmonary contusions could become radiographically appreciable within 1–2 days of injury. The thorax should be re-radiographed the day before surgery. Casting of the fracture would likely result in overriding and propagation of the fissure. Intramedullary pinning and cerclage could be attempted; however, the comminutions would not allow rotational stability to be achieved. Open reduction and internal fixation with plates and screws could be attempted, but the comminutions would be difficult to appose and the longitudinal fissure may complicate screw placement of a medial plate. Stabilization of this fracture with an external fixator would be a good choice. A limited approach should be made to assure adequate fracture reduction and also to assure that fixation pins avoid the fissure of the proximal diaphysis. A type II (bilateral) or type Ib (unilateral, biplanar) of sufficient strength and stiffness to provide load bearing should be chosen.

## Fracture repair and evaluation

The fracture was repaired with a type II (bilateral) fixator. A 7-cm limited approach was made on the medial aspect of the femur and the fissure lines visualized. The fracture was reduced using the hanging limb technique and was manipulated using bone-holding forceps. A proximal and distal positive-profile full pin were placed near the ends of the tibia and connecting bars attached to these. Additional full pins were applied using an aiming tool. The fissure lines were avoided.

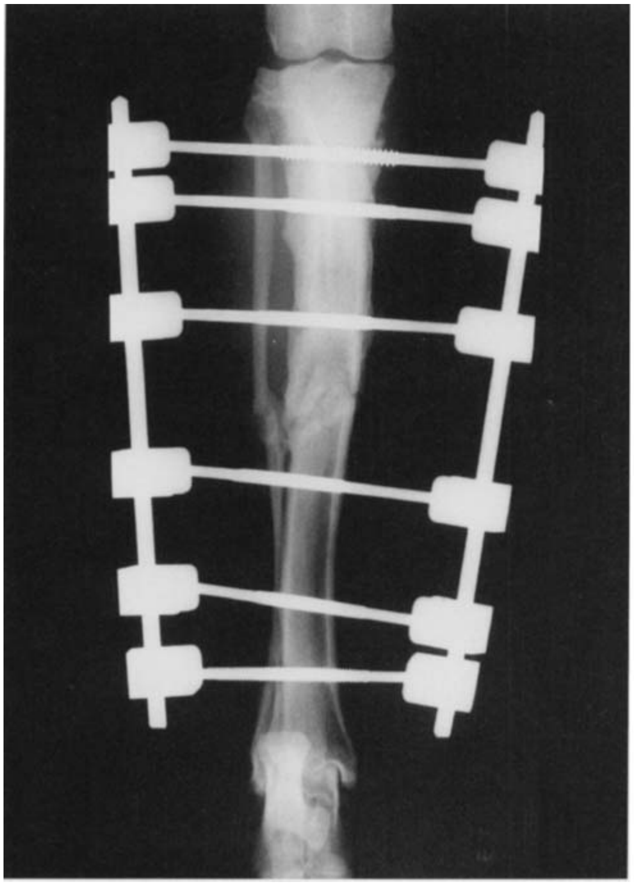
Fracture alignment was adequate. Fragment apposition was good, although there was displacement of comminuted fragments at the fracture. The fixation pins were placed appropriately close to the joints

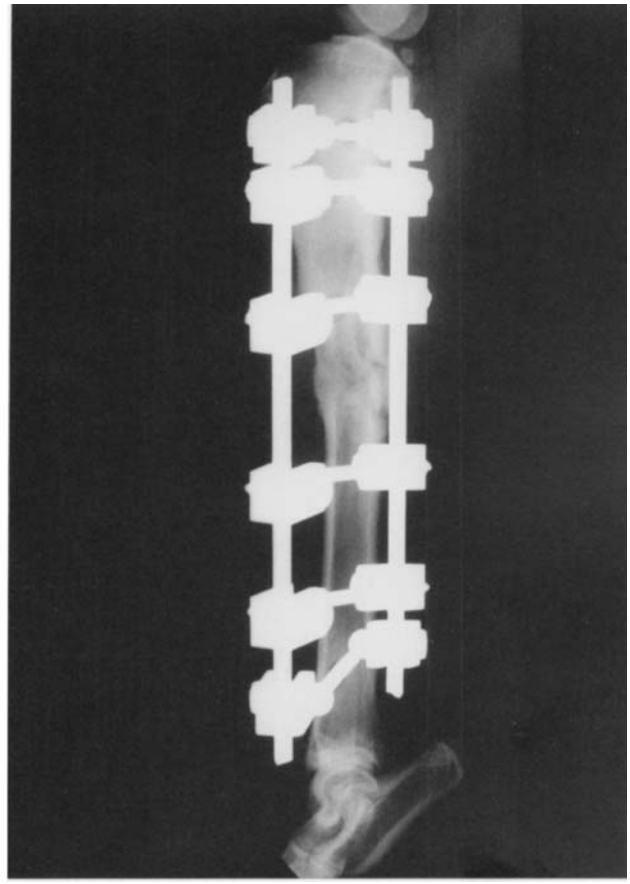


and as close as possible to the fracture. The third pin from proximal was close to the noted fissure line. The stiffness and strength of this fixator should be considered sufficient for load bearing for this size of dog.

## Follow-up evaluation

At the 6-week follow-up the dog was lame but would support some weight on the limb, and would lift the limb at a stand. The pin sites showed moderate discharge on the lateral aspect of the tibia. Radiographs revealed that alignment and apposition had been maintained. The fixator had not changed in position. Loosening of the three proximal full pins was evident. There was modest callus formation that could be seen bridging the fracture on all aspects. As callus had bridged the fracture, the fixator was removed. Fracture healing was not complete, so strict exercise restriction was recommended for an additional 3 weeks. Follow-up radiographic evaluation was recommended but declined.





# Case study 5

## Clinical presentation, history, and fracture

A 5-year-old, 22-kg, spayed, female Border Collie sustained a right tibia fracture in a motor vehicle accident. The dog was treated for shock and placed in a Robert Jones bandage. The fracture was a transverse, midshaft tibia fracture with at least three small comminutions. The fracture was displaced caudally and was overriding by 2 cm.

## Surgical planning

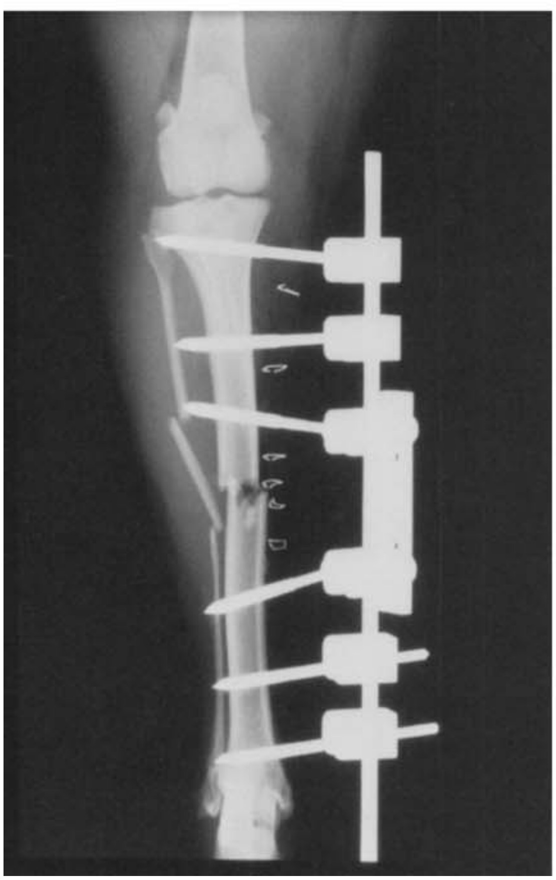
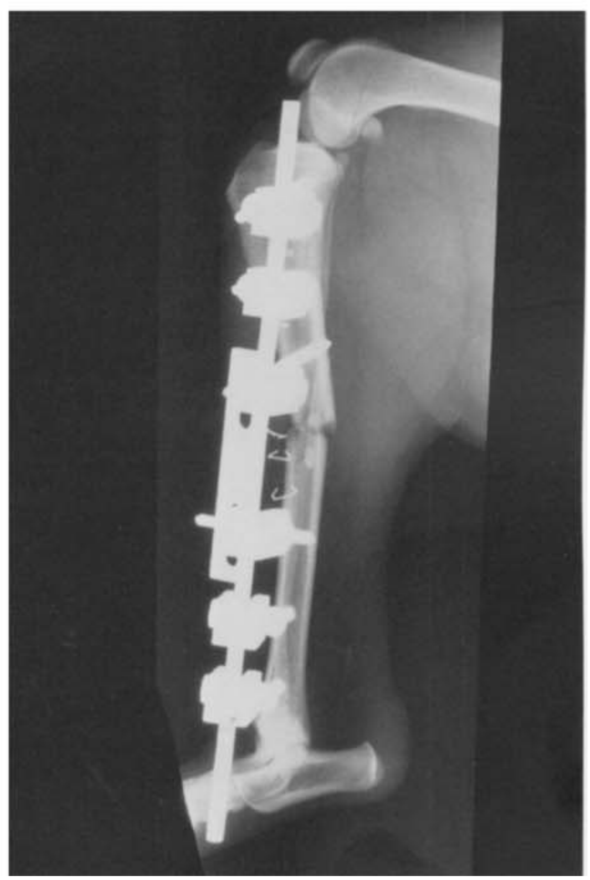
This closed fracture is best operated following stabilization of the patient and the placement of a Robert Jones bandage for 1–2 days. Repair methods for this fracture might include casting if the fracture could be successfully reduced. However, the comminutions and probable radiographically inapparent fissures could result in inadequate stabilization. Pin and wire fixation alone would probably not result in adequate rotational stability of this transverse fracture, especially in light of the small comminutions. Plate fixation would be appropriate, although reduction of the comminuted pieces and radiographically undetectable fissures could be potential complications. External fixation would also be appropriate, although the amount of aftercare required would be greater than after plate fixation. If contact of the two main fracture fragments could be accomplished, then load sharing could be achieved and a maximal fixator configuration would not be needed. For this 22-kg dog a type II (bilateral) or type Ib (unilateral, biplanar) configuration could be chosen if the surgeon wished to support the fracture fully. If load sharing could be achieved, a type I fixator of the appropriate size should be chosen. Reduction with a limited approach or using a closed approach should be considered.

## Fracture repair and evaluation

The fracture was repaired with a type I (unilateral) external fixator. The limb was reduced using the hanging limb technique and a limited approach. One half-pin was placed in the proximal and distal fracture fragments and the fracture reduced. Consecutive positive-profile half-pins were placed by predrilling techniques until there were three fixation pins in both the proximal and distal segments. An augmentation plate was added to increase stiffness.

Fracture alignment and fragment apposition were adequate. The fixation pins were placed appropriately close to the joint and as close



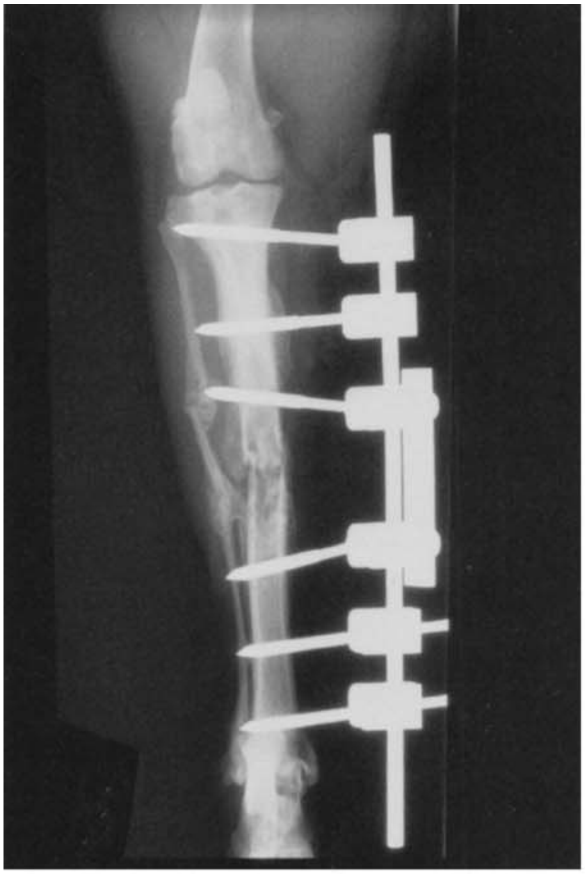
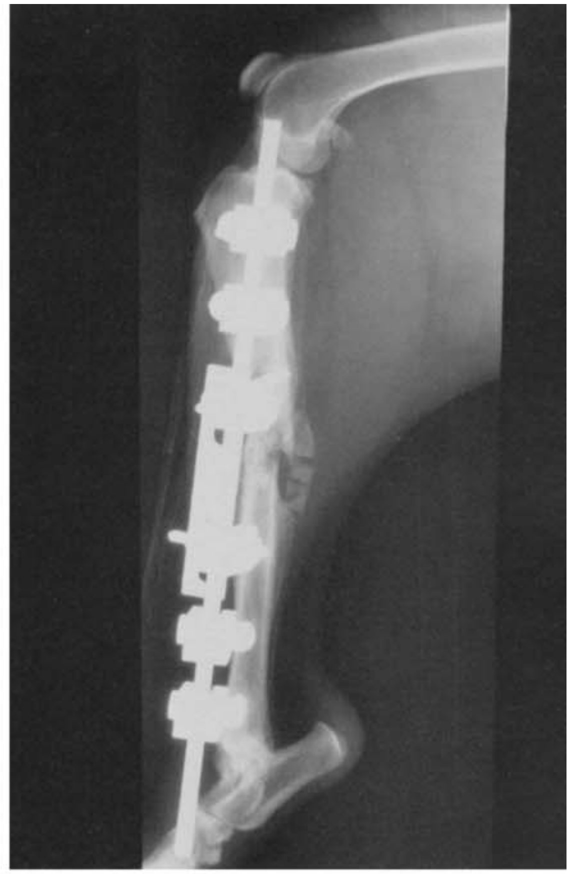
as possible to the fracture without invading it. This fixator should be of sufficient stiffness if there is fracture apposition, but this is not clear from the postoperative radiographs as there is some translation of the fracture fragments.

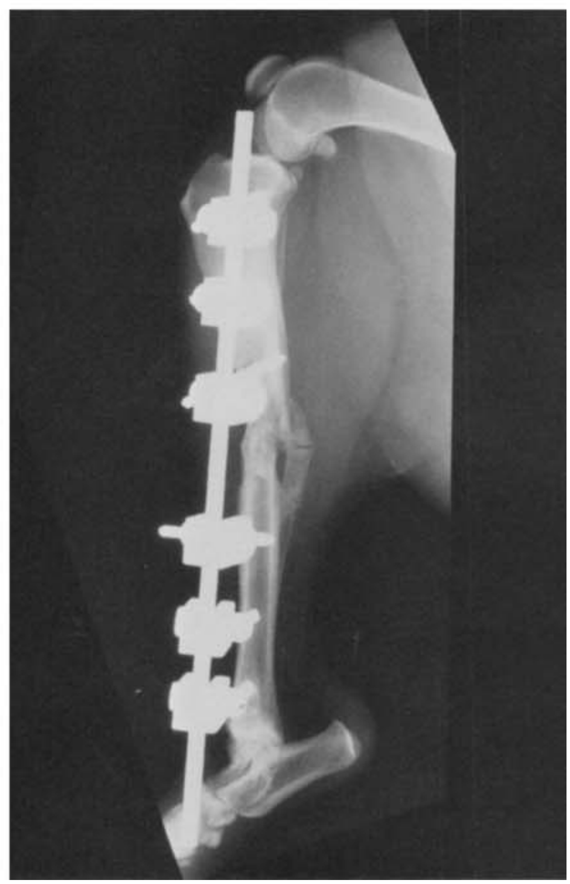
## Follow-up evaluation

At the 8-week follow-up the dog had some lameness and would carry the limb occasionally when running (running was not suggested in the discharge instructions). The alignment and fragment apposition have been maintained. The fixator is unchanged, but there is early pin loosening around the second and third pins and associated periosteal reaction. Radiographs revealed bridging callus but lack of mature healing, as evidenced by relatively lucent-appearing bone at the fracture site. This could be stress protection, but most likely lack of complete healing. The augmentation plate was removed, and leash walks were recommended for 3 weeks.

## Second follow-up evaluation

At the 11-week follow-up the dog continued to have some lameness at a walk but was very active and would run using the limb. Alignment and apposition of the fracture were maintained. There was greater lucency around the second and third fixator pins. Radiographs demonstrated more mature bone healing, as evidenced by the greater radiodensity of the fracture callus. The fixator was removed and the dog allowed to return to normal activity following an additional 2 weeks' leash restriction.



# Case study 6

## Clinical presentation, history, and fracture

A 1-year-old, 34-kg, intact, male Labrador Retriever sustained a fracture of the right tibia when hit by a car 1 week prior to presentation. The injured leg was initially placed in a cylindrical fiberglass cast, but inability to obtain adequate reduction and persistent discomfort resulted in referral of the case.

Thoracic radiographs were normal. Radiographs of the right tibia revealed a closed, jagged, short, oblique fracture at the junction of the middle and distal one-third of the diaphysis with mild comminution represented by several tiny intermediate fragments. There was some overriding of the fracture with the distal end of the major proximal segment displaced caudally and medially. A small fissure line was evident in the distal end of the proximal segment.

## Surgical planning

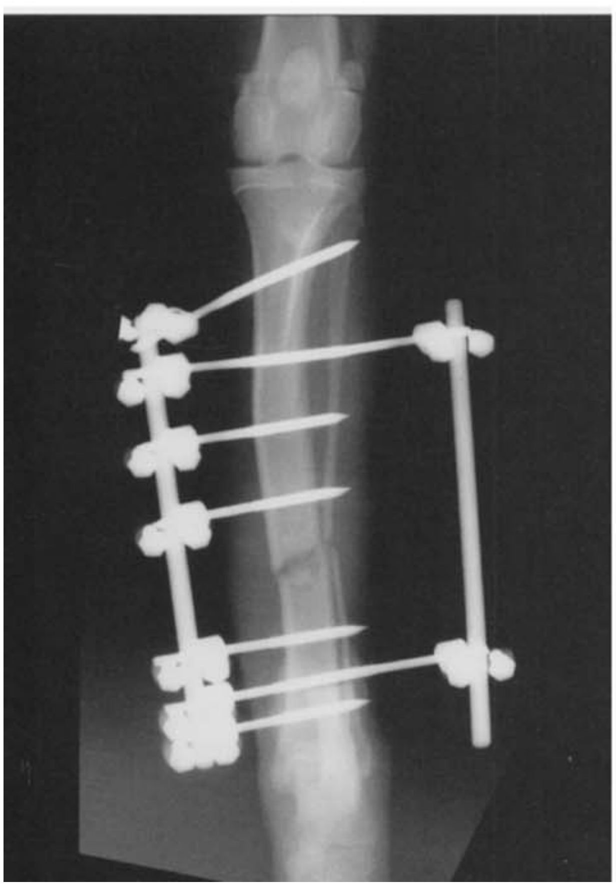
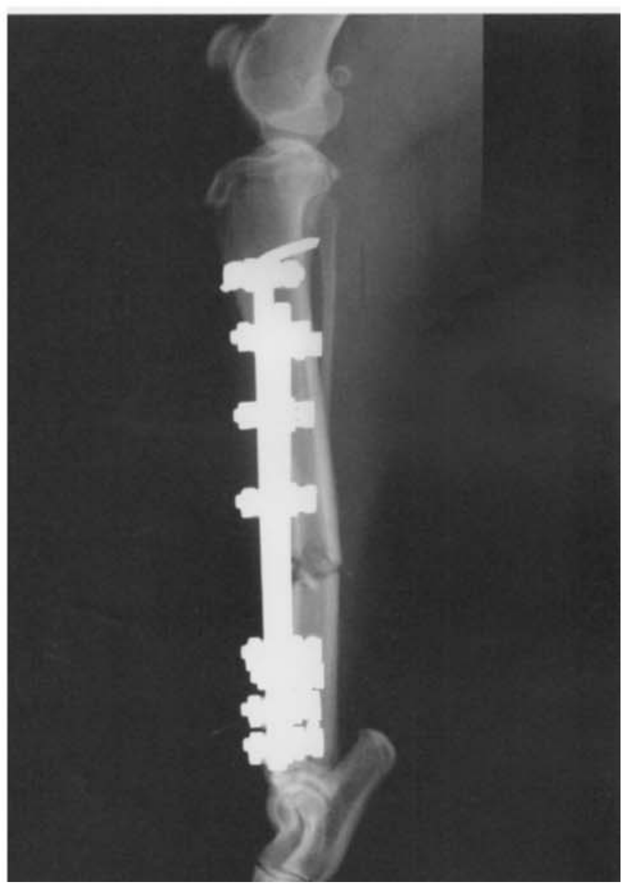
Owing to the large size and high energy level of the dog combined with the difficulty in obtaining adequate alignment, external coaptation with a cast is probably not a good choice for this patient, even though it is a young dog with high healing potential. The dog was anesthetized, the cast was removed, a better-quality lateral radiograph was taken, and the dog was taken to surgery.

Although the major distal segment is somewhat short, this would not preclude successful treatment with a medially applied bone plate and screws. Interlocking nail fixation is possible but might require a three-hole rather than a four-hole nail. Fixation with an intramedullary pin alone would probably not provide adequate stability in this large, active dog, although combining an intramedullary pin with a type Ia external fixator might be a reasonable option. External fixation with a limited approach or closed manipulation and application of a type Ib or a type II frame is another strategy that should be considered for this fracture.

## Fracture repair and evaluation

The fracture was repaired with a bilateral (minimal type II) external fixator using small SK clamps and titanium connecting rods. Approximate alignment of the fractures was obtained using the hanging limb technique with the dog positioned in dorsal recumbency. A "mini-approach" was made over the medial aspect of the fracture to verify alignment and improve it if necessary. One full pin was placed in the proximal segment and a second full pin was placed in the distal segment. These were connected with single clamps and rods bilaterally. Fracture alignment was adjusted slightly and the four clamps were tightened to maintain alignment. Clamps were added to the medial rod and five additional half-



pins were applied, three to the proximal segment and two to the distal segment. A half-pin rather than a full pin was used in the most proximal position to avoid the thick soft-tissue layer overlying the lateral aspect of the proximal tibia. If the pins are numbered 1–7 from proximal to distal, pins 3, 4, 5, and 7 could have been placed as full pins rather than half-pins if additional construct stiffness was needed.

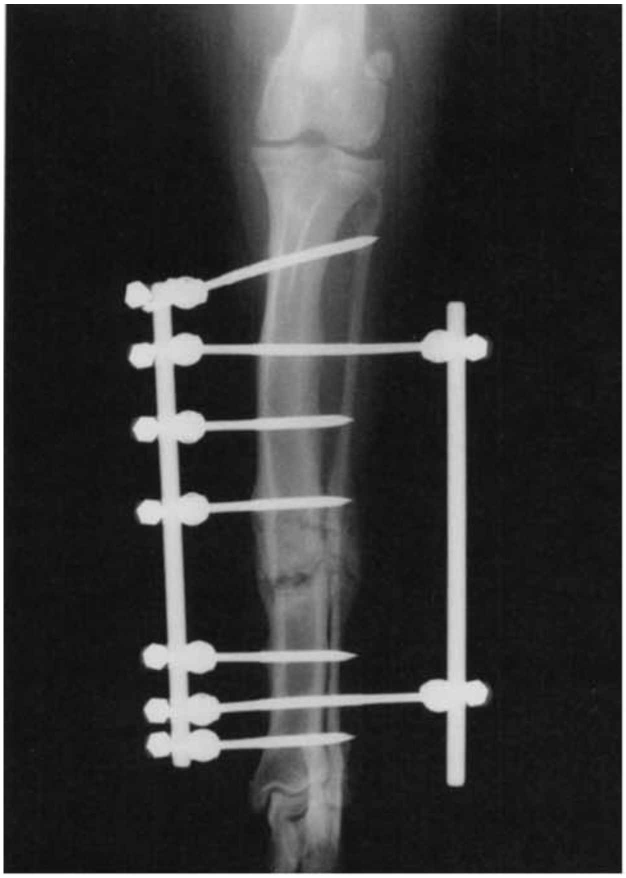
Postoperative radiographs demonstrated adequate alignment with slight caudal bowing as viewed in the lateral radiograph. Large clamps and rods could have been used to obtain a more rigid construct in the patient during the early phase of healing. If a longer rod had been used medially, there would have been no need to angle pin 1 as seen in the craniocaudal projection radiograph. If this pin had been placed perpendicular to the long axis of the bone, its working length would have been reduced. A cancellous bone graft was not performed but would have been advisable even though this is a young patient with high healing potential.

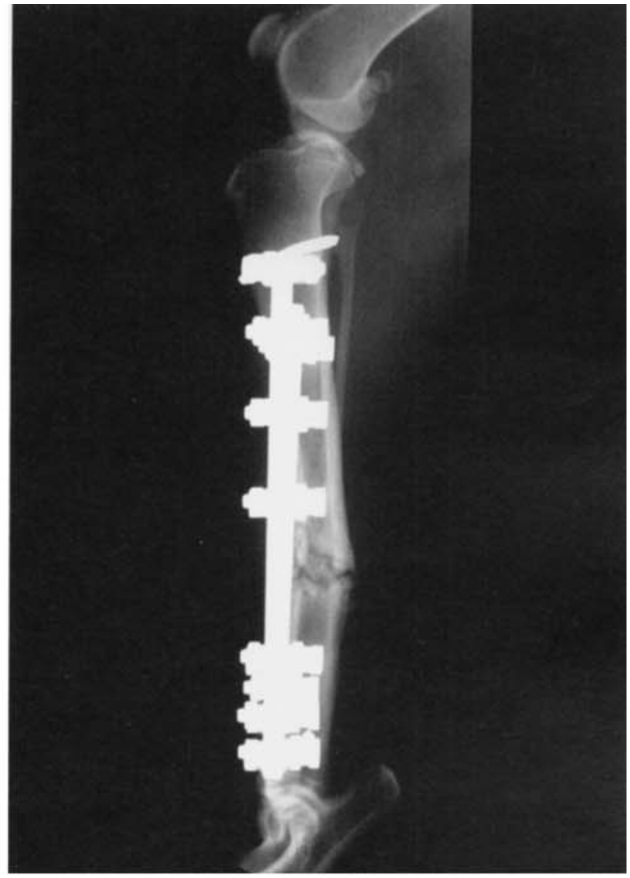
## Follow-up evaluation

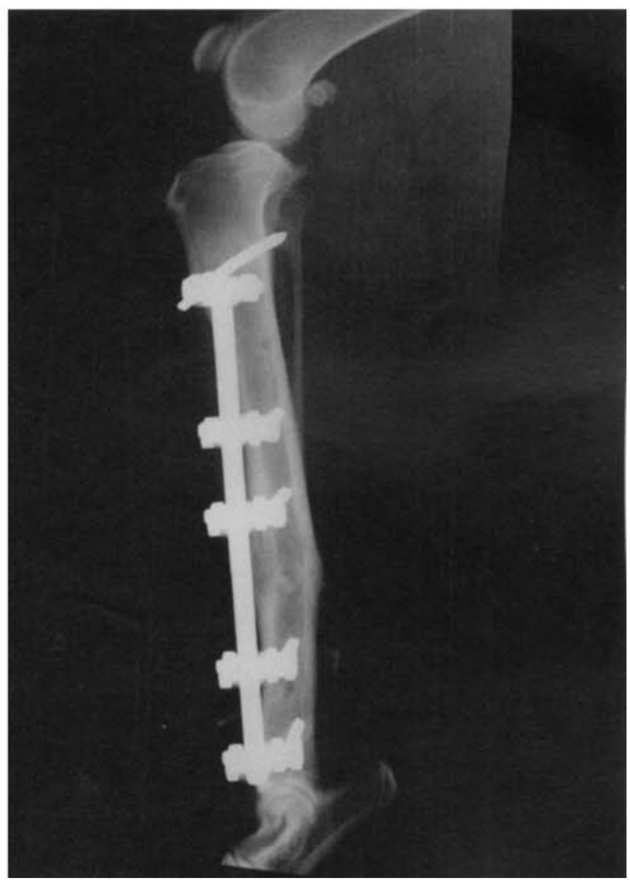
At 6 weeks the dog was re-evaluated and radiographs of the right tibia were made. Functional use of the limb had progressively improved, with resolution of lameness about 4 weeks after surgery. The owner had been maintaining a protective bandage over the fixator that was changed several times per week. There was mild discharge from the proximal full pin on the lateral side and the most proximal half-pin on the medial side; otherwise, the pin sites were clean and dry. Radiographs demonstrated good callus formation bridging the fracture site. There was a new area of lucency in close proximity to the most distal half-pin in the proximal segment, suggestive of an additional fracture line associated with this pin placement. The clamp holding this pin was loosened to assess security of the pin, which was found to still be secure within the bone. Staged disassembly was initiated by removal of both full pins, their associated clamps, and the lateral connecting rod, thus converting the bilateral (minimal type II) fixator to a unilateral (type Ia) fixator.

## Second follow-up evaluation

The patient was seen again at 10 weeks following surgery. Functional use of the right pelvic limb had remained normal since the last examination. There was mild drainage from the most proximal pin site, and the others were clean and dry. The dog was sedated for radiographic evaluation and palpation of the tibia. Radiographs revealed smooth, mature bridging callus and adequate healing at both the original fracture line and the secondary fracture line seen at 6 weeks. Synostosis of the tibia and fibula was evident in the fracture region. The clamps were loosened and palpation of the tibia confirmed clinical union. The fixator was removed. The dog was placed in a modified Robert Jones bandage for 2 weeks and confined to leash walking for 6 weeks following fixator removal.







# Case study 7

## Clinical presentation, history, and fracture

A 6-month-old, 21-kg, intact, female Staffordshire Terrier was hit by a car and sustained a closed fracture of the left tibia. Radiographs taken by the referring veterinarian revealed a slightly displaced, spiral, oblique fracture involving the proximal diaphyseal region of the bone. The fibula appeared to be intact. The long distal segment appeared to have a fissure line most easily seen in the craniocaudal projection. A Robert Jones bandage was applied to the injured limb and the case was referred for surgical treatment. The dog was stable on presentation. The only other abnormality found was a fracture of the first phalanx of the fifth digit of the left hind paw.

## Surgical planning

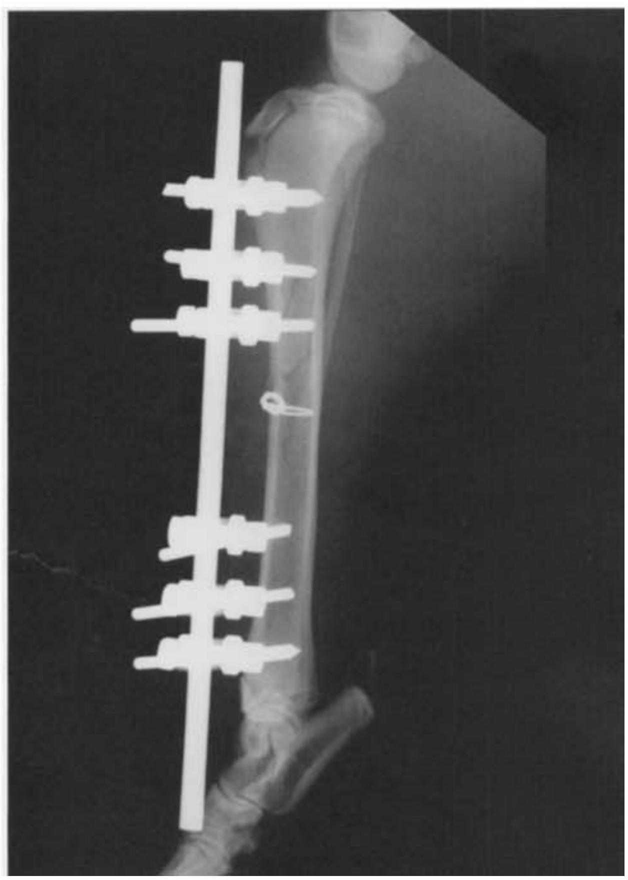
The dog is young and has a two-piece, relatively nondisplaced tibia fracture with an intact fibula. Despite the proximal location of the fracture, this probably could have been managed successfully with a cylindrical fiberglass cast. However, the thick, muscular thigh region of this dog will make cast application challenging. The dog still has physiologically active growth plates that must be respected if surgical treatment is carried out. Surgical options would include intramedullary pinning, bone plating, and external skeletal fixation. It may be difficult to place an optimal number of screws or fixation pins in the short proximal segment without coming dangerously close to the growth plate if plating or external fixation is employed.

A better set of radiographs should have been obtained prior to surgery. This was not done (at the request of the owner) to save money. The importance of having good-quality radiographs taken in two projections and including the joints above and below the fractured bone cannot be overemphasized. These are used to "map out" regions of intact bone where fixation implants can be safely placed. Failure to obtain good-quality radiographs in this case set the stage for technical errors that should have been avoidable.

## Fracture repair and evaluation

The dog was placed in dorsal recumbency and the hanging limb technique was used to obtain approximate alignment of the fracture. A "mini-approach" was made to the medial aspect of the fracture to enable anatomic reduction. Fracture reduction was initially maintained with self-centering bone-holding forceps. This allowed placement of a hemi-cerclage wire such that fracture reduction would be maintained after the bone-holding forceps was removed. The fracture was stabilized with a medially applied unilateral, uniplanar (type Ia) external fixator using small SK clamps and a titanium connecting rod. A predrilling technique was used and a cancellous profile threaded pin was placed in the soft bone



of the proximal diaphysis. A cortical positive-profile threaded pin was similarly placed in the distal metaphysis. Clamps and a titanium rod were applied medially, fracture reduction was verified, and the clamps were tightened. Four additional clamps were placed on the rod, predrilling was done, and smooth Steinmann fixation pins were applied in these central positions to save money. The phalangeal fracture was treated with an external coaptation bandage containing a caudally placed metasplint.

Postoperative radiographs showed anatomic reduction of the fracture. The second and third pins in the proximal segment appeared to violate the fracture region. The proximal cancellous pin could have been placed more proximally without jeopardizing the proximal growth plate. Failure to obtain good-quality radiographs resulted in poor appreciation of the safe bone target in the proximal segment and led to less than optimal placement of fixation pins here. Fixation pin placements in the distal segment were felt to be adequate.

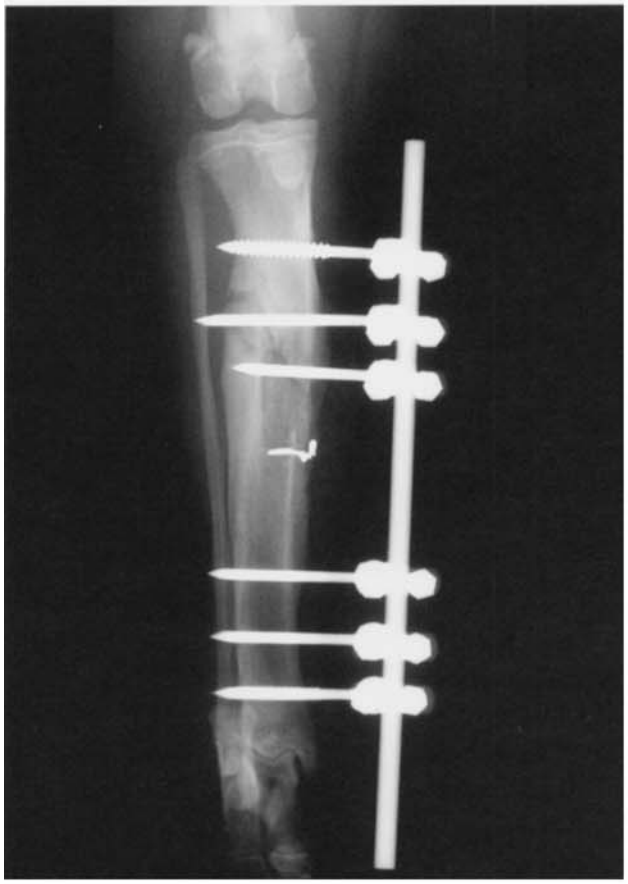
## Follow-up evaluation

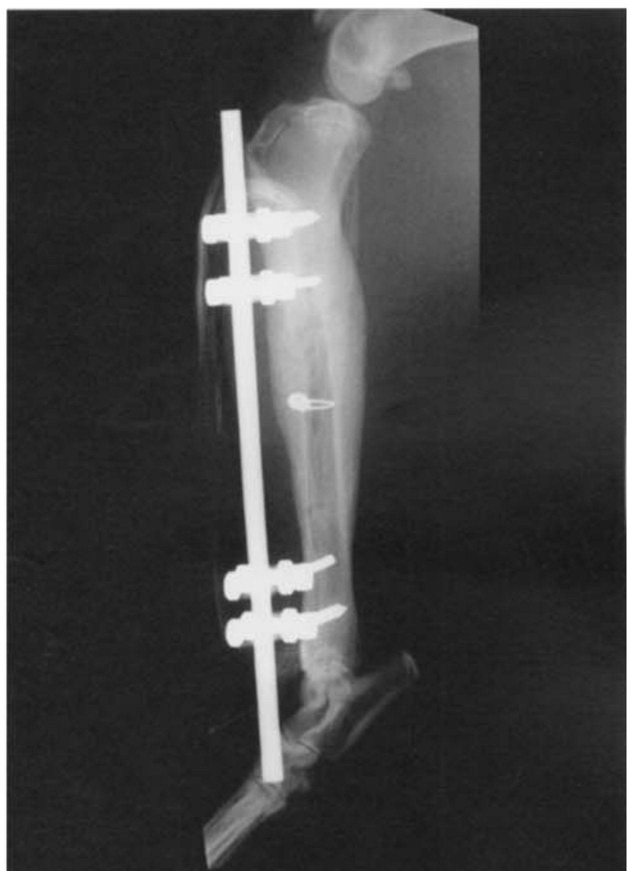
At 4 weeks the dog was re-evaluated and radiographs were taken. The dog was weight bearing, and functional use of the limb had progressively improved, but mild residual lameness was still present. The owner had regularly changed bandages on the fixator and the pin sites were clean and dry. Radiographs revealed abundant bridging callus, especially along the caudal aspect of the fracture region. The most distal pin in the proximal segment and the most proximal pin in the distal segment were removed to increase the working length of the frame, thus reducing its stiffness.

## Second follow-up evaluation

The dog was seen again 6 weeks after surgery and radiographs were taken. Smooth, mature bridging callus was evident. The fixation clamps were loosened and palpation of the fracture confirmed clinical union. The fixator was removed. The limb was placed in a modified Robert Jones bandage for 1 week and exercise was restricted to leash walking for 4 weeks after removal of the fixator.

This case had a successful outcome in spite of faulty decision-making and technical errors. A complete radiographic work-up should have been obtained prior to surgery. Had this been done, accurate placement of the proximal fixation pins would have been much more likely. With the use of modern frame components (such as Securos and IMEX-SK) there was no good reason to use smooth Steinmann pins rather than positive-profile pins in the central positions within the fixator. This is often done with K–E splints because positive-profile pins cannot pass through or be easily accommodated by K–E clamps. The cost differential between smooth pins and positive-profile pins is small (especially when one considers the prohibitive cost of treating complications if fracture healing is disrupted by fixation failure). Positive-profile pins should have been used at all locations within this fixator. Fortunately, the surgeon's decision to use smooth pins resulted in a successful outcome, but only because this was a very young patient with a rapidly healing fracture.





# Case study 8

## Clinical presentation, history, and fracture

An 8-month-old, 27-kg, intact, male golden retriever sustained a right tibia fracture from a snowplow. The dog was treated for shock then placed in a Robert Jones bandage. The fracture was a closed transverse midshaft tibia fracture with one large and several small fragments. There were fissures extending into the proximal tibia segment. The fracture was displaced caudally and medially and was overriding by 2 cm.

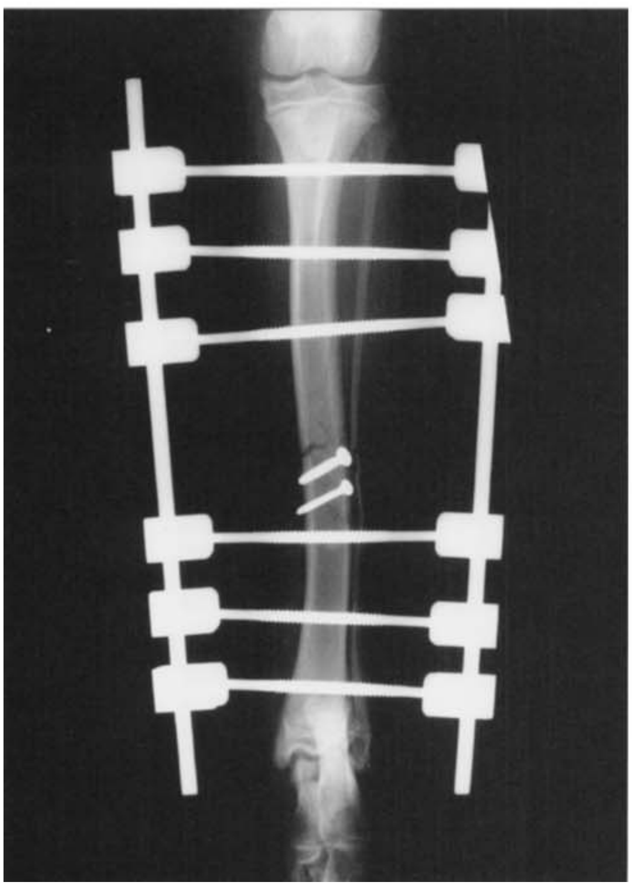
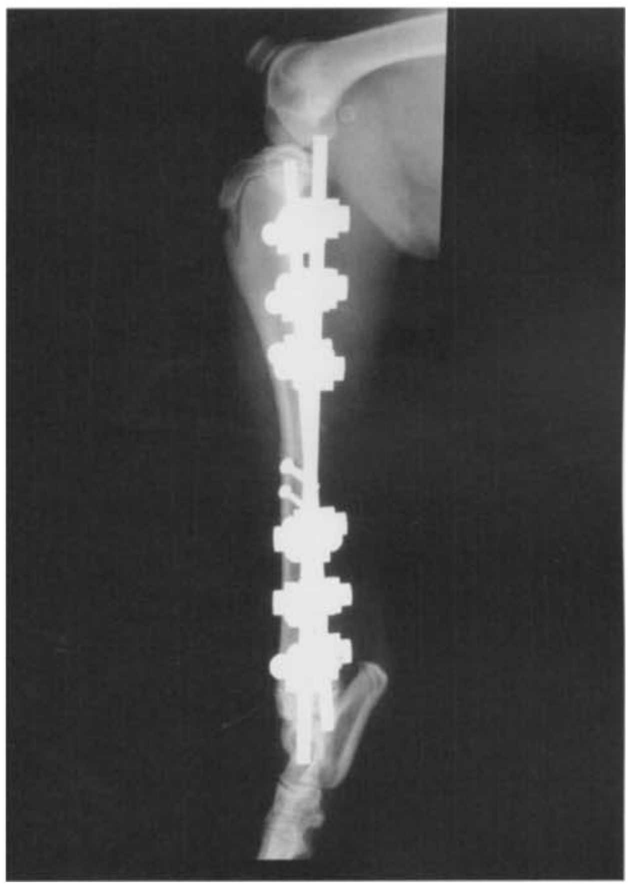
## Surgical planning

The patient should be stabilized and the limb placed in a Robert Jones bandage. The fracture should be stabilized once the patient is stable or 1–2 days following injury. Repair methods could include casting, although adequate reduction would probably be difficult to maintain because of the longitudinal fissures and large comminuted fragment. Cerclage wires could be used to reduce the large fragment and secure the fissure, but they would probably not provide sufficient rotational stability for the transverse fracture. Open reduction and internal fixation with a plate and screws would be a good choice, although care must be taken to adequately reduce the large fragment and avoid fissures. External fixation could be used, but the large fragment should be apposed to avoid leaving a large deficit at the fracture. If adequate apposition of the fracture fragments could be achieved, load sharing could also be achieved. However, the longitudinal fissure may be displaced if the fixator allows too much motion at the fracture site. Thus, a fixator of sufficient stiffness for load bearing should be chosen even if fracture fragments are apposed. For this 27-kg dog a type II (bilateral) or type Ib (unilateral, biplanar) configuration should be chosen. Reduction using an open approach in which the large fracture fragment is apposed should be considered.

## Fracture repair and evaluation

The fracture was repaired with a type II (bilateral) fixator. The limb was reduced using the hanging limb technique and an approach was made on the medial aspect of the tibia. The large fragment was reduced and stabilized with one 3.5-mm and one 2.7-mm bone screw in lag fashion. One positive-profile full pin was placed in each of the proximal and distal fracture fragments, close to, but not invading, the physis. The fracture was reduced and connecting bars applied. Consecutive positive-profile full pins were placed using an aiming tool and predrilling techniques until there were three fixation pins in both the proximal and distal segments.



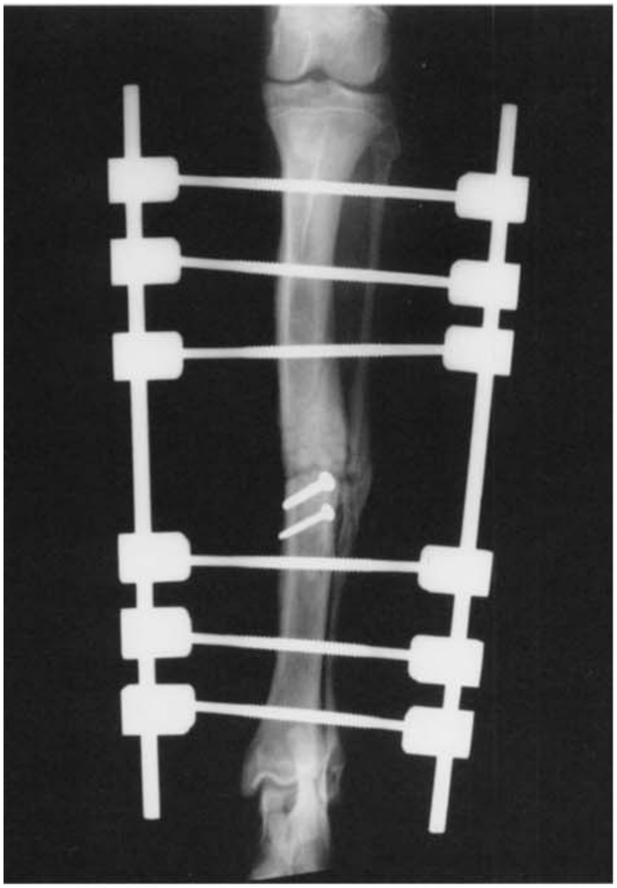
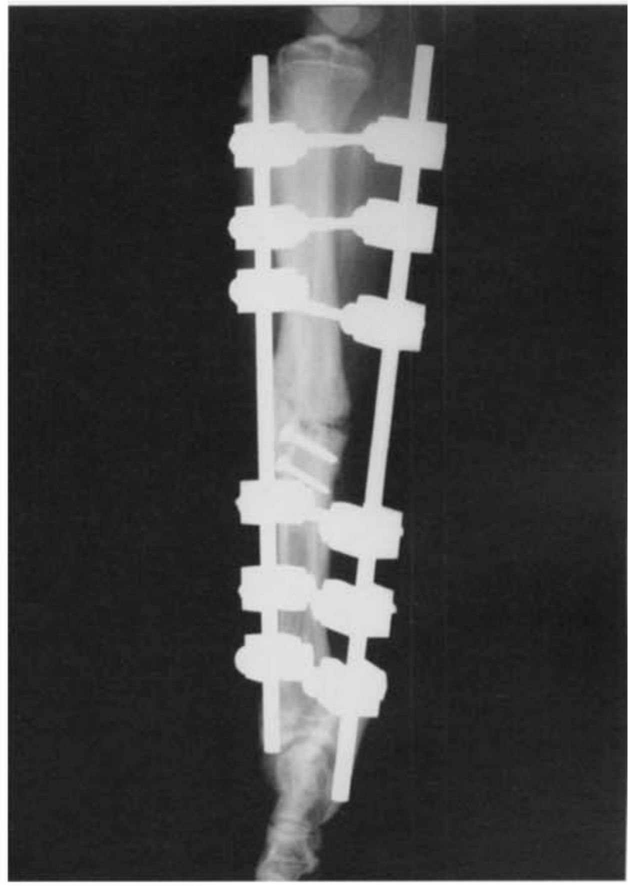
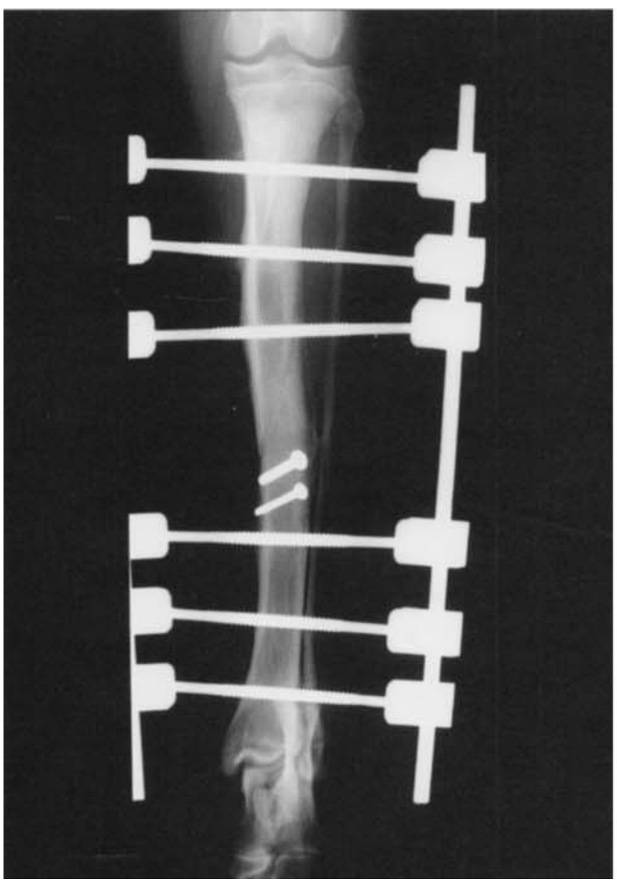
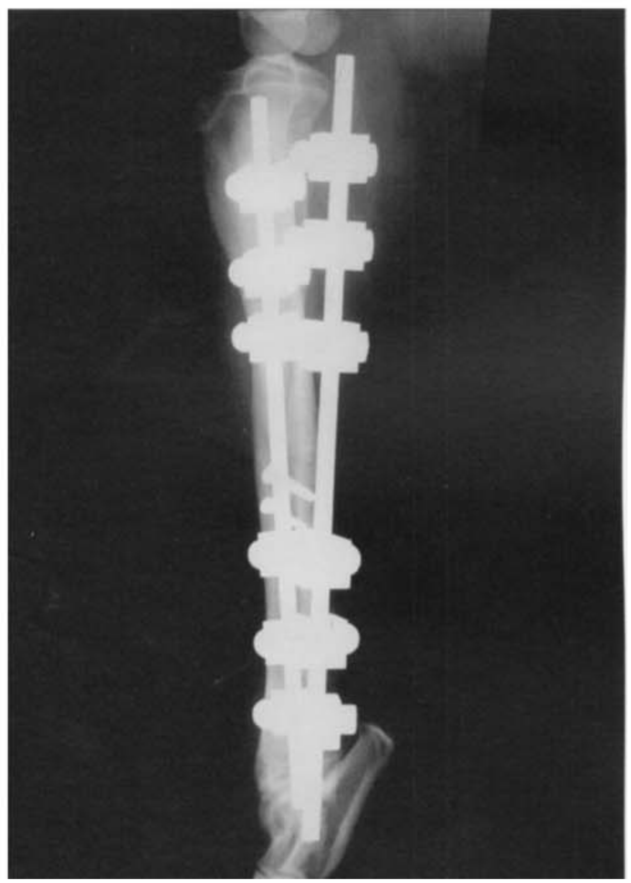
Fracture alignment and apposition were adequate. The fixation pins were placed appropriately close to the joints and as close as possible to the fracture. The stiffness and strength of this fixator should be considered sufficient for load bearing for this size of dog.

## Follow-up evaluation

At 4 weeks the dog was presented for re-evaluation. Several days before this early follow-up evaluation, the dog's limb had become swollen. An antibiotic had been prescribed and the swelling had subsided. The pin sites did not show signs of discharge and the dog was using the limb well. Radiographs revealed that alignment and apposition had been maintained. The fixator had not changed in position and pin loosening was not evident. The bone screws were stabile. There was a large callus that bridged the fracture cranially and laterally, but not medially and caudally. At this time, the three distal clamps on the medial connecting rod were converted to sliding clamps to increase axial load. At this early time point and without radiographic signs of stress protection osteopenia, this does not seem necessary. The patient was discharged with instructions for leash walks and continued exercise restriction.

## Second follow-up evaluation

At 8 weeks postoperatively the dog was using the limb well. The pin tracts showed no signs of complication and there was no discharge or pain on palpation. Radiographs demonstrated healing of the tibia fracture as well as the fibular fracture with remodeling and re-establishment of the tibia cortices. The fixator was removed.

# Case study 9

## Clinical presentation, history, and fracture

A 2-year-old, 34-kg, spayed, female pit bull cross sustained a grade II open left tibia fracture in a motor vehicle accident. The dog was treated for shock then anesthetized. The wound was debrided, copiously lavaged, then placed in a Robert Jones bandage. The fracture was an open, transverse, midshaft tibia fracture with at least three comminutions. The fracture was displaced laterally and was overriding by 1 cm.

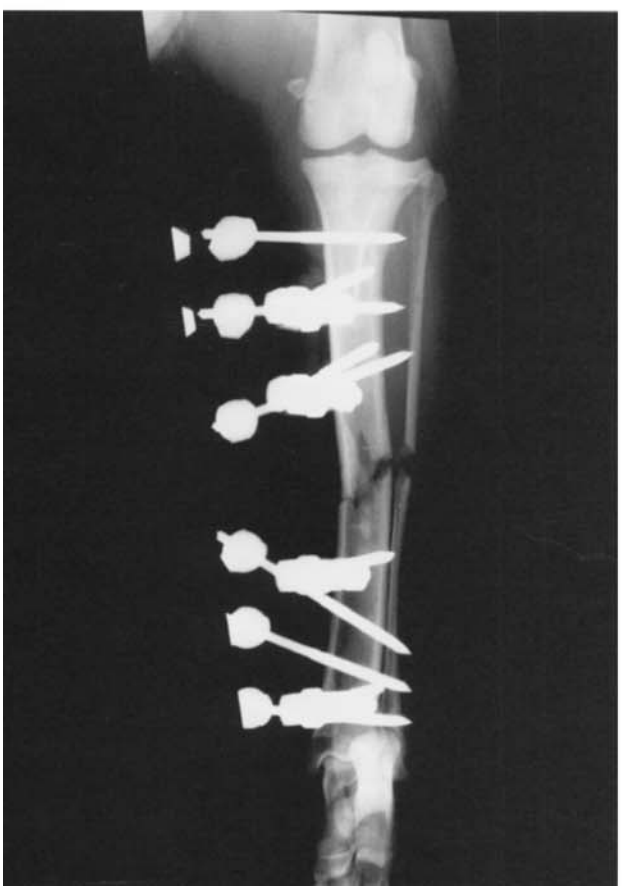
## Surgical planning

This grade II open fracture does not need emergency fracture repair, but the wound should be treated immediately and the patient placed in a Robert Jones bandage. The fracture should be stabilized as soon as practical once the patient is in stable condition. As the fracture is open, repair methods should not include casting. Pin and wire fixation alone would not result in rotational stability of this fracture because of comminution and the potential for propagating infection. Plate fixation could be considered, but adequate stabilization of the small comminuted fragments may not be achieved and the necessary exposure might increase the potential for infection. This fracture is best repaired with external fixation. It is unlikely that load sharing would be achieved because of the comminution, therefore a fixator adequate to provide load bearing should be used. For this 34-kg dog a type II (bilateral) or type Ib (unilateral, biplanar) configuration should be chosen. Reduction using a limited approach should be considered.

## Fracture repair and evaluation

The fracture was repaired with a type Ib (unilateral, biplanar) fixator. The limb was reduced using the hanging limb technique and a limited approach that included the wound from the open fracture. One half-pin was placed in each of the proximal and distal fracture fragments on the medial aspect of the tibia and the fracture reduced. Consecutive positive-profile half-pins were placed by predrilling techniques until there were three fixation pins in both the proximal and distal segments. A second unilateral connecting rod was placed slightly less than 90° to the first with the fixation pins entering the fragments from a cranial direction. Two positive-profile fixation pins per segment were applied to the second connecting rod.





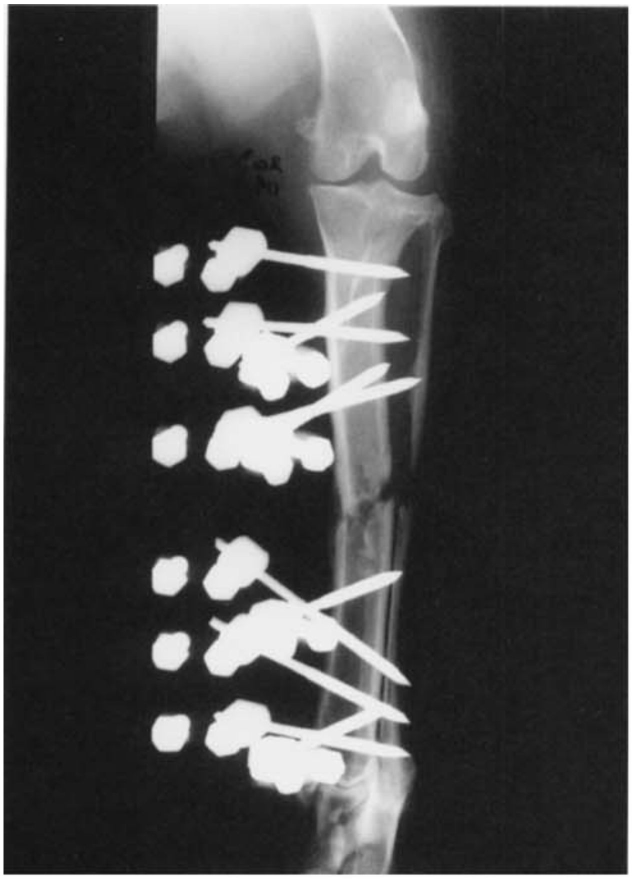

Fracture alignment was adequate. A comminuted fragment was displaced medially, leaving a deficit on the lateral cortex. The fixation pins were placed appropriately close to the joints and as close as possible to the fracture. The stiffness and strength of this fixator should be considered sufficient for load bearing for this size of dog.

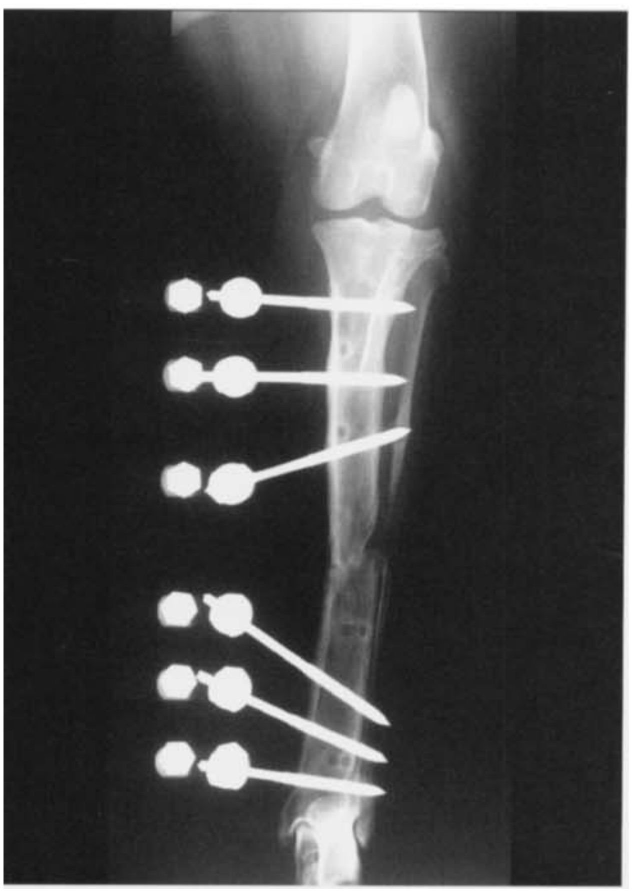
## Follow-up evaluation

At the 10-week follow-up the dog was using the limb for ambulation, but would occasionally lift the limb at a stand. The pin sites showed no sign of complications and there was no discharge. Radiographs revealed that alignment and apposition had been maintained. The fixator had not changed in position and pin loosening was not evident. There was modest callus formation that could be seen bridging the callus cranially, caudally, and medially, but not laterally. At this time the cranial connecting rod with its four fixation pins was removed and the patient discharged with instructions for leash walks and continued exercise restriction.

## Second follow-up evaluation

At 14 weeks postoperatively the dog was using the limb well but would lift the limb occasionally with excessive activity. The pin tracts showed no signs of complication and there was no discharge or pain on palpation. Radiographs demonstrated healing of the tibia fracture. Although there was continuity of the lateral tibia cortex, there was a deficit due to the displacement of the fragment noted postoperatively. Although there was lack of cortical continuity on the lateral tibia, the tibia had healed sufficiently. The fibula had not healed.






# Humerus

# Case study 1

## Clinical presentation, history, and fracture

A 3-year-old, 4.4-kg, intact, male, domestic short-hair cat was presented to a local veterinary clinic after having been shot with a firearm. It had been treated conservatively for 2 days then referred after becoming anorexic. The wound appeared infected and the cat was febrile. Thoracic radiographs were within normal limits. There was sensation to the dorsum of the right front paw. The fracture was an open transverse fracture of the distal humerus, displaced caudally and medially and overriding by 1 cm.

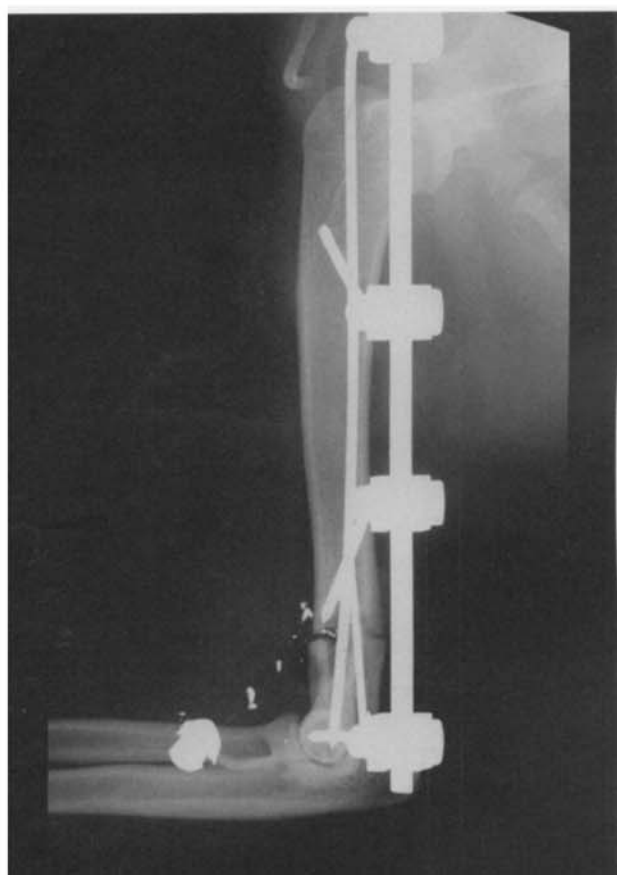
## Surgical planning

Because the fracture was a grade III gunshot wound and infected, it should be treated with sterile surgical debridement, lavage, and open wound management. Because of the area of involvement, careful attention should be paid to the function of the radial nerve. The fracture should be operated open and stabilized as soon as possible. Open reduction and plate fixation could be considered; however, this is a grossly infected fracture that should be left open, thus leaving the plate exposed. Intramedullary pinning could result in extension of the infection in the medullary cavity. The fracture was transverse and not amenable to cerclage wiring. Unilateral fixation alone may not result in adequate stiffness because of the smaller size of fixation pins that would be used. An option for this fracture would be a unilateral triplanar fixator. A full pin could be placed through the distal humeral condyle and tied to the proximal half-pins with a connecting rod that crosses cranially over the humerus (see Chapter 1). The distal fracture fragment could accommodate an additional half-pin for rotational stability.

## Fracture repair and evaluation

The cat was anesthetized and the wound surgically clipped, prepared, debrided, and lavaged. The infection appeared to involve only the subcutaneous tissues, but the fracture site was cultured and left open. No attempt was made to retrieve the bullet slug. The fracture was repaired with a 1.6-mm intramedullary pin placed in the medial epicondyle. The fracture was reduced and a 1.6-mm smooth pin was placed through the humeral condyle. The intramedullary pin was bent lateral and a connecting rod was used to connect the intramedullary pin to the fixation pin. Two additional 1.6-mm smooth half-pins were placed into the diaphysis of the humerus. A smaller Kirschner wire was placed in the lateral epicondyle.



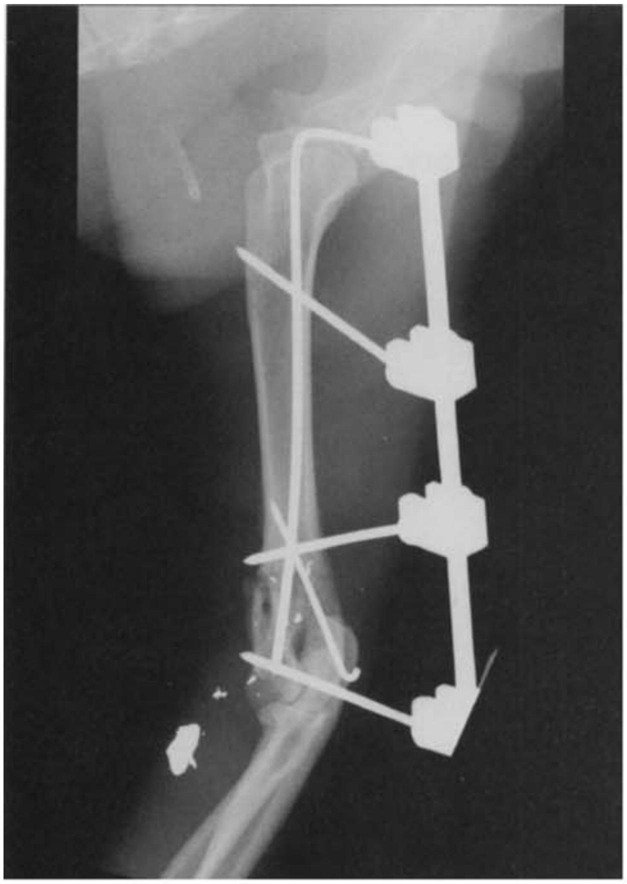
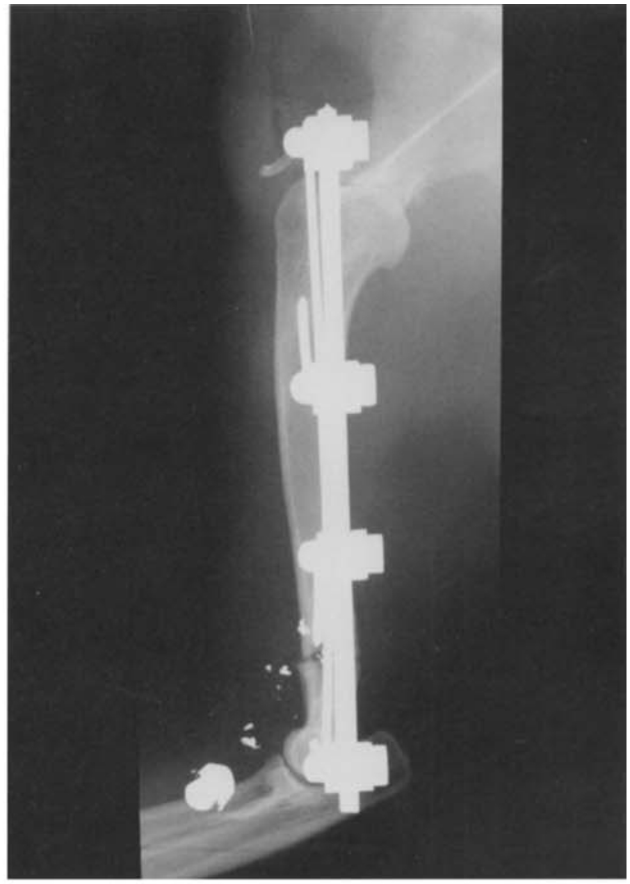
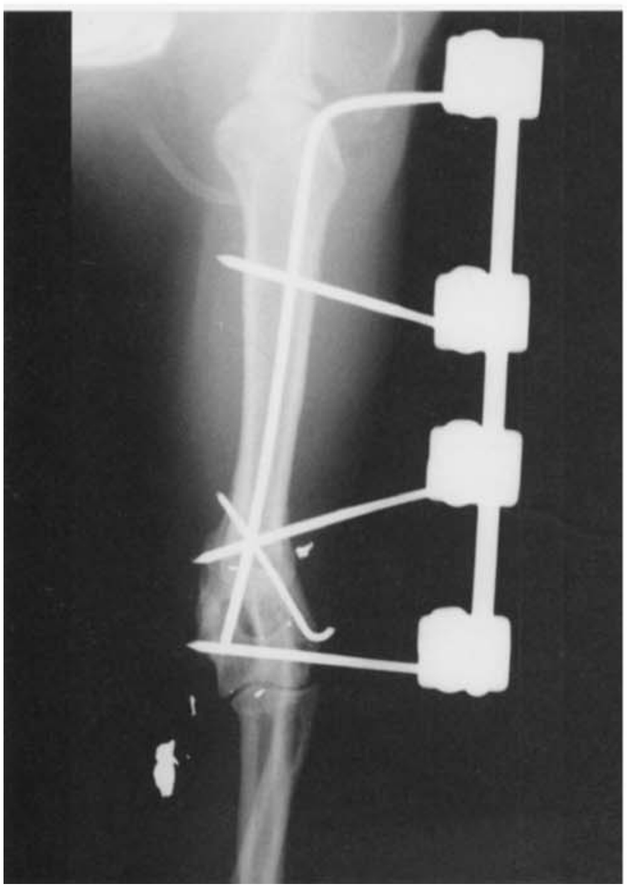
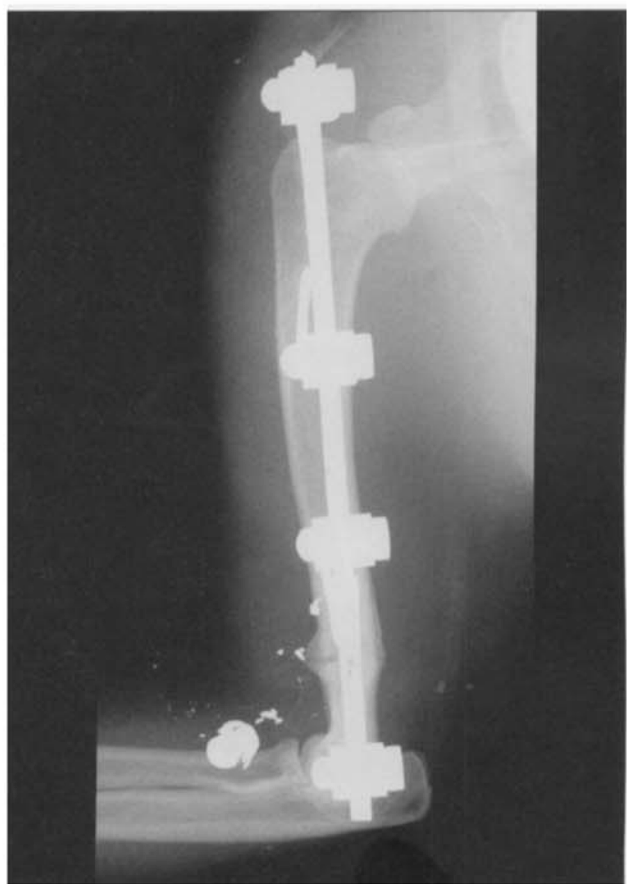
Fracture alignment was good. Fragment apposition was adequate. The intramedullary pin was well seated but could have been larger. This is also true for the fixation pins. Had 2.4-mm fixation pins been used, positive-profile threaded pins rather than smooth pins could have been used. Using an intramedullary tie-in configuration, the stiffness of this fixator is increased. The intramedullary rod acts, to a degree, like a second connecting rod within the bone. Other than being narrow, the fixation pins are adequately positioned. The intramedullary pins could support bacterial infection, leading to osteomyelitis. The wound was treated open for 1 week, at which time it closed by secondary wound healing. The cat was discharged to be cage confined and prescribed antibiotics for 3 weeks.

## Follow-up evaluation

Four weeks later the cat was presented for evaluation. The cat would not be confined to a cage and the owner had been taking it on leash walks, when it ambulated well. The pin sites were slightly inflamed. Radiographs showed that alignment and fragment apposition had been maintained. The fixator and intramedullary pins had not changed in position. There was minimal callus formation at the fracture site.

## Second follow-up evaluation

At 8 weeks the patient was presented for further evaluation. He had been using the limb well and could run and jump, contrary to discharge instructions. There was moderate inflammation at the proximal intramedullary pin site. Radiographs showed that alignment and apposition had been maintained. The fixator pins were stable with no pin loosening. The fracture had healed with bridging callus on all aspects of the humerus. The external fixator was removed and the cat returned to normal outdoor activity.

# Case study 2

## Clinical presentation, history, and fracture

A 4-year-old, 20-kg, castrated, male wheaten terrier sustained a left humerus fracture in a motor vehicle accident. Thoracic radiographs showed mild pulmonary contusions, but the dog was otherwise in good condition. There was recognition of painful stimuli of the dorsum of the paw, reflecting intact radial nerve function. Radiographs showed a closed, distal third, long oblique humerus fracture, displaced caudally and overriding by 1 cm.

## Surgical planning

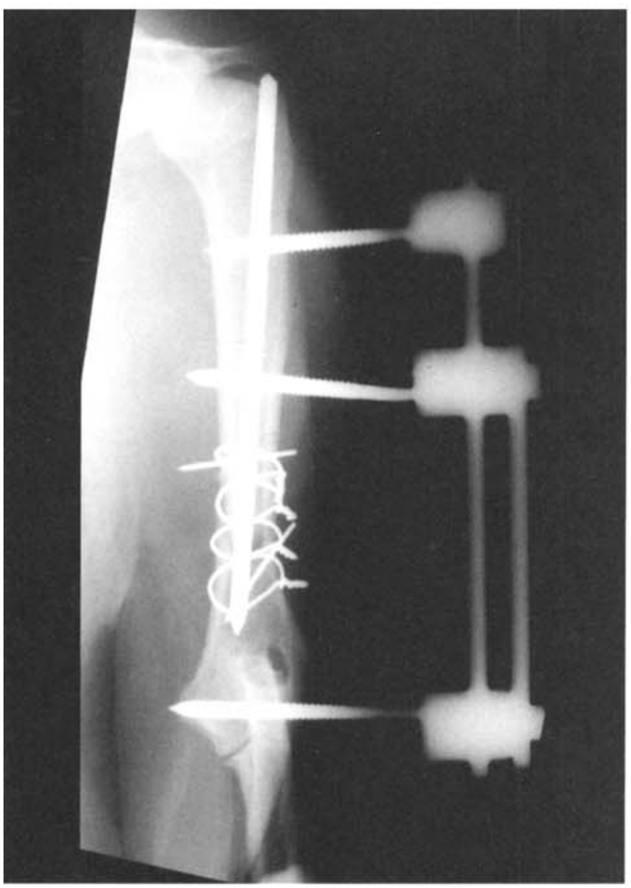
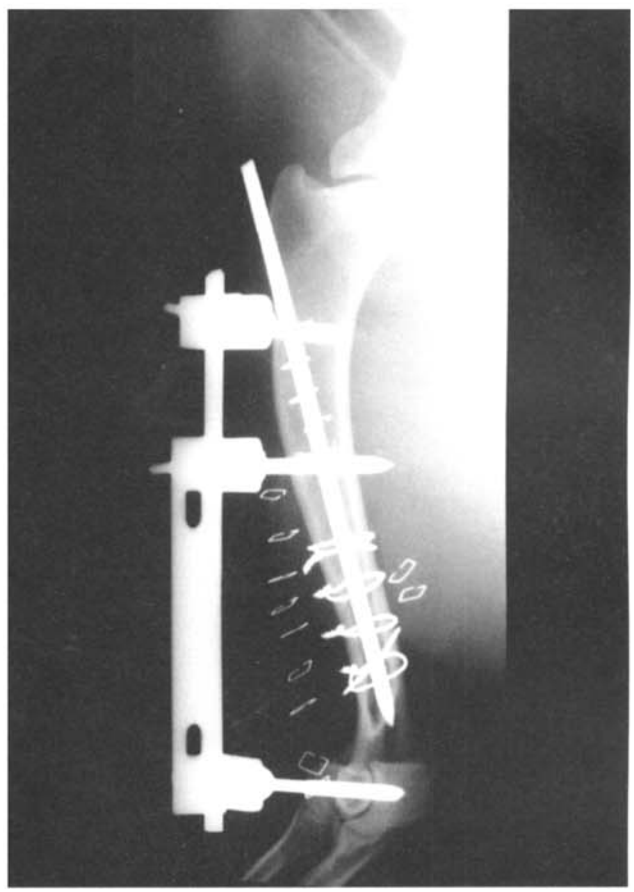
Bandaging was not necessary, and the dog was operated on the following day. Because of the location of the fracture, radial nerve damage was possible. External coaptation is not appropriate. Open reduction and plate fixation should be considered with either a medial or lateral plate. A radiographically unseen fissure line could complicate screw placement. As the fracture was a long oblique fracture, cerclage wire and intramedullary pinning should be considered. External fixation alone would not be appropriate as a unilateral fixator would have insufficient stiffness and strain across the oblique fracture would complicate healing. An external fixator could be added to supplement pin and cerclage fixation.

## Fracture repair and evaluation

A lateral approach to the humerus was made and the fracture reduced. Four cerclage wires were placed. A small Kirschner wire was placed across the fracture to prevent slipping of the most proximal and most distal cerclage wires. An intramedullary pin was place normograde toward the medial epicondyle. A three-pin unilateral fixator with an augmentation plate was placed with 3.2-mm positive-profile threaded pins but without predrilling the pin holes. The single pin in the distal fracture fragment was through the condyle.

Fracture alignment and fragment apposition were good. A sufficient number of cerclage wires of the correct size and in the appropriate location were used. However, the Kirschner wire used to support the most proximal cerclage wire was too long. The intramedullary pin was of adequate size and in general well placed, but it could have been seated farther into the epicondylar ridge.

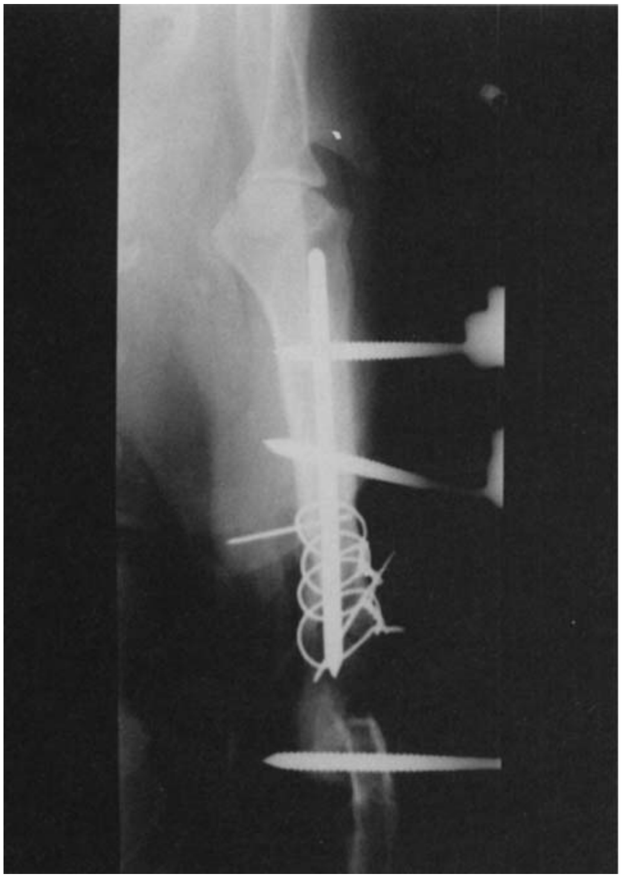
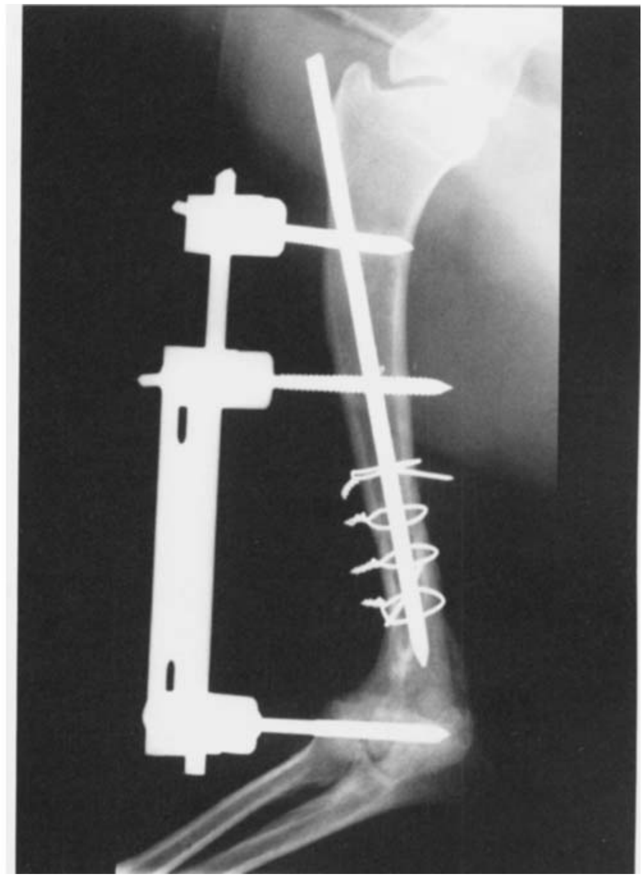


The external fixator was well placed, although predrilling is preferred. The stiffness of this fixator is sufficient to support the pin and wire fixation but would be insufficient if used alone.

## Follow-up evaluation

At 8 weeks the patient was presented for evaluation. He had stopped using the limb a few days prior to evaluation. There was substantial serosanguinous discharge from the distal pin site. Radiographs showed that alignment and apposition had been maintained. The proximal Kirschner wire had migrated medially and could be palpated beneath the skin. The distal fixation pin was loose. The fracture had healed, but there was periosteal new bone formation on the humeral condyle and distal metaphysis, suggesting osteomyelitis. The fixator and Kirschner wire were removed, the bone cultured, and the dog was prescribed appropriate antibiotics, specifically clindamycin 11 mg/kg p.o. twice a day. Physical therapy was initiated with gentle range of motion three times a day. The dog began using the limb the day after implant removal and returned to normal activity.

# Case study 3

## Clinical presentation, history, and fracture

A 7-month-old, 36-kg, female Newfoundland Shepherd was presented with a left humerus fracture incurred in a motor vehicle accident. Following injury, the dog was ambulatory on the other three limbs. Pulmonary contusions were noted on thoracic radiographs. There was recognition of painful stimuli on all aspects of the left forelimb. The fracture was a closed, long, oblique humerus fracture, displaced cranially and overriding by 4 cm.

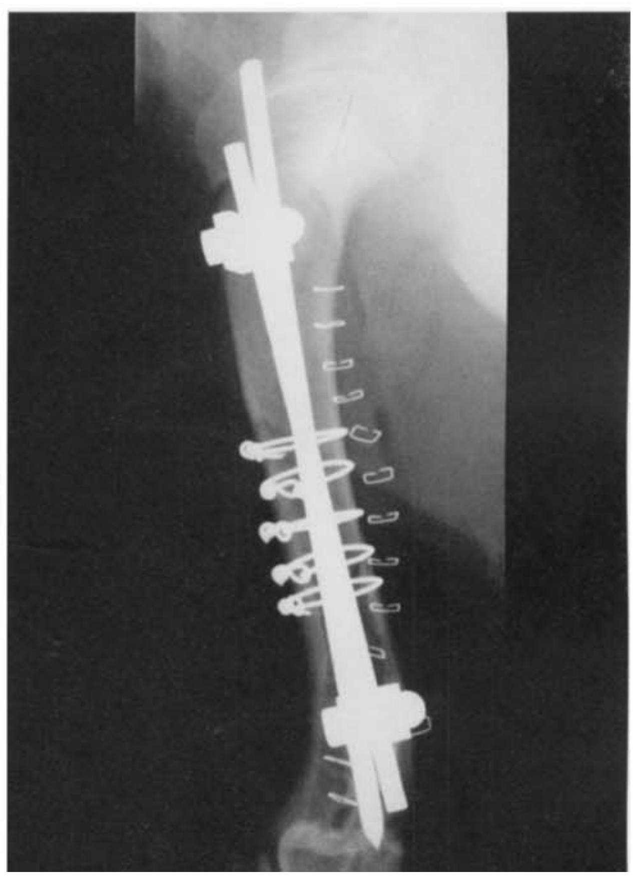
## Surgical planning

The mild pulmonary contusions did not result in impaired respiratory ability. However, the pulmonary contusions could become radiographically appreciable within 1–2 days of injury. The thorax should be re-radiographed the day before surgery. As this fracture is in the area of the radial nerve, and additionally because it is displaced, careful assessment of the brachial plexus and radial nerve is important. Casting or splinting would not be appropriate. Intramedullary pinning and cerclage would be an excellent method of repair because of the long obliquity. Open reduction and internal fixation with either a medial or lateral plate and shaft screws across the oblique fracture would also be a very good choice as long as radiographically unseen fissures did not compromise screw placement. Stabilization of this fracture with a unilateral external fixator alone would not be a good choice because of the amount of soft tissue lateral to the humerus and the consequent long connecting rod to bone distance. In addition, there would be substantial benefit to load sharing by cerclage wiring the long oblique fracture. Failure to provide interfragmentary compression across the oblique fracture would result in substantial shear forces, which would be detrimental to fracture healing. A unilateral fixator could be added to the pin and wire fixation if additional support were deemed necessary. Tying in the intramedullary rod to the external fixator would enhance fixator stiffness, but this may be difficult because of the size of the intramedullary pin in this 36-kg dog and amount of muscle and soft tissue at the shoulder.

## Fracture repair and evaluation

The fracture was repaired with an intramedullary pin and five cerclage wires using a lateral approach to the humerus. A two-pin unilateral fixator was added to the fixation using 3.2-mm positive-profile threaded pins and a 4.8-mm connecting rod.

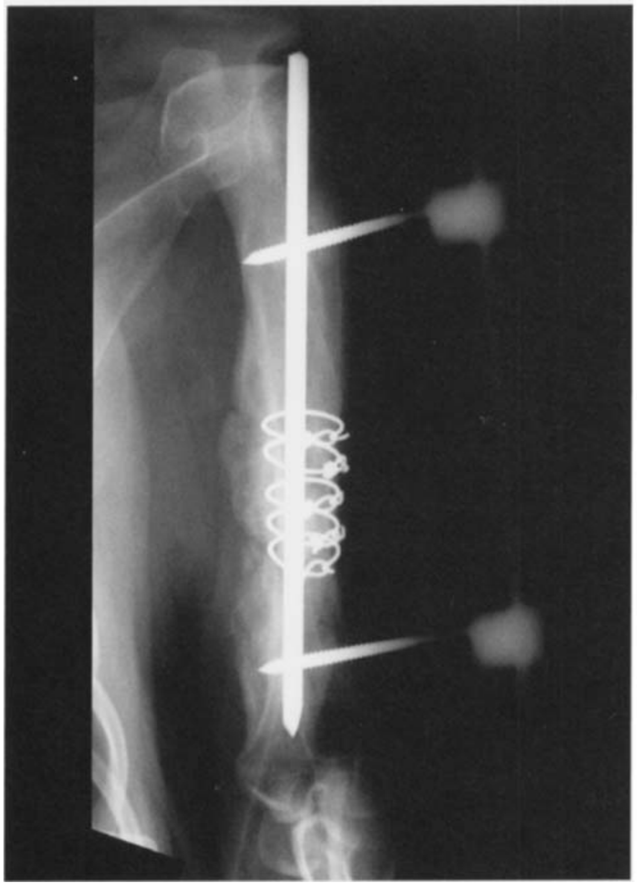


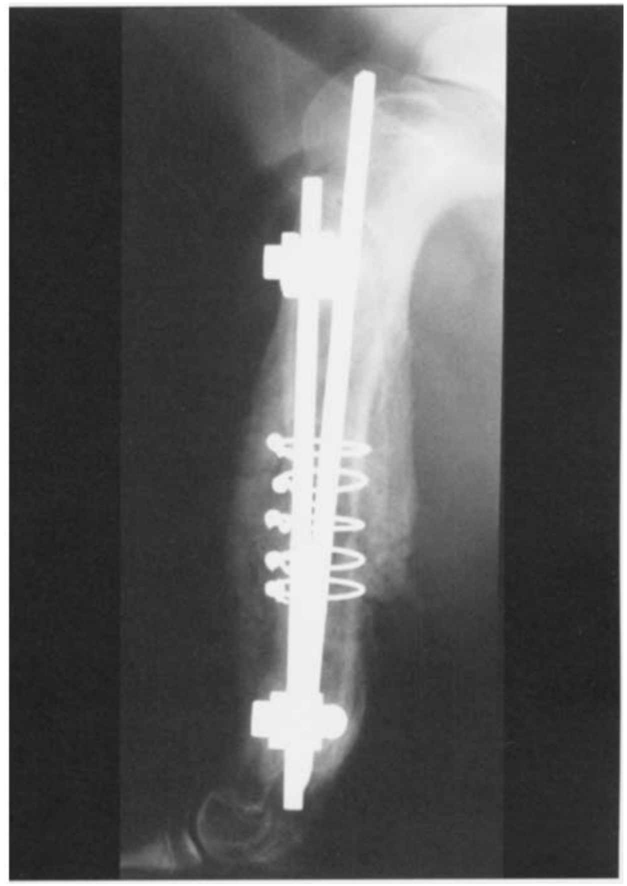



Fracture alignment and fragment apposition were very good. The intramedullary pin was appropriately placed in the medial epicondyle, and the number, size, and position of cerclage wires were appropriate. The unilateral fixator pins were placed 3 cm proximal and 2 cm distal to the fracture. The strength and stiffness of this fixator added little to the overall fixation. Alternatively, a unilateral four-pin fixator with a 9.5-mm connecting rod would have been many times stiffer. Pins could have been placed more proximally and more distally without compromising the physes.

## Follow-up evaluation

At 4 weeks the dog was re-presented because of discharge from the proximal fixation pin. The dog had been weight bearing since surgery and had increased its activity thereafter. Radiographs showed that alignment and apposition of the fracture had been maintained. The intramedullary pin appeared to have migrated proximally. The cerclage wires did not appear loose and were encased in fracture callus. There was no external fixator pin loosening. There was substantial callus bridging the fracture. The amount of callus was probably due to the age of the patient but also could be due to increased motion at the fracture site. As the external fixator was causing complications and stability was not reliant on it, the fixator was removed.





# Femur

# Case study 1

## Clinical presentation, history, and fracture

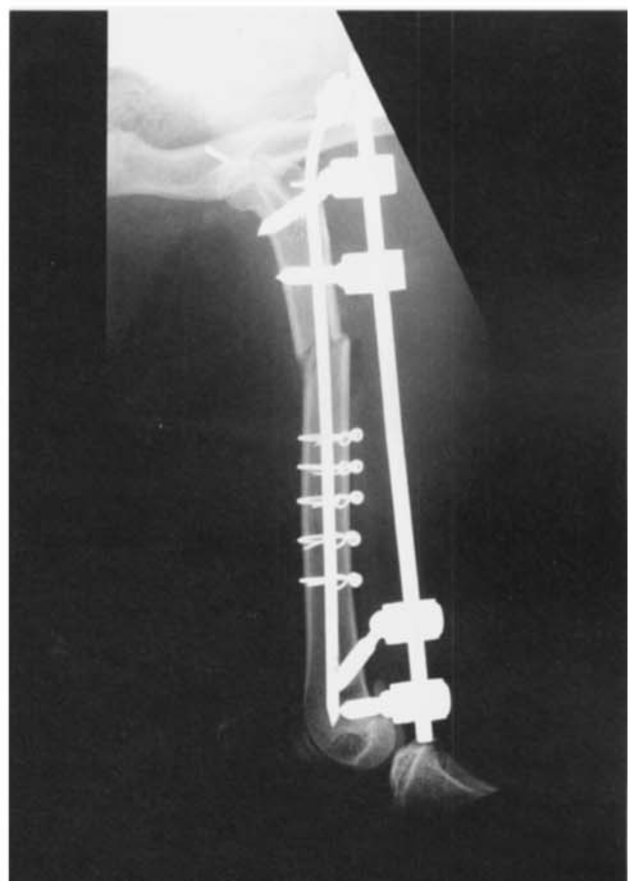
A 2-year-old, 4-kg castrated, male, domestic, short-hair cat sustained an unknown trauma after being missing for 7 days. The cat was found in good condition and nonweight bearing on its caudal limb. There were no wounds. Thoracic radiographs were within normal limits. Radiographs demonstrated a closed, comminuted, proximal third right fracture of the femur. There were several small fragments and two long fragments originating from the diaphysis. There was a longitudinal fissure extending to the distal third of the femur.

## Surgical planning

The cat was in a stable condition but requires prompt surgery as the fracture is now 1 week old. Coaptation is not appropriate. Pin and cerclage wire fixation could be used. The long fragments should be able to be reduced and the long fissure in the femoral diaphysis could be repaired with cerclage wires. Pinning would resist bending forces. However, once this was accomplished, the fracture would be reduced to a proximal third transverse fracture without any rotational support. An external fixator could be added to counter rotational forces or a plate applied over the cerclage wires. Open reduction and internal fixation with a plate and screws alone could be attempted but, because of the fragments and fissures, the plate would have to be applied in load bearing. Longitudinal fissures would interfere with screw placement. An external fixator alone would not be appropriate because of the fissures and the lack of stiffness of a unilateral fixator. The intramedullary pin described above could be incorporated with the external fixator. The use of a tie-in configuration greatly increases the strength and stiffness of a unilateral fixator.

## Fracture repair and evaluation

The fracture was repaired with open reduction with a lateral approach to the femur. The long fracture fragments were reduced and the diaphysis of the femur repaired with five cerclage wires. A 2.4-mm intramedullary pin was placed and seated into the distal femur. The segment of pin protruding from the greater trochanter was bent laterally. A 2.4-mm positive-profile threaded pin was placed in the distal condyle of the femur by predrilling the pin hole. A connecting rod was placed between the intramedullary pin and distal fixation pin. Two additional 2.4-mm fixation pins were placed in the proximal fragment and one in the distal fragment, avoiding the



longitudinal fissures. Although there were small deficits at the transverse fracture site, no cancellous graft was placed.

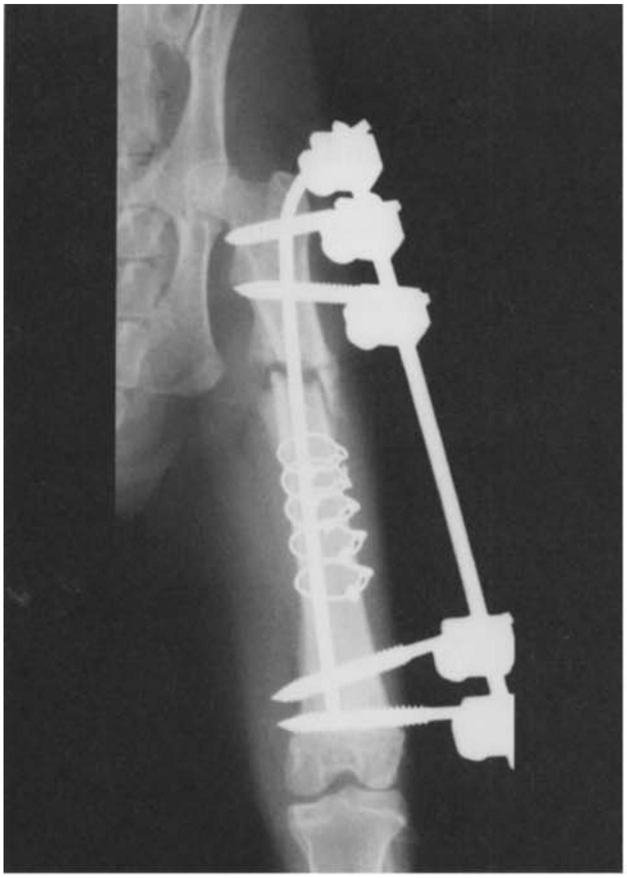
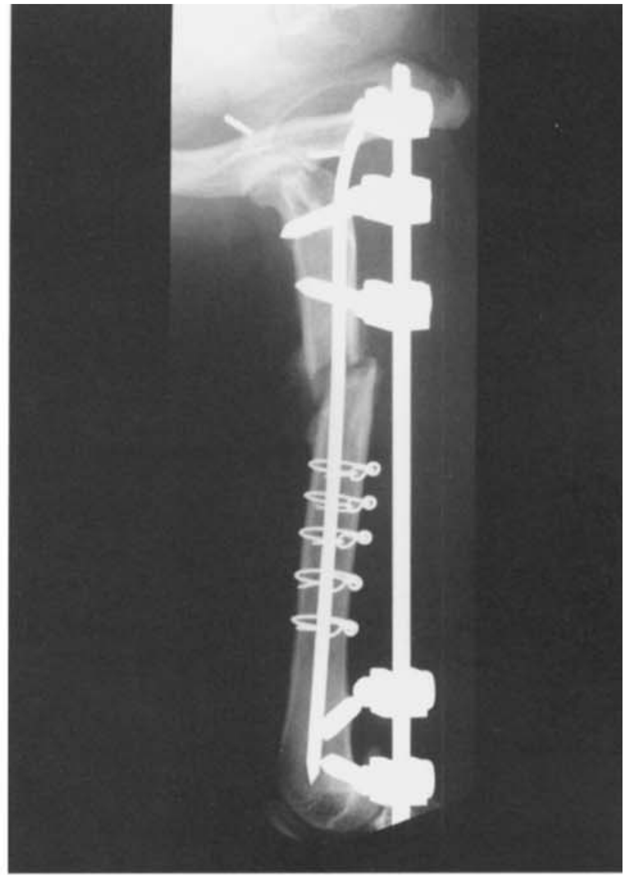
Postoperative radiographs showed good alignment, but there was slight lateral bending of the proximal fragment. Apposition of the longitudinal fragments and fissure was good. It appears that the 2.4-mm intramedullary pin is too small and that a 3.2-mm pin could be used and still tied into the external fixator. The size, number, and location of the cerclage wires are appropriate. The external fixator is well placed. However, the distance from the distal two fixation pins to the fracture site is large. This allows a large lever arm and may result in lack of stability at the fracture site. This was unavoidable because fixation pins could not be placed close to the fracture because of the fissures and cerclage wires. However, this deficiency, combined with a lack of resistance to bending forces owing to the small size of the intramedullary pins, could result in insufficient stability. The cat was discharged with exercise restriction.

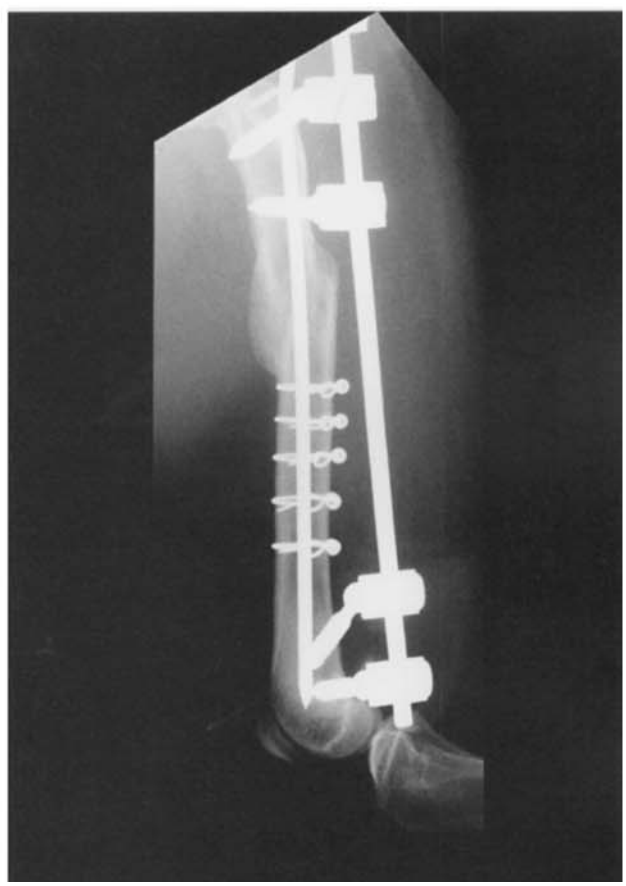
## Follow-up evaluation

At 6 weeks the cat was presented for evaluation. He had been using the limb well. There were no pin site complications. Radiographs showed that limb alignment had not been maintained. There was caudal displacement of the distal fragment at the transverse fracture site. Apposition at this site was altered. The cerclage wires were intact and unchanged. There was healing of the fracture lines apposed by the cerclage. Callus had bridged the fracture laterally, but not cranially, caudally, or medially at the transverse fracture. As the cat was using the limb well and there was a bridging callus, further surgery was not performed. The cat was discharged with cage restriction for an additional 4 weeks.

## Second follow-up evaluation

The patient was presented for re-evaluation 10 weeks postoperatively. The cat was ambulating normally and there were no pin site complications. Radiographs showed that alignment and apposition were unchanged from the previous follow-up evaluation. All implants were stable and there was no fixator pin loosening. A smooth callus bridged the transverse fracture site and remodeling to re-establish the cortices was under way. The fixator pins and intramedullary pins were removed and the cat returned to normal function.



# Case study 2

## Clinical presentation, history, and fracture

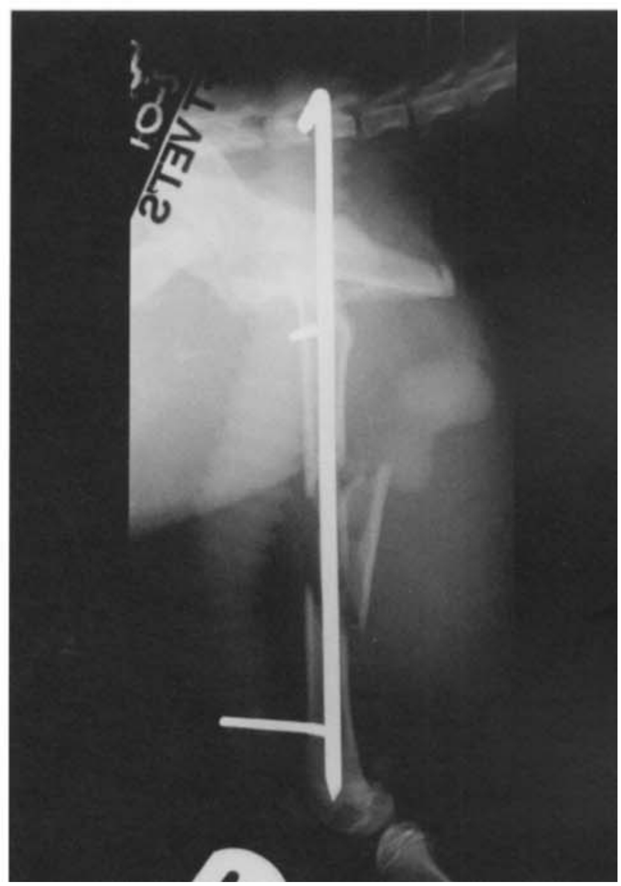
A 10-month-old, 4-kg, castrated, male, domestic, short-hair cat was presented with a right femur fracture following unseen trauma the previous day. Thoracic radiographs were within normal limits and there were no further abnormalities on physical examination. Radiographs of the right caudal limb demonstrated a closed, comminuted fracture of the mid-diaphysis of the right femur. There were several large fragments. The fracture was displaced caudally and was overriding by 1 cm.

## Surgical planning

Conservative management should not be considered optimal, although healing can occur. Coaptation in cats is difficult and is not ideal for femur fractures. Intramedullary pinning and cerclage wiring in this fracture would be technically difficult because of the number and configuration of fracture fragments. Open reduction and internal fixation with plate and screw fixation would be difficult if the goal were to achieve anatomic reconstruction of the femur. An intramedullary pin and plate fixation spanning the area of comminution should be considered. This biologic repair can be very effective in comminuted mid-diaphyseal fractures of the femur. However, external fixation alone is not ideal for repairing femur fractures because of the relatively large area of soft-tissue coverage and lack of access to the medial aspect of the bone. Composite repairs involving the use of external fixation and intramedullary pins provide a viable and effective method for managing this type of fracture.

## Fracture repair and evaluation

The fracture was repaired using a single intramedullary pin placed with minimal surgical exposure. No attempt was made to explore or reduce the fracture fragments. The fracture was aligned and the femur length re-established, then two threaded half-pins were placed in each major fragment. The intramedullary pin was bent laterally and these three pins incorporated into a connecting column of acrylic using the APEF system.



Radiographs showed acceptable limb length and alignment. A single large fragment was lying caudal to the intramedullary pin. The apparatus could have been augmented with additional half-pins. The cat was tentatively weight bearing on the repair the day after surgery.

## Follow-up evaluation

Five weeks after surgery, the cat was using the operated leg confidently. Radiographs demonstrated that alignment had been maintained. The large fragment remained caudal to the intramedullary pin. There was smoothing of the edges of bone fragments and some bridging callus and formation of periosteal new bone. There was early pin loosening of the two threaded half-pins. The cat was discharged with instructions for continued exercise restriction.

## Second follow-up evaluation

At 7 weeks the cat was re-evaluated. The cat had been using the limb well. Radiographs showed that limb alignment had been maintained. There was loosening of the fixation pins. Bridging callus could be seen across the medial and caudal aspects of the fracture. The distal fixation pin was removed as well as a section of the acrylic connecting column. This was done to maintain the intramedullary pin. These implants were removed following 2 additional weeks of exercise restriction. Although both half-pins loosened, this did not cause significant complication. The two threaded fixation pins were responsible for maintaining femur length and rotational stability of the femur. As such, the bone–pin interfaces were under considerable stress, and this probably led to early loosening of the implants. Additional half-pins in each fracture fragment could have been used to distribute weight-bearing forces more evenly and may have decreased or prevented pin loosening.




# Case study 3

## Clinical presentation, history, and fracture

A 9-year-old, 30-kg, intact, male Irish Setter sustained an unknown trauma after being lost for several hours. The dog was observed to be lame and nonweight bearing on the right hind limb. The fracture was a closed, short oblique, midshaft femur fracture, caudally displaced. There were three or more small comminuted fragments and a radiographically visible fissure extending up the proximal diaphyseal fragment. The preoperative craniocaudal view was not of sufficient quality for publication.

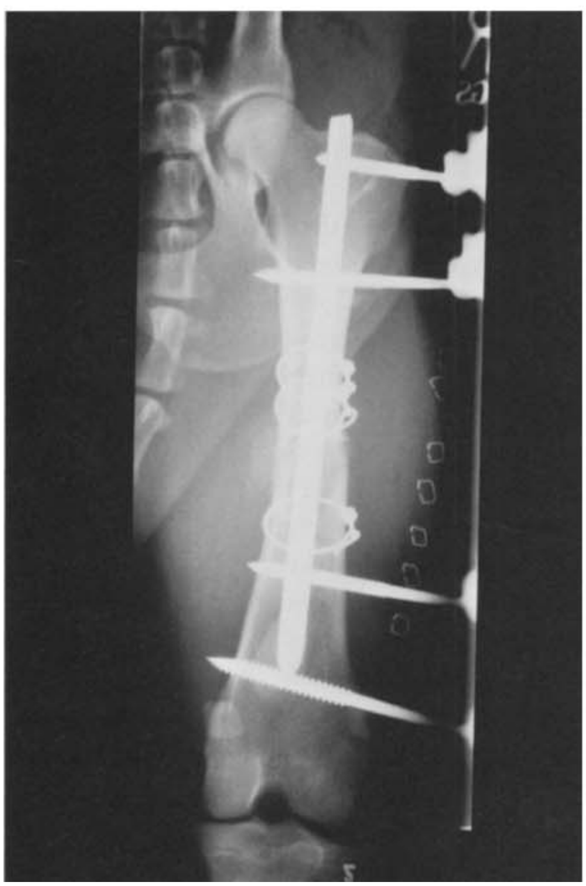
## Surgical planning

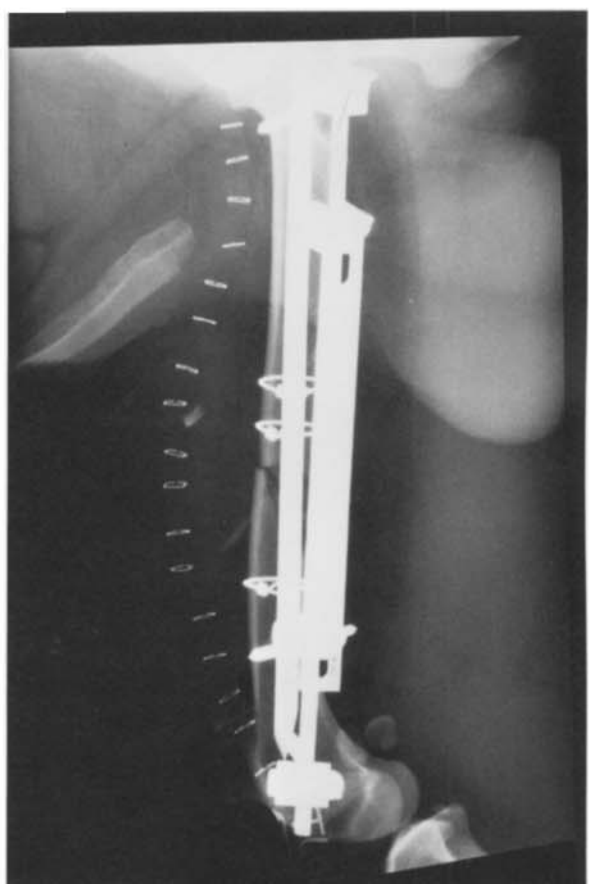
The patient was in a stable condition and was placed on intravenous fluids and pain medication. The options for surgical repair would include plate fixation. There is sufficient proximal and distal diaphyseal length to obtain appropriate screw purchase. The location of the proximal fissure is lateral and may have complicated placement of screws close to the fracture. The small comminuted fragments would have made complete reconstruction difficult, and the plate would have to be placed in buttress fashion. An intramedullary pin with a buttress plate could have also been used and would have been the best choice for this fracture. Cerclage wiring could have been employed to prevent propagation of the fissures, along with intramedullary pinning. However, the fracture was a short oblique fracture, preventing full cerclage wiring at the major fracture. This, along with the small comminutions, would have prevented sufficient rotational stability being achieved in this area. An external fixator could be added to cerclage wiring and intramedullary pinning to provide rotational stability.

## Fracture repair and evaluation

The fracture was repaired with open reduction. Two full cerclage wires were placed to reduce the fissure in the proximal diaphyseal fragment. A single full cerclage wire was placed in the distal diaphyseal fragment to prevent propagation of undetected fissures. An intramedullary pin was placed. A four-pin unilateral fixator was applied using predrilling and positive-profile threaded pins. An augmentation bar was added to the unilateral fixator to increase stiffness.

Postoperative radiographs demonstrated good alignment and apposition of the fracture. The proximal cerclage wires appear appropriate. At least two cerclage wires should have been placed in the distal fragment even





though no fissures were noted during surgery. The intramedullary pin is of appropriate size. It appears that it could have been seated more distally. The proximal fixator pin does not engage the entire metaphysis but only the greater trochanter. The other three pins are placed appropriately.

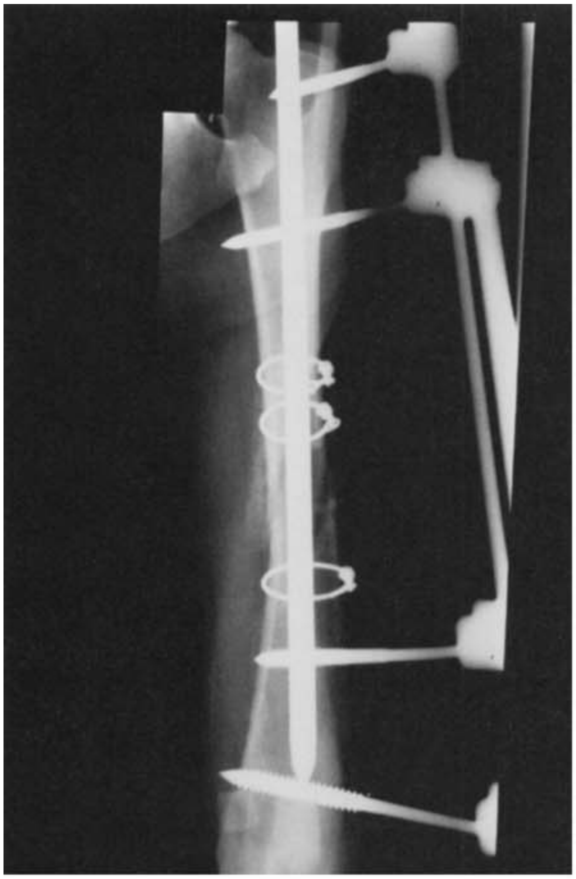
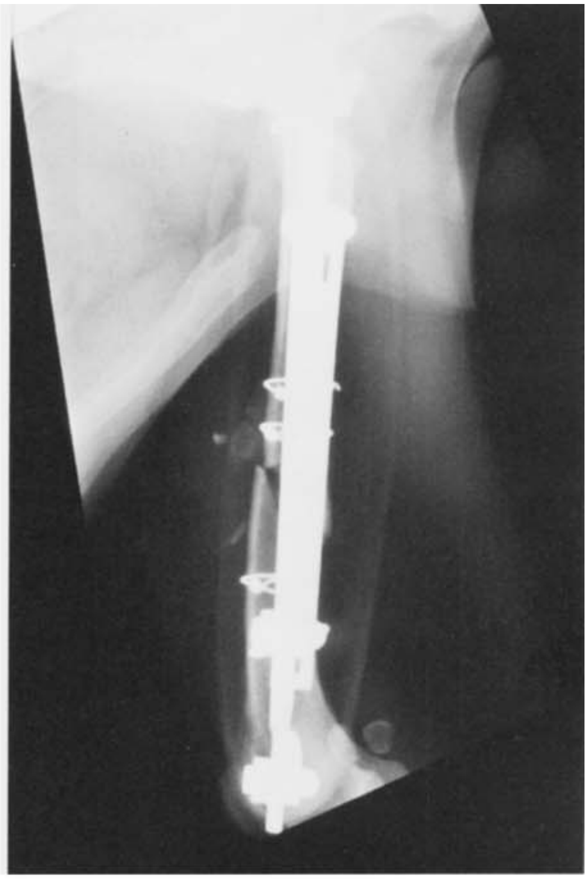
The use of external fixation in the femur poses several difficulties. There is relatively low stiffness of these fixators, primarily because of the long length of fixation pin from the connecting column to the bone needed to traverse soft tissues. Pins can often interfere with soft tissues at the stifle, where movement can result in pin site morbidity, specifically minor pin tract infection (see Chapter 12).

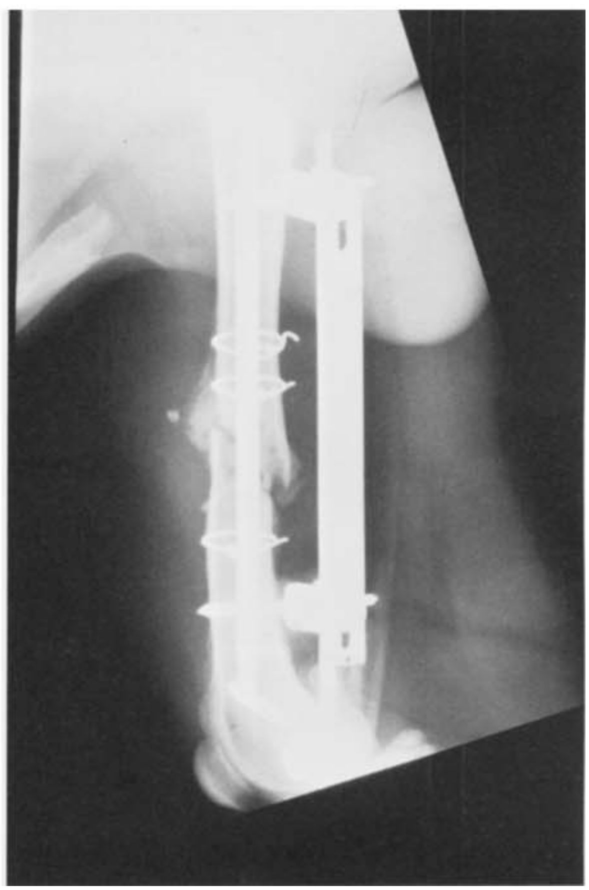
## Follow-up evaluation

The dog was re-presented at 4 weeks. The dog had been using the limb but with a severe lameness. There were minor pin tract infections at the pin sites and decreased range of motion at the stifle. There was pain associated with palpation at the proximal pin site. Radiographs showed that alignment and apposition had been maintained. The most proximal pin showed loosening. There was early callus formation at the fracture site, demonstrating appropriate secondary bone healing. The proximal pin was removed because of the loosening. Replacing the proximal pin at this time would have led to greater rigidity of the fixator. Physical therapy, including leash walks and passive range of motion of the stifle joint, was initiated.

## Second follow-up evaluation

The patient was presented for re-evaluation at 7 weeks postoperatively. His lameness had improved, but he still had a weight-bearing lameness. Range of motion of the stifle had improved. There were minor pin tract infections at the remaining three pin sites. Radiographs showed that alignment and apposition had been maintained. All orthopedic implants were stable and unchanged from previous radiographic evaluations. There was no loosening of the remaining three external fixation pins. There was increased callus formation at the fracture site that appeared to bridge the fracture at the cranial, caudal, and lateral aspects of the femur. The fixator was removed. Physical therapy was continued and leash walks were slowly increased over the next 4 weeks, followed by return to normal activity. An additional radiographic evaluation after 3 weeks was recommended but declined by the owner.



# Case study 4

## Clinical presentation, history, and fracture

A 4-month-old, 15-kg Labrador retriever sustained a left femur fracture falling from a bed. The fracture was a closed, distal, fourth transverse diaphyseal fracture displaced caudally and laterally and not overriding. There were two or more small comminutions.

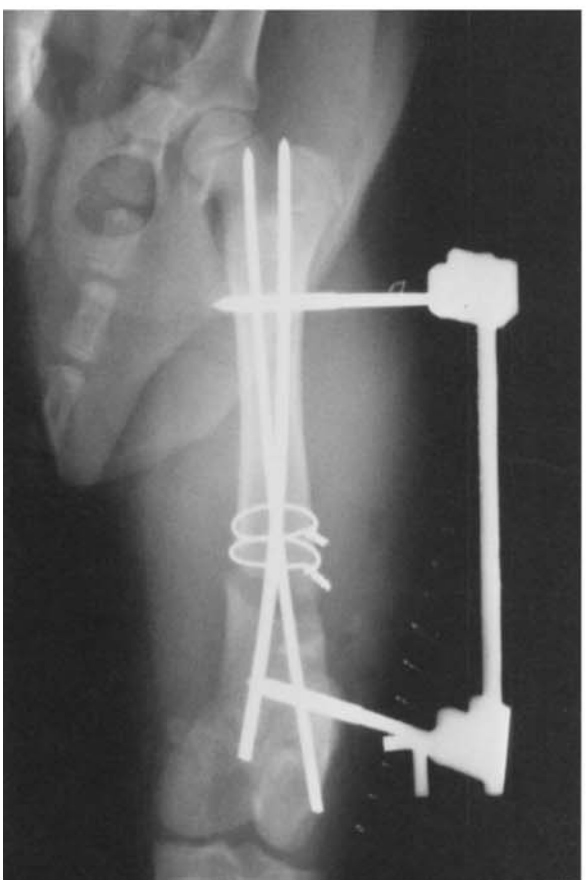
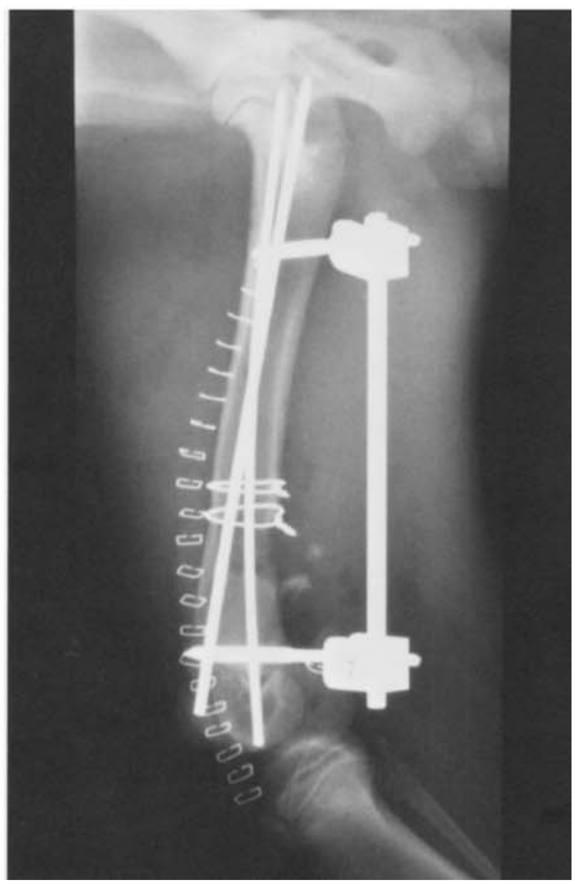
## Surgical planning

This fracture was caused by a relatively low-energy trauma in a juvenile dog. Fracture repair must allow continued growth and consider the softness of juvenile bone. Plate fixation could be considered; however, screw pullout strength would be low because of the soft bone. The plate should not cross the physis. Pin and wire fixation should be considered, but standard intramedullary pinning techniques may not counter bending forces because the fracture was very distal. An interlocking nail could be considered, but the distal fragment may not allow placement of two screws. Cross-pinning or modified rush pinning, as used in more commonly occurring Salter fractures in juvenile dogs, could be employed. Pinning techniques for Salter I or II fractures of the distal femur provide rotational stability as a result of the conformation of the physis and location of the pins across the fracture. This fracture is essentially transverse and is at the junction between the diaphysis and metaphysis. In addition, there were small comminutions. Pins may not provide rotational support. Modified Rush pinning with a unilateral fixator for rotational support was chosen.

## Fracture repair and evaluation

The fracture was repaired with two full cerclage wires placed because of fissures noted during surgery. Steinmann pins were placed like Rush pins from the distal epiphysis and seated in the proximal epiphysis. A two-pin unilateral external fixator was applied for rotational support. The alignment was good. Fracture gaps were noted caudally and medially as a result of loss of comminuted bone fragments. The Steinmann pins placed in Rush fashion crossed close to the fracture line. The proximal external



fixation pin could have been placed more proximally, and additional fixation pins could have been placed in both the proximal and distal fragment to provide additional support.

## Follow-up evaluation

The dog was presented 5 weeks postoperatively. He had been weight bearing with some drainage occurring from the distal pin site. The drainage had increased during the week prior to presentation. Radiographs showed callus formation across the fracture as well as the adjacent bone. There was a distinct lucency around the distal pin, indicating loosening of that pin. The fixator was removed and the patient discharged with instructions for passive range of motion physical therapy for that stifle.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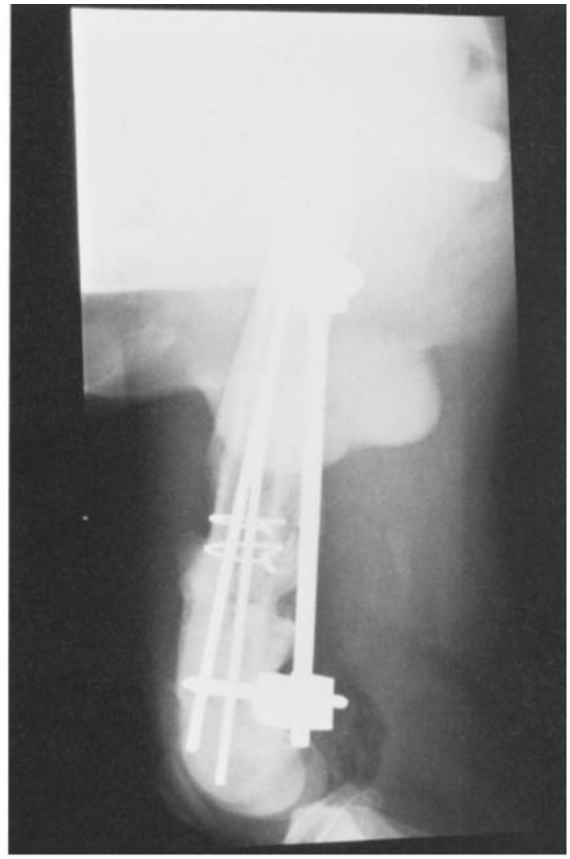


# Transarticular

# Case study 1

## Clinical presentation, history, and fracture

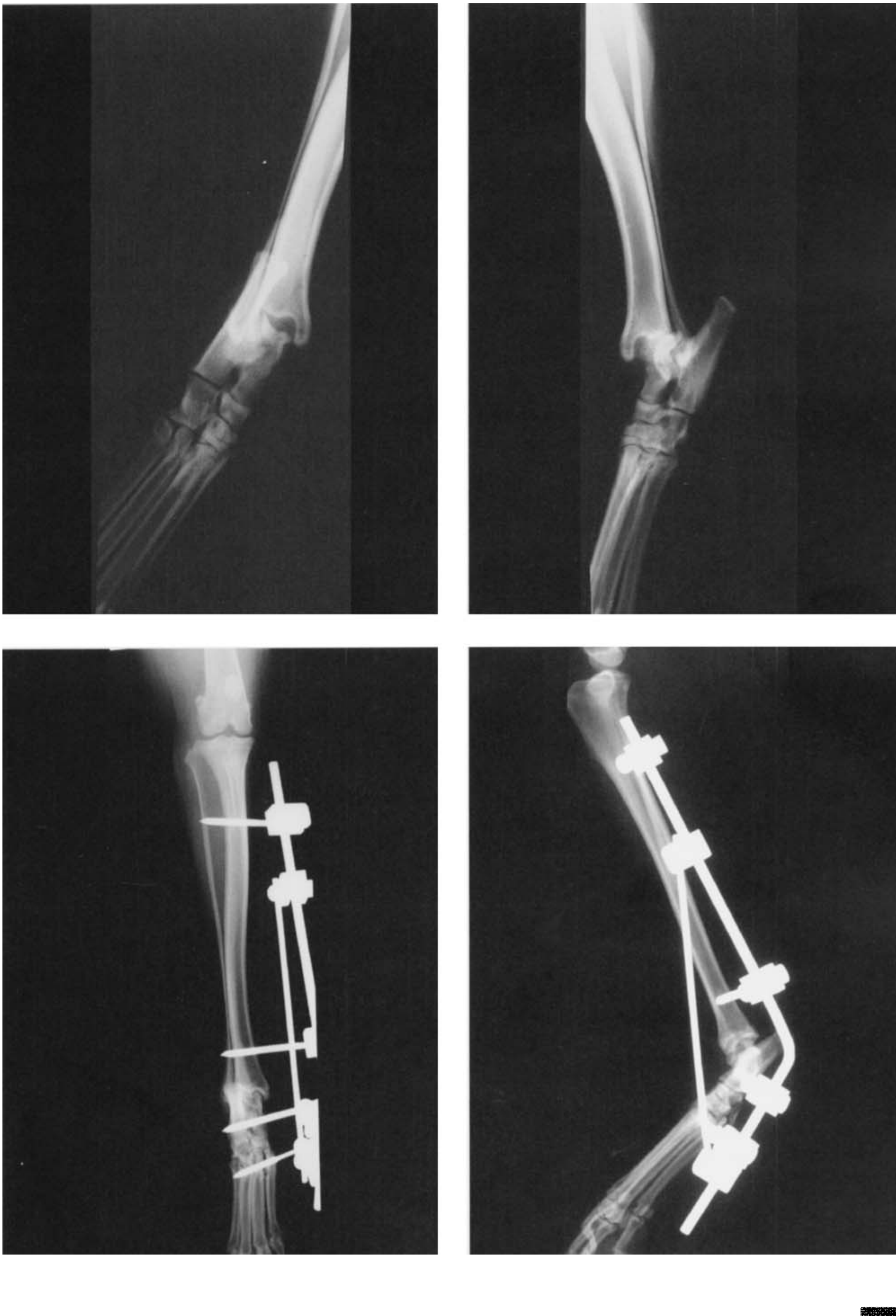
A 4-year-old, 15-kg, spayed, female, mix-breed dog sustained multiple traumas following a motor vehicle accident. The dog was presented to an emergency clinic, where she was treated for pleural effusion, pneumothorax, pneumomediastinum, and premature ventricular contractions. A left ulna fracture and left tarsal luxation were treated with splints. The dog was presented to the referral hospital 4 days later. Thoracic pathology was resolving and the patient was in a stable condition. Radiographs of the left ulna revealed a closed oblique articular fracture of the left ulna involving the proximal ulna and the semilunar notch. The proximal fragment was slightly displaced caudally. Stress views of the left tarsus revealed the medial aspect of the joint to be luxated, resulting in caudomedial displacement of the distal segment. On palpation, both long and short components of the medial tibial tarsal joint were deficient while the lateral collateral ligaments were intact.

## Surgical planning

The articular ulna fracture was repaired with open reduction and internal fixation with a dynamic compression plate. Splint or cast fixation was not chosen because this would increase stress on the joint and the patient would need to bear more weight on that joint as a result of the ulna fracture. Lack of rigid fixation could result in increased joint laxity. The tarsal luxation could be repaired with screws, and wire or suture to stabilize both long and short components of the medial collateral ligaments. Alternatively, the joint could be stabilized with a transarticular fixator. A unilateral fixator could be used to stabilize the medial aspect of the joint as the lateral collateral ligaments were intact.

## Fracture repair and evaluation

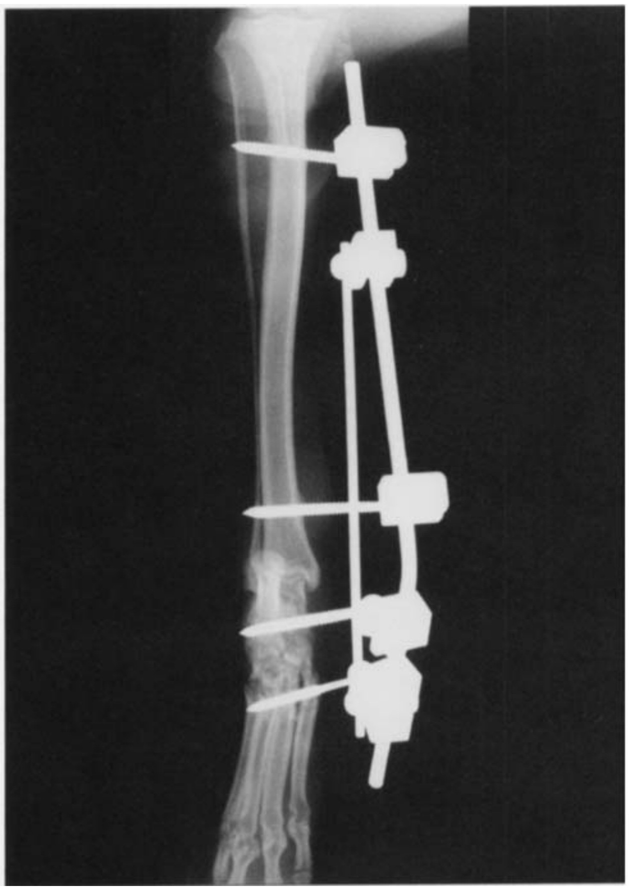
The luxation was repaired with a lateral unilateral fixator. An approach to the joint was made to assure adequate reduction of the luxation. One positive-profile 3.2-mm pin was placed in the distal tibia and another was passed into the talus and calcaneus. A bent connecting rod was used to connect these two pins. The luxation was reduced and these clamps tightened. A 3.2-mm positive-profile threaded half-pin was placed in the proximal tibia and a 2.4-mm positive-profile threaded pin was placed across the proximal metatarsals. An additional 3.2-mm connecting bar was placed between the proximal two fixation pins in the tibia and distal

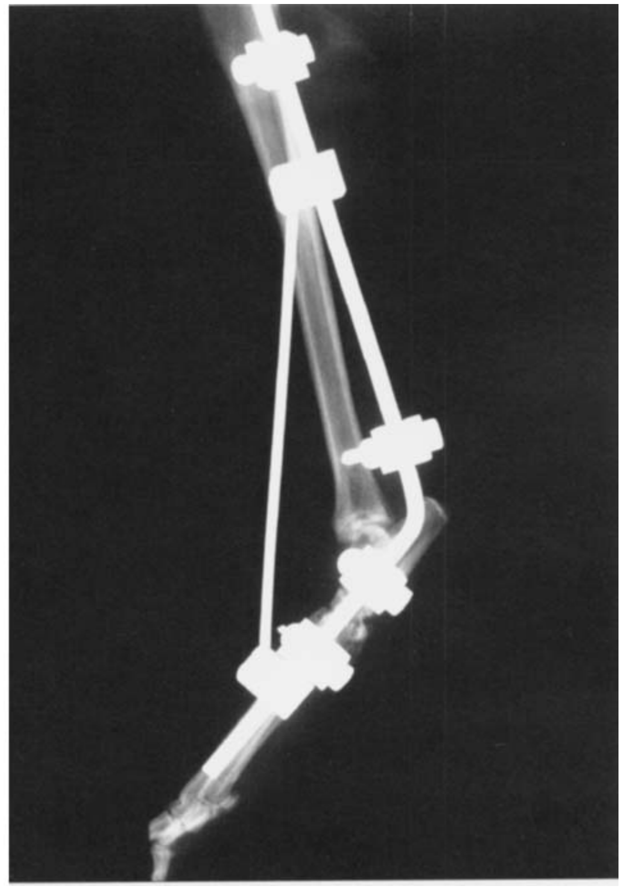


to the metatarsal fixation pin using single clamps. The alignment and apposition of the tarsal joints was adequate. The fixator apparatus was sufficient for this weight of dog, in this application.

## Follow-up evaluation

The dog was ambulatory soon after surgical stabilization of the fracture and luxation. Physical therapy was performed three times a day on the left elbow. The dog fell down a flight of stairs 10 days following discharge, and radiographs at that time demonstrated no change to the apparatus of either the ulnar or tarsal implants. The dog was evaluated 4 weeks later. Although it had been ambulating well, lameness had increased over the last week on the left caudal limb. There was mild discharge and swelling at the proximal pin site. Radiographs demonstrated continued reduction of the luxation. The proximal tibial fixation pin was loose. The fixator was removed and the tarsal joint was stable on palpation. The tarsal joint exhibited a decreased range of motion. The dog was discharged with 2 additional weeks of exercise restriction and returned to normal activity.





# Case study 2

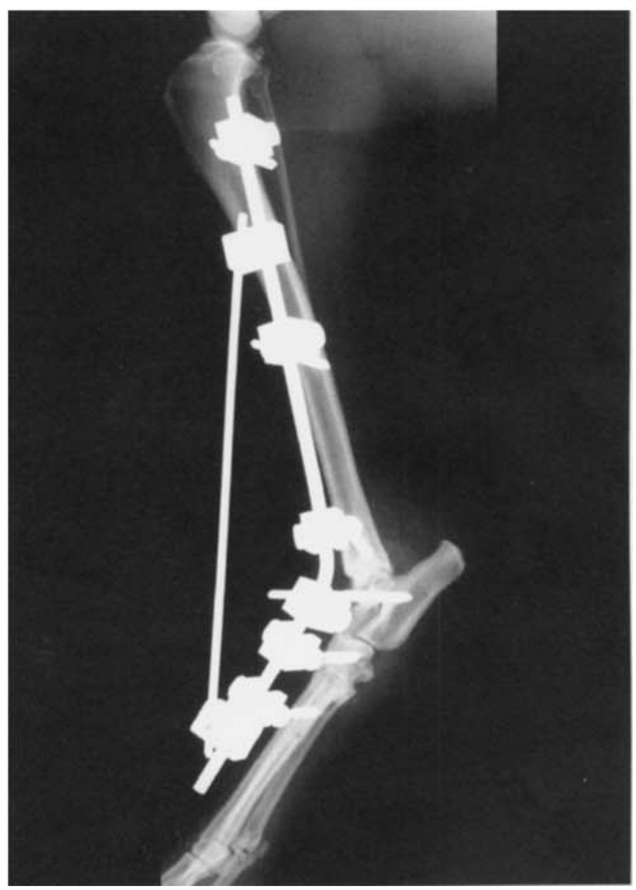
## Clinical presentation, history, and fracture

A 2-year-old, 25-kg, intact, male German Shepherd was absent from the owner's care and returned later that day nonweight bearing on the left caudal limb. The dog had sustained a degloving and shearing wound to the left metatarsus and digits. The left upper canine tooth was fractured. Once stabilized, the wound was debrided, lavaged, and placed in a wet-to-dry Robert Jones bandage. There was a 7 × 15 cm loss of soft tissue on the craniolateral aspect of the limb centered on the metatarsus. Although the wound was primarily over the cranial and craniolateral metatarsal area, there was structural loss of both the long and short components of the medial collateral ligaments of the tibial tarsal joint, with mostly preserved lateral collateral ligament support. Radiographs showed that bone loss was minimal. Preoperative craniocaudal radiographs were of insufficient quality to print.

## Surgical planning

A vital pulpotomy was performed on the fractured canine. As soon as the patient was stable, the wound was surgically debrided and lavaged. The damaged limb was placed in a Robert Jones bandage, which was changed daily for 3 days. The tibiotarsal luxation could be stabilized with screws and suture or wire repair of the short and long components of the tibiotarsal joint. However, there would be communication with the open wound, and these implants often need to be removed. External support with a cast or splint could be used, but the joint would be unstable during frequent bandage changes. Achieving adequate joint stability would be less likely. External fixation could be used to stabilize the tibiotarsal joint. The external fixator would stabilize the joint during wound healing. The wound should be allowed to heal by secondary wound healing, enabling supportive structures to re-form in the wound scar via granulation, fibrosis, and maturation. The prognosis for functional recovery would be good, though some arthritis would be expected and an arthrodesis may be needed in the future.

Either a bilateral or unilateral fixator could be employed. As the lateral collateral ligaments were intact, a medial unilateral fixator could be used to support the medial joint and would share support with those lateral structures.

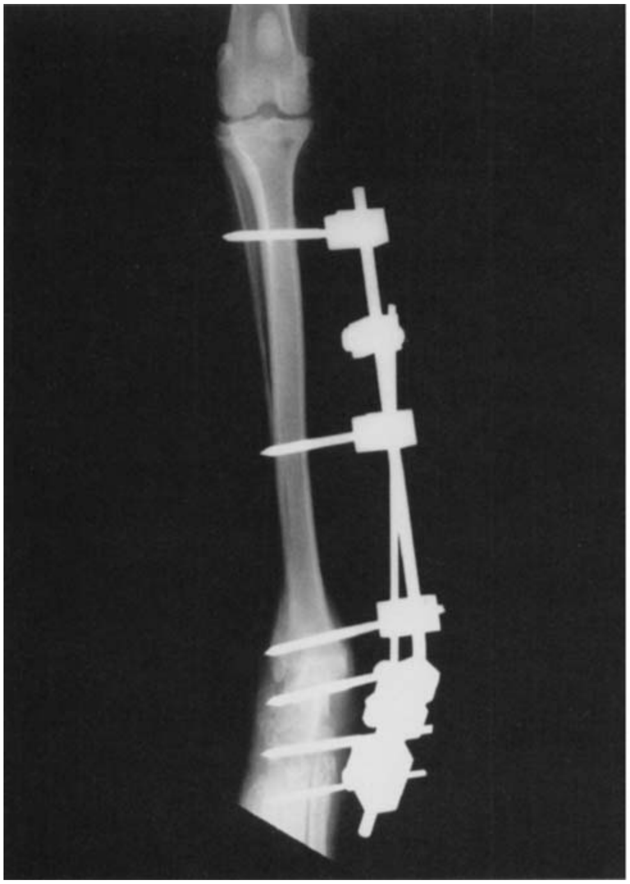


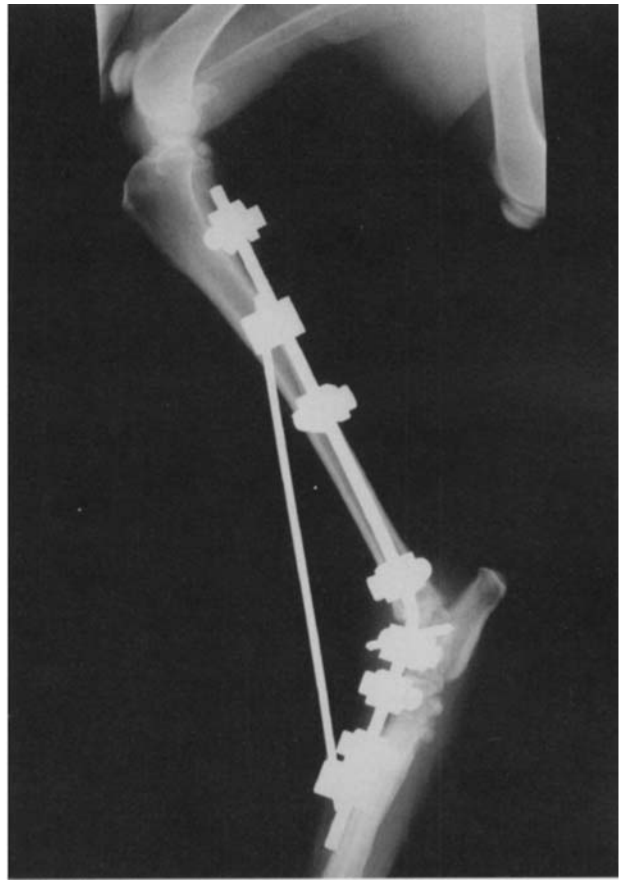
## Fracture repair and evaluation

The fracture–luxation was repaired with a medial unilateral fixator. One positive-profile 3.2-mm pin was placed in the distal tibia and another passed into the talus and calcaneus. A bent connecting rod was used to connect these two pins. The luxation was reduced and the clamps tightened, making sure that the proximal and distal ends of the connecting rod approximated the tibia and metatarsus. A 3.2-mm positive-profile threaded pin was placed in the proximal tibia and a 2.4-mm positive-profile threaded pin placed across the proximal metatarsals. Additional 3.2-mm positive-profile threaded pins were placed in the diaphysis of the tibia and the central row of tarsal bones. An additional 3.2-mm connecting bar was placed between the proximal two fixation pins and distal to the metatarsal fixation pin using single clamps. The alignment and apposition of the tarsal joints were adequate. The fixator apparatus was sufficient for this weight of dog.

## Follow-up evaluation

The wound was treated with daily bandage changes until granulated, then every 2–4 days with a nonadherent dressing to provide moist wound healing. The dog was weight bearing with a mild lameness. At 6 weeks the patient was readmitted for evaluation. The wound was reduced to a 1 × 6 cm strip of granulation tissue. Radiographs showed that the alignment and apposition of the fracture–luxation had not changed. The position of fixator had not changed, but there was loosening of the tarsal and metatarsal fixation pins. There was new bone formation on the cranial and craniolateral tarsal bones, with bone bridging the intertarsal and tarsometatarsal joints. There was radiographic evidence of tibiotarsal osteoarthritis. The fixator was removed. The dog returned to activity with mild lameness.





# Case study 3

## Clinical presentation, history, and fracture

A 5-year-old, 33-kg, spayed, female, mix-breed dog was probably involved in a motor vehicle accident while absent from the owner's care for several hours. The dog returned ambulatory on three legs with several abrasions on the left caudal limb. On presentation, she was tachycardic and tachypneic. The dog was administered intravenous fluids. Thoracic radiographs were within normal limits. The limb was clipped, wounds were debrided and lavaged, and the leg was placed in a wet-to-dry Robert Jones bandage. The wounds were found to communicate with the fracture. The fracture was a grade I open, comminuted, distal left tibia fracture. There was one relatively large (2 × 3 cm) and several small comminutions. The distal metaphyseal segment of the tibia had only 1 cm of medial cortical bone. The fracture was displaced laterally and was overriding by 0.5 cm.

## Surgical planning

This fracture was not amenable to casting because it was open and comminuted. An intramedullary pin would not counter bending forces because the fracture was very distal. Open reduction and internal fixation with a bone plate would not allow an adequate number of cortices to be engaged because of the small distal tibia fragment. An adequate number of fixation pins could not engage the small distal tibia segment if an external fixator were applied to the tibia alone. A transarticular external fixator could be applied across the tarsus to stabilize the limb. Although lengthy immobilization of the tarsus would result in decreased range of motion of this joint, it should allow the fracture to heal.

## Fracture repair and evaluation

The fracture was repaired with a bilateral fixator. Reduction was achieved with a hanging limb preparation. A limited approach was made to the distal tibia to assure adequate alignment. A longitudinal fissure was seen extending up the diaphysis of the tibia and was secured with cerclage wires. A 3.2-mm positive-profile threaded full pin was placed across the distal tibia with visualization of the fracture through the limited approach to assure adequate purchase of the small distal segment. A second full pin was placed across the proximal tibia. These two fixation pins were connected medially and laterally with long fixation bars that extended past the tarsus. The fracture was aligned and fixation clamps tightened. Two additional fixation pins were applied to the diaphysis of the tibia with an aiming tool. The connecting bars extending past the tarsus were bent using a plate-bending iron to follow the contour of the distal limb. A 3.2-mm positive-profile threaded full pin was placed through the proximal metatarsal bones. Two additional 2.4-mm positive-profile half-pins were placed into the metatarsal bones.

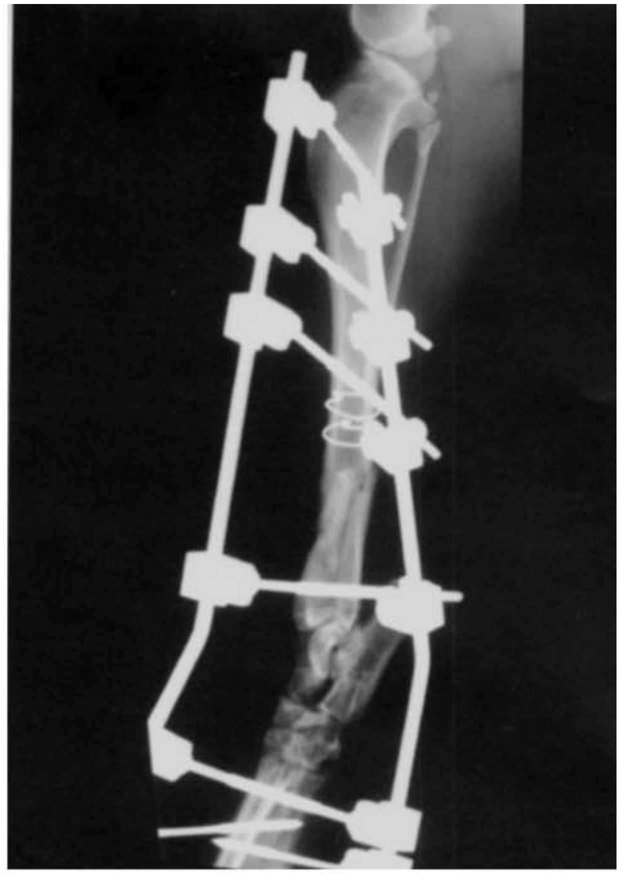
Fracture alignment was adequate. There were fracture gaps as a result of the large comminuted fracture fragment displacing into the medullary cavity of the distal tibia. The fixator stabilized the fracture in medial to lateral bending. The single fixation pin in the distal tibia would allow this segment to rotate around this fixation pin, therefore cranial to caudal bending forces were not fully countered. The stress risers at the bends in the connecting bars were not supported, with a triangular bar connecting the proximal and distal ends of the connecting bars. This could lead to breaking of the connecting rods if bending forces were great enough to cycle the relatively small 4.8-mm bars.

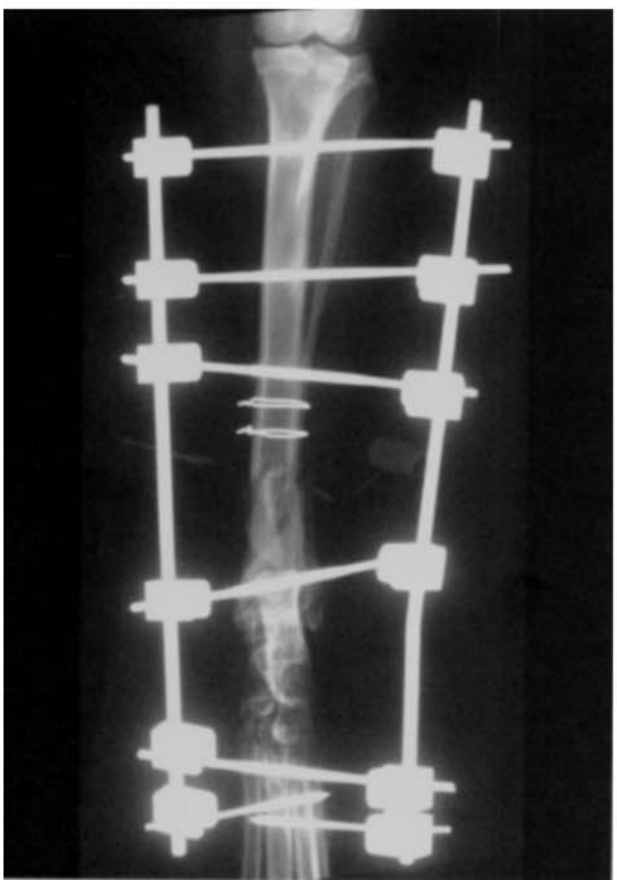
## Follow-up evaluation

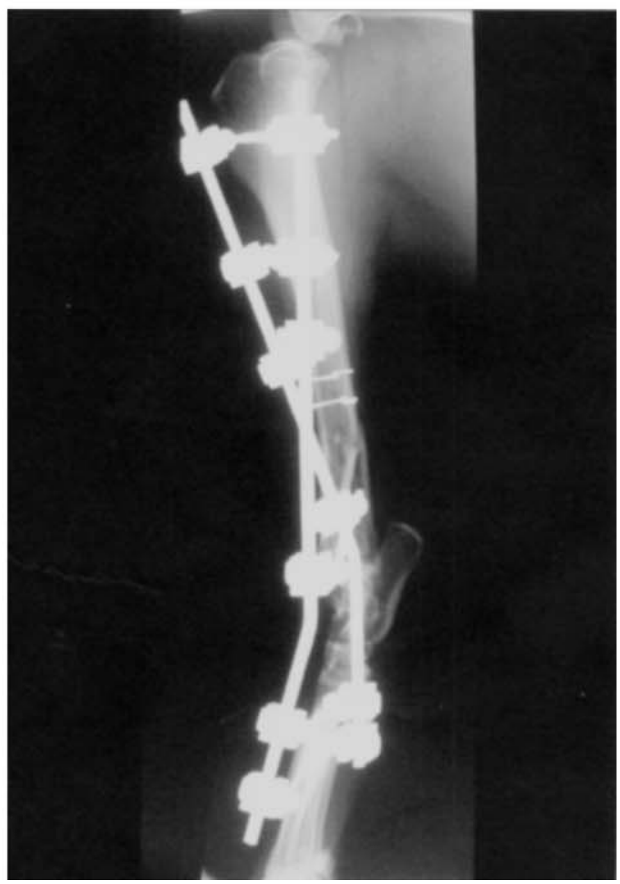
At the 10-week follow-up the dog was re-presented for evaluation. The patient had been using the limb well and wounds were healed. The pin sites showed no complications. Radiographs demonstrated that alignment had been maintained. The fixation was intact and there was no pin loosening. There was minimal smooth callus crossing the fracture on all aspects. The lack of a more substantial callus suggested minimal motion of the fracture fragments. No alterations to the fixator were made as the fracture was healing and the dog was ambulating well.

## Second follow-up evaluation

At 14 weeks the patient was re-evaluated. The dog had been walking well and there were no pin site complications. Radiographs demonstrated maintained limb alignment and fragment apposition. The position of the fixator was unchanged and there was no pin loosening. Progressive remodeling was seen on radiographs, with continuity of cortex on all aspects of the fracture. The fixator was removed. The tarsal joint had 20° of motion. The dog was discharged with instructions for confinement and leash walks for an additional 3 weeks. The dog returned to normal activity without complication. The decision to completely remove the fixator was controversial. Although there was smooth bridging callus, complete restoration of the distal tibial cortices was not observed. As the range of motion of the tarsal joint was reduced, weight bearing could result in increased cranial to caudal bending at the remodeling fracture site. An alternative plan would be to remove the parts of the fixator distal to the tarsus. This would allow bending at the tarsal joint, increasing the range of motion. The remaining parts of the fixator would protect the fracture site to some degree as the fracture continued to remodel.







# Case study 4

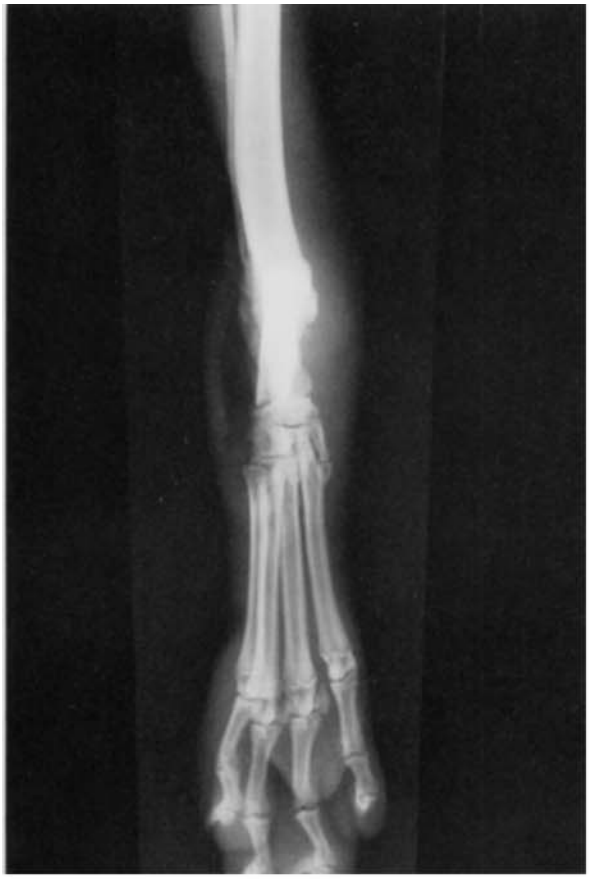
## Clinical presentation, history, and fracture

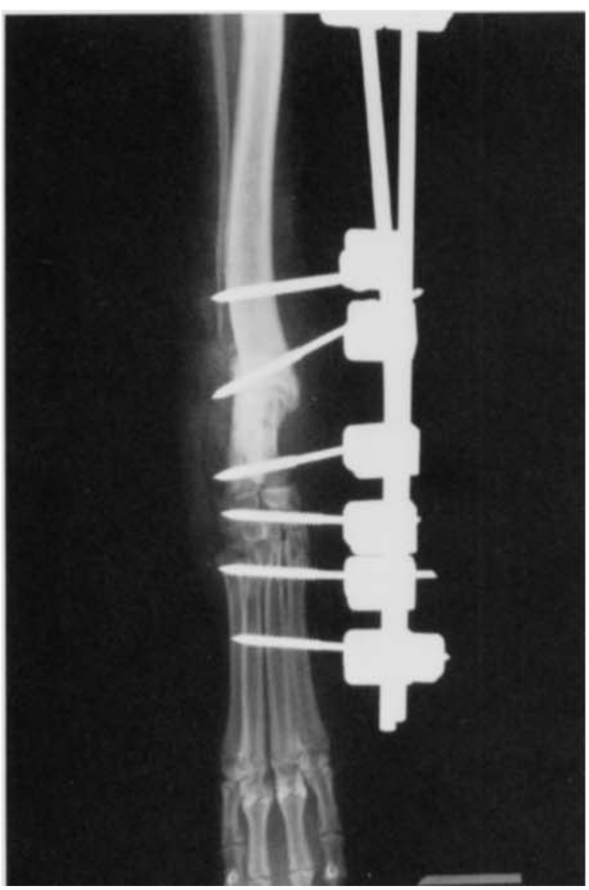
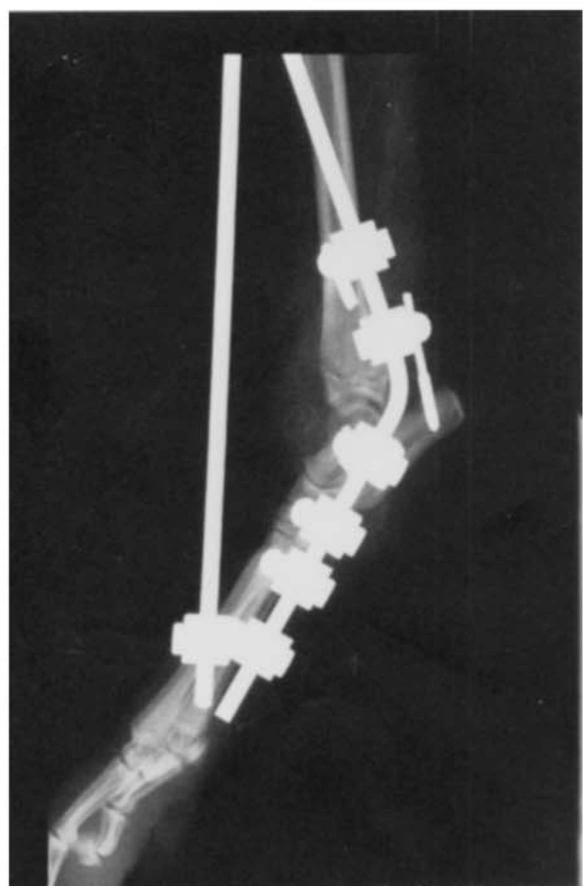
A 9-month-old, 18-kg, female Labrador Retriever cross sustained a degloving and shearing wound to the right hock during a motor vehicle accident. She was in respiratory distress and thoracic radiographs showed a pneumothorax. A thoracocentesis was performed and she was stabilized with intravenous fluids and pain medication. Once stabilized, the wound was debrided, lavaged, and placed in a wet-to-dry Robert Jones bandage. There was a 7 × 15 cm loss of soft tissue on the craniolateral aspect of the limb centered on the tarsus. Radiographs showed loss of portions of the lateral malleolus, the lateral aspect of the distal tibial metaphysis, the calcaneus, the tallus, and the fourth tarsal bones. A stressed lateral radiograph (not shown) demonstrated instability of the tarsocrural, proximal intertarsal, and talocalcaneal joints.

## Surgical planning

As soon as the patient is stable, it is important to surgically debride and lavage this wound. The limb should be placed in a wet-to-dry Robert Jones bandage that is changed daily, or more often if needed. External fixation offers a unique method of stabilization for these fracture–luxations. As bone and soft-tissue loss is extensive, primary repair of ligamentous structures is impossible. The external fixator stabilizes the joint during wound healing. The wound is left to heal by second intention, allowing a supportive structure to reform in the wound scar via granulation, fibrosis, and maturation. Skin closure occurs by contraction. In many instances, even large wounds can heal by second intention. Occasionally, a secondary skin grafting procedure must be performed once granulation tissue has formed. Functional recovery is good to excellent in most cases depending on the degree of joint trauma. If joint damage is severe, immediate arthrodesis can be performed at the time of initial stabilization.

The mechanics of transarticular external fixators are different from those for long bones. With long bone fixators, primary forces are axial, along the long axis of the bone. Transarticular fixators result in a bend within the fixator, concentrating forces at the bend. They also result in a long lever arm, concentrating forces at the top of the fixator. Strategies to support the fixator at the bend include attaching the proximal and distal fixator pin with an additional connecting bar, making a triangular shape to the connecting column. The fixator must extend to the proximal aspect of the adjacent bones to prevent concentrating forces within the diaphysis, which will predispose the bone to fracture. Bilateral fixators are preferred to unilateral fixators if the fixation pins can be brought out through skin on either side of the limb. If the wound will not allow this, unilateral fixators can be placed as pins exiting the wound can complicate wound healing.



## Fracture repair and evaluation

The fracture–luxation was repaired with a unilateral fixator and immediate arthrodesis. The articular cartilage was removed with a high-speed burr. Positive-profile 3.2-mm pins were placed in the proximal and distal tibia, calcaneus, calcaneus and tallus, the distal row of tarsal bones, and the proximal metatarsal bones. A 2.4-mm pin was placed through the diaphyses of the metatarsal bones. An additional connecting bar was placed between the most proximal and most distal fixation pins using single clamps. An autogenous cancellous bone graft was taken from the proximal humerus and applied to the tibiotarsal joint. The alignment and apposition of the tarsal joints was adequate. The fixator apparatus was sufficient for a dog of this weight.

## Follow-up evaluation

The wound was treated with daily bandage changes until granulated, then every 2–4 days with a nonadherent dressing to provide moist wound healing. The dog was weight bearing with a mild lameness. At 5 weeks the patient was readmitted for skin grafting as the wound had stopped contracting. Radiographs showed that the alignment and apposition of the fracture–luxation had not changed. The position of the fixator had not changed and there was no pin loosening. Callus bridged the tibiotarsal joint. Skin grafting was performed using a partially expanded free mesh graft. The fixator was removed 2 weeks later. Mild lameness consistent with a tarsal arthrodesis was present, but the dog did not appear to be in pain.

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