Bone Anatomy

IN THE MATURE DOG

The proximal femur is formed by the femoral head, femoral neck, and the greater and lesser trochanters. Several angles are present that are of importance. The femoral head and neck meet the femoral shaft and form the neck-shaft angle. In the normal dog this angle is approximately 130° if measured by conventional means, or 146° if measured by the technique of Hauptman. (27) Both techniques are applicable; however, the first method is more commonly used.

Variation from a normal neck-shaft angle may reflect anatomical variation or disease of natural or acquired origin. A decreased angle is termed coxa vara. In a varus position the femoral head tends to seat more deeply into the acetabulum and the hip remains very stable. An increased neck-shaft angle is termed coxa valga. A valgus hip tends to allow poor contact with the dorsal acetabulum and subluxation or luxation may result (Fig. 29-1).

The femoral head and neck also have a specific relationship to the acetabulum in a cranial-caudal dimension. The normal femoral neck inclines cranially approximately 24°. (45) This is termed the angle of anteversion. If the angle is greatly increased, the hip may subluxate cranially. If the angle is considerably less than normal or approaching 0°, the hip still remains stable. However, if the angle begins to retrovert, incline caudally, subluxation caudally may occur. The angle of anteversion is measured in one of two methods. The direct measurement following image intensification is the most accurate; however, it can also be determined using the trigonometric charts applied to neck-shaft angle. (27,46) Increased angles of anteversion are misleading and appear on a standard ventral-dorsal view of the hips to result in a short femoral neck and a valgus hip.

For many years the degree of femoral neck anteversion has been recognized in humans as an important clinical entity. In 1915 a radiographic method of determining femoral neck anteversion in congenital hip luxation of children was described. (13) Since then additional clinical and radiographic techniques have been described for such measurement. (12,15,30,50)
Methods of clinical assessment have been unreliable in humans. Direct and indirect radiographic techniques of measurement have been the most accurate. The indirect radiographic techniques use one or two projections of the femur, from which anteversion is calculated by geometric equations.(41) This technique is theoretically precise but subject to many errors of radiographic positioning.(5,30) Without tomography, the radiographic techniques, while accurate, require excessive exposure of the patient to radiation and usually necessitate hip arthrography(15,38,41) With tomography, radiography has been used in humans to produce accurate measurements of femoral neck anteversion.(30) Its use, however, has been limited because it requires expensive and complex equipment. (19)

The normal angle of femoral neck anteversion in humans is 5¡ to 15¡ (18,23) Human infants with congenital hip luxations have anteversion angles of 33¡ to 84¡.(43)These angles have been associated with hip subluxation(2,9,59)

Another anatomical feature of the proximal femur is the heavy cortex of the ventral femoral neck. This heavy cortex is termed the calcar femorius and is a functional adaptation to help transfer weight-bearing forces from the femoral head to the medial cortex of the femoral shaft.(20) The femoral shaft of the mature dog tapers to a midshaft isthmus and then flares to the distal metaphysis. The normal diaphysis is curved, with the convex surface cranially. The distal femur is composed of the two condyles, which articulate with the tibial plateau via the menisci. The cranial articulating surface, the trochlea, articulates with the patella (Fig. 29-2, A-D).

IN THE MATURE CAT
The normal femoral anatomy of the cat mimics that of the dog (Fig. 29-2, E). The one difference involves the femoral diaphysis. The feline femoral shaft is virtually straight and has no real isthmus. It is assumed that feline femoral neck anteversion is similar to that of the dog; however, this has not been documented.

IN THE IMMATURE DOG OR CAT
The immature animal has three femoral epiphyses of significance. The capital epiphysis sits upon the femoral neck. The growth plate forms a 120¡ angle that truly allows the epiphysis to sit upon the neck. Premature cessation of growth of this epiphysis with concurrent growth of the greater trochanteric epiphysis can result in genu varus.

The greater trochanteric epiphysis begins confluent with the capital epiphysis. With advancing maturity it separates and remains separate. The growth plate is L-shaped and courses cranially and laterally around the lateral proximal femur. The epiphysis sits above the metaphysis. Premature cessation of growth with continued growth of the femoral head and neck in this epiphysis may result in genu valgus.

The distal femoral epiphysis forms the femoral condyles and trochlea. The epiphysis possesses four diamond-shaped depressions in its dorsal surface, which match four similarly shaped projections on the metaphysis. This anatomical feature makes reduction of fractures through this growth plate very stable. Premature cessation of growth from this epiphysis may result in femoral shortening or bowing if the closure is asymmetric (Fig. 29-3).
BLOOD SUPPLY TO THE FEMORAL SHAFT
In the mature dog or cat the major diaphyseal artery enters the bone in the proximal one-third on the caudal side of the shaft. It is a branch of the medial circumflex femoral artery. The immature dog or cat has a significant diaphyseal blood supply from vessels in the adductor muscle along the caudal surface of the diaphysis.(43)

HISTORICAL TREATMENT OF FEMORAL FRACTURES
A lack of other methods for treatment of femoral fractures resulted in confinement or cage rest as the only available treatment until the 1920s. Fortunately for most small animals, the technique was highly successful. Because this period predated radiography as a method of documenting fracture positions, veterinarians were unaware of the degree of malposition, comminution, or overriding. Owing to the heavy thigh musculature, which generally became swollen following fractures, a form of physiologic immobilization was produced; because of adequate blood supply to this bone, most bones healed. Certainly limbs shortened and all degrees of malunion occurred, but animals walked and used the limbs. The functional end result was considered a success at that time.

Prior to the 1930s open surgery was an unlikely choice of treatment because neither aseptic surgical technique nor antibiotics were in existence. The absence of these two factors, so critical to successful open surgery, led to more sophisticated types of external fixation for femoral fractures. These external splints and casts allowed better bone fragment alignment and immobilization.

Plaster of Paris casts were often suggested for fixation. Most were applied from the toes of the foot up the limb and over the back forming a spica. This method of fixation was certainly adequate if alignment had been attained. To help with alignment, bony fragments were often angled or wedged with pads made of oakum. Occasionally fragment alignment or contact was ensured via a small incision to wire bone ends together with silver or copper wire, then the plaster cast was applied(26)

As asepsis of instruments and skin became common knowledge, many types of semi-invasive methods were used in femoral fractures. The more widespread use of radiography by the 1930s also improved fracture reduction. In 1931 Dibbell(11) suggested wire traction tongs in the distal femoral fragment to provide true skeletal traction and better reduction. This technique had become popular in human orthopaedics during World War I. After aseptically inserting the tongs, distraction was applied hopefully to reduce the fracture and was maintained while a cast or splint was applied. Eventually the tongs were incorporated into the cast to maintain traction. Results were gratifying.

In 1933 Schroeder(52,53) began describing his modification of the Thomas splint, a human extension splint. His device became known as a Schroeder-Thomas splint and was used to keep traction of the femoral shaft fragments with skin traction, using tape or cotton bands. When reduction was insufficient, skeletal tongs were used to improve bony alignment (Fig. 29-4).

In 1934 Ehmer(16) suggested returning to the idea of minimal fixation and simply accepting the shortening. He placed the limbs in a non-weight-bearing sling, which kept the fragments in adequate anatomical alignment although allowing shortening to occur. This permitted union with shortening but generally good results. He felt this required less technical skill than the use of casts or splints and could therefore be used successfully by a greater number of veterinarians. The Ehmer sling remains in use today, although the use has changed.

Another modification of these techniques, actually a forerunner to full-pin splintage, was advocated in 1934 by Stader.(54) He suggested aseptically placing Kirschner wires or chrome bicycle spokes through the lateral thigh muscles, through the femur, and out the medial thigh muscles. Three such pins were employed; two above the fracture site and one below, generally through the proximal tibia. After fracture reduction the limb was placed in a coaptation splint of wood or plaster with the pins incorporated into the splint or cast. His results were good and his technique was adapted by others.(14)
Full-pin splintage was adapted by Stader(55) into his half-pin device, the Stader splint. This device was introduced to veterinarians in 1939. It allowed for reduction and very rigid fixation of femoral shaft fractures. The added advantage was free use of the hip and knee in the dog or cat. The postoperative or postfracture return to function was hastened, since the joints did not become stiff in the Stader splint.

With the availability of antibiotics to veterinarians following World War II, more thought was given to open fracture reduction and the use of intramedullary fixatives. Since their first reported use by Kuntscher(37) in femora, the use of intramedullary pins and nails has been widely adapted for small animal practice. In 1946 and 1947 the use of pins and nails for femoral fractures appeared in the Swiss(33) and French(47) literature. In 1948 four(4,6,21,36) American authors advocated the use of intramedullary pins for femoral fractures, and in 1950 Jenny(34) described the use of the Kuntscher nail for dog femoral fractures. With the advent of solid intramedullary fixation, most animal femoral fractures could be treated successfully.

Another form of internal fixation for the femur was introduced in 1954 by Wolf.(61) It was the use of interfragmentary screw fixation for oblique femoral fractures. While bone screws and Lane bone plates had been around for many decades,(24) plates had not been used in long-bone fractures in small animals. The use of screw fixation was the first step, which then led to the modern technology of plate and screw fixation.

Veterinary surgeons developed these forms of fixation for femoral fractures over the brief period of 1920 to 1954. Since that time the methods have been refined, improved, and applied to other long bones. Today the veterinary orthopaedic surgeon can select from many forms of external fixation or internal fixation for treating fractures of the femur.

SURGICAL APPROACHES TO THE FEMUR
All aspects of the femoral shaft are relatively easy to expose surgically.(47) All require caudal retraction of the biceps femoris muscle and cranial retraction of the vastus lateralis muscle. Variations on this approach exist for special applications.

PROXIMAL FEMORAL FRACTURE OR SUBTROCHANTERIC FRACTURE
Following routine fascia lata incision, the biceps femoris should be retracted caudally and the vastus lateralis should be retracted cranially. Further proximal and medial exposure can be obtained by incision of the origin of the vastus lateralis. Very proximal medial exposure may require complete severance of the origin. Proximal caudal exposure is improved by adductor myotomy; however, this should be performed only when necessary.

MIDSHAFT FEMORAL EXPOSURE
In a routine lateral approach to the femoral shaft, the adductor may be severed where necessary; however, it should always be done minimally. The surgeon should be aware that a significant source of diaphyseal blood comes through the adductor insertion in the immature animal.

DISTAL FEMORAL SHAFT
Supracondylar fractures are approached adequately through a standard lateral approach to the femoral shaft coupled with a lateral approach to the stifle. This will allow for full visualization of both fracture components. Such an approach requires incision through the fascia lata and appropriate biceps and vastus lateralis retraction. The fascia lata incision is continued distally over the lateral side of the stifle and arthrotomy is performed. The two incisions are then connected to allow for complete medial patellar luxation and quadriceps retraction. Hemorrhage necessitating ligation will occur from branches of the caudal femoral artery.

CLASSIFICATION OF FEMORAL SHAFT FRACTURES
Fractures of the femoral metaphysis and diaphysis can be divided into several subcategories that reflect their anatomical location and better denote differences that require special handling. Fractures of the shaft can be classified best as subtrochanteric, diaphyseal, and supracondylar.
SUBTROCHANTERIC FRACTURES

SIGNS AT PRESENTATION
Most dogs or cats present with complete dysfunction of the involved limb. Mild to severe soft-tissue swelling may be present depending on the degree of associated vascular injury. Since most subtrochanteric fractures displace medially and are very near the femoral artery and vein, the possibility for injury to the vessel is great but uncommon.

RADIOGRAPHIC FINDINGS
Radiology will demonstrate the complete severance of the femoral shaft. One should also observe carefully for soft tissue densities suggestive of large hematoma at the fracture site and for evidence of associated fracture of the greater trochanter and femoral neck, since they are often already fractured. Injury may occur to associated vascular structures or to the regional peripheral nerves. While uncommon, injury to the sciatic nerve or femoral nerves may occur. Tearing of muscles is usually severe in the immediate fracture site.

METHODS OF REDUCTION AND FIXATION
CLOSED REDUCTION AND EXTERNAL FIXATION
Manipulative reduction of this fracture by closed means is not possible. The anatomical location, that is, heavy muscling and proximal medial bony displacement, is responsible for the inability to gain anatomical reduction. External fixation is not an adequate method of treatment for these fractures unless the fracture is incomplete. The only devices that could be useful would be any splint or cast that was made into a spica to completely immobilize the hip region. The device could be plaster, plastic, wood, or a reinforced Robert Jones dressing, as long as a spica was formed.

OPEN REDUCTION AND INTERNAL FIXATION
Open reduction is accomplished by the proximal surgical approach to the femur. Traction and manipulation are needed to restore alignment. In cases of comminution, especially with loss of a medial buttress, reduction may be accomplished by coaptation of bony fragments to the internal fixative.

Comminuted or transverse subtrochanteric fractures may be fixed using angle blade plates or contoured standard plates. When reducing comminuted fractures it must be remembered that the fixative will have to sustain the full force of weight bearing until union occurs. In the subtrochanteric region this is complicated by incredible bending forces; therefore, the metal must be adequate and properly applied. To counteract these forces all devices must be placed on the tension band surface. In the proximal femur that surface is lateral.

When using standard plates, the plate must be bent to conform perfectly to the lateral surface of the proximal femur. The second or third screws from the proximal end of the plate should be directed into the femoral neck for purchase. A minimum of three screws should be placed through the plate into the distal fragment. All medial bony defects require large cancellous bone grafts (Figs. 29-5 and 29-6).

FIG. 29-5 Line drawing demonstrates typical plate and screw placement for fixation of a subtrochanteric femoral fracture.

FIG. 29-6 (A) Cranial-caudal radiograph of a comminuted subtrochanteric femoral fracture in a 10-year-old mixed breed dog. (B) Radiograph demonstrates reduction and fixation using a contoured plate and screws.
Angle blade plate fixation mimics standard plate fixation except that the blade is driven through the greater trochanter into the femoral neck for proximal purchase. The side plate is then attached to the distal fragment. Where possible, better fixation is accomplished if one screw can be angled to accomplish interfragmentary compression. The plate should also be applied in tension to compress the fracture site. Any bony defects require a cancellous graft (Fig. 29-7).

![FIG. 29-7 (A) Lateral-medial radiograph of a comminuted subtrochanteric femoral fracture in a 2-year-old German shepherd. (B) Cranial-caudal radiograph demonstrates the fracture following reduction and fixation using an angled blade plate and screws. (C) Radiograph demonstrates the healed fracture 8 months following surgery.](image)

Although tension band wiring can be used, it is best reserved for relatively transverse fractures. It is difficult to gain rotational stability in this region using only a tension band wire, but comminution makes the problem worse. When using a tension band wire for this fracture, the two parallel pins are best placed through the greater trochanter to ensure adequate bone contact with the pins proximally.

**POSTOPERATIVE CARE**

Dogs or cats should be allowed restricted activity following surgery. Activity should be sufficient to ensure a normal range of hip motion yet limited so as to prevent undue forces on the fracture site. Normal activity should not be allowed until radiographic evidence of bony union is present.

**COMPLICATIONS**

Subtrochanteric fractures are very difficult to immobilize using either external or internal means. In weight bearing, bending and torsional forces tend to fatigue the implant and lead to metal breakage or fracture fragment motion about the metal. Failure of surgical repair is common in the first 2 to 4 weeks postoperatively. If the metal remains in place and does not fail, the possibility of nonunion due to motion, via bending, exists. Subtrochanteric fractures in humans have a very high failure rate for the same reasons. Infection may be a complicating factor; however, this is much less likely than a mechanical complication. Prognosis With adequate internal fixation and good bony reconstruction, the prognosis is good.

**DIAPHYSEAL FRACTURES**

**SIGNS AT PRESENTATION**

Small animals with femoral diaphyseal fractures usually present with the affected limb dragging. The animal is incapable of weight bearing, and likewise the pain or discomfort does not allow the dog or cat to carry the limb. Deformity from the fracture site is possible but not usual. Soft tissue swelling due to fracture hematoma will appear as a swelling in the thigh. With time impaired venous return may lead to edema of the entire limb. In extreme instances serum exudation through the skin is seen. Palpation of a fractured femoral diaphysis will produce crepitus unless incomplete fracture has occurred.

**RADIOGRAPHIC FINDINGS**

Radiography in a minimum of two views will help to demonstrate the extent of the fracture. Femoral diaphyseal fractures may be transverse, oblique, spiral, or, more commonly, comminuted. Radiography usually allows the surgeon to preplan the type of fixation to be used. Radiography may be used to determine the extent of soft tissue injury, to demonstrate the size of the hematoma or swollen muscles, and in open fractures to demonstrate the presence of gas.

**ASSOCIATED SOFT TISSUE INJURIES**

Most soft tissue injuries are the result of sharp spiral fracture fragments. These may occur in a simple spiral fracture or as a sharp fragment in a comminuted fracture. Most damage occurs if the animal attempts to bear weight on the affected limb, thus driving sharp bony fragments into the surrounding soft tissues. Common soft tissue injuries include the following: quadriceps muscle laceration; biceps muscle laceration; femoral artery or vein laceration; sciatic nerve stretching, bruising, or laceration; femoral nerve stretching, bruising, or laceration; and skin penetration resulting in skin laceration and a
METHODS OF REDUCTION AND FIXATION
CLOSED REDUCTION AND EXTERNAL FIXATION
All complete femoral diaphyseal fractures override as a result of muscle contracture. In addition most proximal fragment will tend to rotate externally owing to the iliopsoas muscle. Both factors must be considered when performing reduction and fixation.

Closed reduction requires general anesthesia. Muscle fatigue to allow for reduction may be accomplished by manually pulling on the limb or by hanging the dog by its fractured limb from an overhead rack. The latter method allows the animal's own weight to help create fatigue muscle contracture.

Once adequate muscle fatigue has been achieved, reduction is accomplished either by toggling, in the case of transverse or short oblique fractures, or by simply accepting the alignment of long oblique, spiral, or comminuted fractures.

The Schroeder-Thomas splint may be used to stabilize femoral shaft fractures only if the bar of the splint is proximal to the fracture. It provides some degree of continued traction and adequate immobilization to allow union to occur. Skeletal traction provided by traction tongs in the femoral condyles is superior to skin traction as provided by the more traditional tape stirrups. When applying the device, the distal limb or distal bony fragment must be slightly rotated externally to ensure rotational alignment with the externally rotated proximal fracture fragment.

The Schroeder-Thomas splint is particularly useful for long oblique or spiral fractures in which traction is necessary to ensure proper bony length. It is also very helpful in severely comminuted fractures that are not amenable to internal fixation. When used for any femoral fracture, incomplete or complete, this device must be made into a spica by bandaging around the dog's body. Without a spica the device cannot immobilize the hip and cannot immobilize the fracture site. Possible complications of using a Schroeder-Thomas splint for a femoral diaphyseal fracture include joint stiffness, quadriceps tie-down, motion at the fracture site leading to a large amount of callus, or splint failure or loosening leading to fracture nonunion. Since the Schroeder-Thomas splint is a traction splint, the bands maintaining traction may loosen and result in fracture site motion or override. They must be adjusted at least once per week. This device can be used very successfully if the above problems are taken into consideration and the splint is used properly (Fig. 29-8).

Coaptation splints may be used as a form of external fixation, but they have severe restrictions. Since they provide no traction, they can be used successfully only in incomplete fractures or transverse or short oblique complete fractures. The surgeon must be willing to accept any shortening already present. To immobilize the fracture site properly, the joint above, namely, the hip, must be immobilized by adding a spica to the coaptation. Complications of this device are similar to those that may be encountered in using a Schroeder-Thomas splint. Joint stiffness and muscle tie down occur easily. While this device may be used as a form of external fixation, its disadvantages far outweigh its advantages, and better forms of fixation will provide for better end results.

Plaster of Paris casts, either fully encircling, bivalved, or as half casts have all the restrictions just mentioned for coaptation splints. If made properly they must immobilize the hip via a spica. While adequate fracture immobilization may be provided, the disadvantages of plaster, including weight, ability to soak up urine or to soften, and the constant threat of decubital ulceration beneath the cast, make this a poor method of fixation. Although fiberglass cast materials eliminate some of the disadvantages, namely, weight, porosity, and softening, they may still produce stiff joints, muscle tie-down, or decubital ulceration.

FIG. 29-8 (A) Lateral radiograph of a comminuted diaphyseal femoral fracture in a 4-month-old mixed breed dog. Cranial-caudal radiographs demonstrate the fracture after reduction and fixation in a Schroeder-Thomas splint: (B) 3 weeks following fixation; (C) 7 weeks following fixation; and (D) 20 weeks following fixation.

contaminated fracture site.
CLOSED REDUCTION AND INTERNAL FIXATION

After performing a closed reduction, the surgeon may feel that better fixation could be achieved by a form of internal fixation. In the very small animal or lightly muscled animal, this may be achieved by placing an intramedullary device or devices into the medullary cavity.

Internal fixation can be accomplished without the use of an open surgical approach to the fracture site. The fixatives, either a Steinmann pin or pins, a Rush pin or pins, or a Kuntscher nail, are introduced into the medullary cavity through the trochanteric foramen. To gain reduction, the fracture is toggled into position. Following alignment the device is slid or hammered into proper position in the distal fragment. This type of internal fixation will provide for fragment alignment and prevent angulation at the fracture site. This technique will not, however, provide rotational stability unless a tight-fitting Kuntscher nail or stacked Steinmann pins are used. In the case of a single Steinmann pin, additional half-pin fixation may provide for adequate rotational stability.

Internal fixation following closed reduction may eliminate the time required for or the dissection necessary for direct visualization of the fracture site. However, these seem minor advantages in comparison with the possible disadvantages: multiple devices or a proper Kuntscher nail probably requires image intensification; rotational stability is rarely achieved; shortening of an oblique, spiral, or comminuted fracture will occur; and fracture gaps cannot be grafted properly. All of the above problems could be avoided or dealt with if the surgeon were working directly with the fractured bone.

Addition of external fixation over this form of internal fixation only complicates the problem further by adding the likelihood of stiff joints, muscle tie-down, and decubital ulcers. Lest the reader totally discard this method of fixation, it should be stated that when used properly by an experienced surgeon, closed reduction with internal fixation can save time and trauma. The animals must be very carefully selected, and probably only very jagged transverse or short oblique fractures should be attempted.

OPEN REDUCTION AND INTERNAL FIXATION

Open reduction of femoral fractures assumes that adequate surgical exposure has been provided. In transverse or short oblique fractures, simple toggling may provide adequate reduction to allow for fixation. The placement of bone-holding forceps near the fracture ends will facilitate the reduction. If muscle contracture is considerable, the toggling may take 10 to 30 minutes as the muscle slowly fatigues and allows for bony alignment. Long oblique or spiral fractures can be reduced similarly; however, they often require more time and more manual manipulation of the fracture itself. Comminuted fractures can be reduced only by slowly reducing fragments and eventually reforming the normal anatomical structure of the femoral diaphysis. Many sets of hands or bone-holding forceps will probably be required for success.

Intramedullary Steinmann pins are the device traditionally used for diaphyseal fractures. They may be introduced into the femoral medullary cavity by retrograde placement, that is, insertion from the fracture site and out the proximal femur; or in a normograde fashion, that is, insertion directly through the trochanteric foramen. The retrograde technique is simple and usually successful; however, placement with the hip in flexion and external rotation may result in sciatic nerve damage. Likewise if the pin exits and damages the femoral neck in the immature animal, an abnormal proximal femur may develop. The normograde technique eliminates these two complications but may require greater anatomical knowledge and manual dexterity on the part of the surgeon for proper pin placement.

A single Steinmann pin will provide suitable fixation only in serrated transverse or short oblique fractures. A single round device in a round medullary cavity cannot of itself prevent rotation; therefore, the fracture shape itself must provide for rotational stability. If a single device is warranted, as in an immature animal with open growth plates, and rotation persists, addition of a half-pin splint or a wiring technique at the fracture site will be required for success. The addition of a tension...
band wire is useful (Fig. 29-9). In the mature dog or cat with rotational instability, the addition of more pins, that is, a stacked pin technique, will be beneficial. The use of half-pins or the tension band wire is also applicable. The application of an additional external splint to prevent rotation should be avoided, since it will hamper joint motion.

Orthopaedic wire is often used in conjunction with one or more Steinmann pins. Orthopaedic wire hemicerclage or full cerclage wires provide interfragmentary compression between oblique, spiral, or comminuted fracture fragments (Fig. 29-10). The use of such pins and wires will allow the surgeon to properly treat long spiral or oblique fractures as well as reconstruct the most difficult comminuted fractures. The use of hemicerclage or full cerclage wires alone, that is, without an intramedullary device, is contraindicated. Fixation failure will probably occur.

As with all fractures, any fracture gaps remaining following fixation should be packed with autogenous cancellous bone. If pins and wires are used in very comminuted fractures or in very large dogs, the surgeon may need to use additionally a half-pin splint laterally on the tension band surface to neutralize the distractive forces of weight bearing and, therefore, minimize the likelihood of rotational instability or shortening.(32)

Stacked Steinmann pins are an excellent technique for use in femoral diaphyseal fractures. They provide alignment and by their tight fit at the fracture site also provide rotational stability. This technique is most applicable for transverse or short oblique fractures of the middle one-third of the diaphysis. If the technique is used for comminuted fractures, full cerclage wires are necessary to hold bony fragments around the stacked pins. Hemicerclage wires present difficulties because the stacked pins occupy the medullary cavity and prevent wire passage. It is advisable when stacking pins into the femur to use four or more pins, since two or three tend to loosen and migrate.

Half-pin fixation using a Kirschner-Ehmer apparatus or Stader apparatus affords excellent fixation. Once properly affixed with a minimum of two pins in the most proximal and the most distal fragments and placed in correct length and rotational position, good fracture immobilization is achieved. This device has the added advantage of allowing normal motion in all joints in the affected limb; therefore, joint stiffness and muscle tie-down will be minimized. The potential for bone infection or wound infection around the pin holes may be a disadvantage; however, adequate bandaging and pin tract care should minimize this problem. The device must be examined weekly to ensure proper wound care and device tightness. The device will fail and result in fixation failure if such care is not provided. The Kirschner-Ehmer splint may also be used in conjunction with an intramedullary device to provide for additional rotational stability and to eliminate fracture override. Rush pins may be used as fixation for diaphyseal fractures; however, they produce poor results.

Rush pins are intended for use in metaphyses or epiphyses, and their use in a diaphysis negates their special flexibility properties and forces them to function as stacked pins. It is unlikely that they could be so precisely placed to be right at a fracture site if only two are used. If more than two pins are needed, they may be inserted through the medial and lateral distal epiphyseal area as well as from the proximal or trochanteric femur. Where necessary ancillary cerclage wires can be used. Steinmann pins are more suitable for this function, and Rush pins should be reserved for their appropriate functions.

The Kuntscher nail is ideally suited for transverse or short oblique fractures of the central three-fifths of the diaphysis. The nail must be premeasured to ensure the proper diameter and length. Following fracture reduction the nail is inserted through the reamed trochanteric foramen and driven across the fracture site and seated in the distal fragment. Reaming in the dog and cat is only through the proximal femur to open the medullary canal. Further reaming of the entire medullary cavity as is done in humans will result in bony failure. The dog has sufficient cranial bowing that further reaming will destroy the caudal cortex. Both dogs and cats have such thin cortices that any degree of reaming is prone to crack the bone or produce holes through the cortex.
The Kuntscher nail will provide excellent fixation and rotational stability if used properly (Fig. 29-11). Insertion of the Kuntscher nail presupposes that the animal is mature; in the immature dog or cat the reaming will destroy the femoral neck sufficiently to produce an abnormal proximal femur. Insertion also assumes that there are no longitudinal cracks that will open when the nail is driven. The surgeon must have on hand a full collection of nails of various diameters to be able to select the proper nail for the fracture. There are many problems associated with the Kuntscher nail; however, once the surgeon owns a proper inventory and masters the technique of proper insertion, the results can be very gratifying.

Bone plates or the use of bone plates and bone screws in concert provides perhaps the most versatile method for femoral diaphyseal fixation. While plates are applicable for most femoral fractures in the dog or cat, they are especially useful in the very comminuted fracture of the large or giant breed dog. (10,29,44,51,62) In transverse or short oblique fractures, the bone plate is contoured to properly fit the lateral tension band surface of the bone. The plate is then applied in a fashion that places tension in the plate and conversely compresses the fracture ends. Such fractures must have excellent medial cortical contact at the fracture site. If contact is not present, cancellous grafts should be used to pack any defect. Failure to do so may result in continued bending at the fracture site, plate bending, and eventual plate failure. In transverse fractures, pre-stressing or over-bending the plate directly over the fracture site will assure medial cortical contact and compression.

The application of the plate and screw in long oblique or spiral fractures is similar. Following reduction, multiple interfragmentary screws are placed to compress the fracture surfaces. Following this fixation a bone plate is contoured to fit the tension band surface and applied using only minimal additional compression to the fracture site. Such a plate functionally neutralizes the forces that would tend to disrupt the fracture site and is called a "neutralization" plate. Occasionally when the fracture line is running from cranial to caudal, the interfragmentary screws may be placed initially through the plate. In no instance is the use of interfragmentary bone screws alone, that is, without the use of a neutralization plate, adequate fracture fixation. If used alone, fixation failure will invariably occur.

Plate and screw fixation is ideally suited for comminuted fractures of the femoral diaphysis. Using individual interfragmentary compression screws, the fracture can be anatomically reconstructed. Various diameters of screws are helpful and are used for appropriate sized bony fragments. Once the bone again resembles a tubular structure, a plate is contoured to fit the bone and span the area of comminution (Fig. 29-12).

Femoral diaphyses comminuted beyond anatomical reconstruction may be handled in other fashions. Severe comminution or bony loss may require bone shortening and fixation. Shortening of 1 cm to 2 cm can be tolerated by most dogs or cats. If the shortening would be greater than 2 cm, another approach may be needed. It is possible to remove the central diaphyseal comminution and replace the entire deficit with femoral diaphysis of appropriate diameter and length from a donor animal. The cortical graft may be fresh or frozen. This allows for normal bony length. The graft is best fixed in place using a bone plate. There is, however, one overriding disadvantage to this technique: the graft does not revascularize completely for up to 2 years. Fixation failure may occur at any time during this interval. Another more physiologic technique is to reconstruct the bone to proper length using a bone plate and maintain the huge gap that resulted from the comminations. The gap is then
filled with a massive autogenous cancellous bone graft. Such gaps fill with healthy vascularized bone within 6 to 10 weeks. The risk to the plate is minimized by a large gap because bending forces that tend to break the plate are distributed over a large area of the plate. This technique works well in both dogs and cats.

POSTOPERATIVE CARE
All dogs and cats whether immobilized with external or internal fixation need restricted exercise until fracture healing occurs. Such restrictions should not allow for any time off the leash and should not allow going up or down stairs or running loose while "restricted" to the house. In comminuted fractures further confinement to a cage may be necessary.

The animal in an external fixative should be reexamined at least weekly to be certain the device is adequate and not loosening. Animals with internal fixation may be seen less frequently.

In instances of large hematoma, postoperative drainage using closed suction may be required for up to 48 hours. Antibiotics are used only in instances of open fracture or in open reductions of inordinately long duration or requiring extensive soft tissue dissection.

COMPLICATIONS
The complications that may accompany the use of external forms of fixation have been mentioned above. They include decreased range of motion or stiffness of the knee, hock, or hip; ankylosis of the knee, hock, or hip; quadriceps tie-down leading to knee stiffness; fracture delayed union, malunion, or nonunion due to inadequate fixation; and soft tissue ulceration of the groin, decubital ulcers, or paw devitalization due to overly tight devices.

Neither is the use of internal fixation free of complications. Delayed union or nonunion may result from inadequate internal fixation. Rotational or angular malunion can occur if a single Steinmann pin is used or if the device is removed inappropriately prior to union. Metal failure can occur as a result of improper use of the appliance or inadequate cancellous grafts. Infection may occur if surgery lasts a long time. Migration of Steinmann pin through the knee can produce arthritis; migration proximally may result in open wounds and osteomyelitis. Shortening of the femoral diaphysis can occur if adequate provision is not made to stabilize comminuted fractures. Sciatic nerve entrapment may occur and result in hip pain, knuckling of the paw, hypoalgesia, or anesthesia in sciatic distribution.

PROGNOSIS
If the femoral diaphysis is aligned well and fixed adequately, the likelihood of success is very good. If inadequate fixation is employed and the poor fixation is aggravated by an additional splint on the limb, the prognosis is poor. A healed bone but impaired limb function is considered a failure. A good to excellent result requires that a fractured diaphysis heal in good alignment and the limb function normally after rehabilitation.

SUPRACONDYLAR FRACTURES
SIGNS AT PRESENTATION
Dogs and cats with supracondylar femoral fractures exhibit various amounts of lameness, from a mild limp to total disuse. The variability of lameness relates to the degree of bony displacement; undisplaced or mildly displaced fractures are compatible with some function, whereas complete displacement results in disuse.

Palpation will demonstrate several abnormal findings: the knee region is enlarged; the patella seems to be located more proximally (in fact the prominence is the proximal fracture fragment); the patella may be difficult to palpate; the quadriceps muscles will be lax; and crepitus will be palpable.

RADIOGRAPHY
Radiographic evaluation will confirm the presence of fracture and indicate the degree and direction of the fragment displacement. In most supracondylar fractures the condylar fragment displaces caudally. Radiography will also answer the following questions concerning the fracture: whether the fracture is metaphyseal or through the epiphyseal plate; in the immature animal whether the fracture is grade I, II, III, IV, or V in the Salter classification (this will help determine the
likelihood of successful end result or of complications); and whether the fracture is comminuted or simple. Radiography will allow the surgeon to better determine the method of reduction and fixation that will best treat the existing fracture.

ASSOCIATED SOFT TISSUE INJURIES
Supracondylar fractures may produce relatively minor trauma to surrounding tissues in low-velocity injuries. This is most typical in the animal in whom fracture results from a 4 to 5 foot drop from its owner's arms. Automobile trauma may produce minor to major amounts of soft tissue trauma. Typically surrounding muscles are torn or cut by the sharp proximal fragment. Such laceration can occur in the quadriceps muscles cranially and in the muscles of the medial thigh, as well. Femoral artery or vein laceration may occur with extreme medial displacement of fragments. Nerve injury is less likely than vascular injury. In very rare instances supracondylar femoral fracture may be associated with ligamentous injuries of the knee.

METHODS OF REDUCTION AND FIXATION
CLOSED REDUCTION AND EXTERNAL FIXATION
Closed reduction of supracondylar fractures can be performed in two fashions. Both are best performed as soon as possible following the fracture, prior to significant muscle contracture or soft tissue swelling. The first method requires traction and digital manipulation. Using traction to distract the fragments, it may be possible to "pop" the epiphyseal fragment back into alignment. This is more likely to be successful in cats or small dogs. The second method requires flexing the bony fragments to 90° and toggling them into reduction.

Results of the above two techniques will depend on the fracture configuration. Transverse or oblique fractures are less likely to stay reduced following closed reduction than a fracture through the growth plate of an immature animal. In the immature animal the bony fragments interdigitate (as described above) and tend to stay reduced following such a reduction.

When reducing supracondylar femoral fractures, it is important to accept only perfect anatomical reduction or overreduction. An underreduced fracture is much more likely to result in soft tissue tie-down and impaired joint function following union.

Closed fixation by external fixation can be accomplished by several means. Traditionally this fracture was one of the first in which traction tongs were used in conjunction with a Schroeder-Thomas splint. This is useful for fixation of transverse or short oblique fractures that cannot stay reduced without continual maintenance of traction. The tongs are placed into the condyles and traction is maintained by incorporating the tongs into a Schroeder-Thomas splint. This device provides for continual traction and allows the knee to be maintained in a normal anatomical position.

The use of a Schroeder-Thomas splint alone is not a good method of fixation in the mature animal. To maintain traction the limb is usually pulled into extension (rather than extending only the fracture site). As a result, when union occurs, there is usually decreased range of motion in the knee because of soft tissue tie-down. Such a splint rarely maintains adequate traction for this specific fracture, and loss of reduction may also occur.

Coaptation splints are successful only if the fracture is anatomically reduced, stable, and does not require traction. Any well-constructed splint that places the limb in a normal midrange position may then be successful. Such a splint must immobilize the limb from the toes to the hip and preferably immobilize the hip via a spica. Since most animals with stability-reduced growth plate fractures tend to heal rapidly, the spica may be unnecessary. To preserve joint motion this device should be removed as soon as union occurs, and rehabilitation of the limb should begin immediately.

Flexion bandages may be used successfully but only in stable reductions.(22) If the knee is flexed sufficiently to place the tibial plateau behind the reduced femoral condyles, the fixation will be stable. This locks the condyles between the tibial plateau, the patella, and the quadriceps. The flexion bandage must not place any rotation at the knee. Following union the limb is quickly rehabilitated. This technique is much less likely to result in impaired range of motion or joint stiffness than any of the others described above.

OPEN REDUCTION AND INTERNAL FIXATION
Surgical exposure is facilitated through the lateral approach described above. Reduction may be accomplished using digital manipulation; however, often a bone forceps on the proximal fragment provides for better manipulation and traction. Reduction usually requires some degree of flexion through the fracture site, traction, and toggling, all performed
simultaneously. If the fracture is transverse or oblique and through the metaphysis, it is less likely to remain reduced than if the fracture is through the growth plate. The reduction may be maintained by digital pressure or a bone forceps while the internal fixation is applied. In comminuted fractures, fragments must be reduced individually to reconstruct a simple supracondylar fracture. Longitudinal fixation can then be performed. As mentioned above, anatomical reduction or overreduction is acceptable. Underreduction is unacceptable.

Rush pins provide excellent internal fixation for supracondylar femoral fractures.(8) The pins are introduced through the femoral condyles using an appropriately sized reamer. The starting locations are laterally, just cranial to the tendon of origin of the long digital extensor muscle, and medially on the distal medial condyle symmetric to the lateral pin placement. Once the fracture is adequately reduced, the pins are hammered into place alternately. If the pins are used for an oblique fracture, it is best to begin first with the pin most tangential to the fracture line. If the other pin, which is at right angles to the fracture line, is driven first, it will tend to distract the fracture (Fig. 29-13).

If Rush pins are used in very immature animals, great care must be taken when driving the pins. Too much hammering may drive the pins through the soft condyles and result in fixation failure, comminution of the condyles, or tearing of the growth plate and subsequent premature closure.(57)

Steinmann pins or Kirschner wires may be used in exactly the same way as Rush pins (Fig. 29-14) Both pins may exit through the trochanteric fossa proximally to facilitate pin removal later. This technique can be used in very immature animals when fear of Rush pin tearing may be a factor. Such pins may be placed with relatively minor trauma to the epiphysis or growth plate. Following union, most animals continue to lengthen their femurs normally despite the pins through the growth plate.

A single Steinmann pin or Kirschner wire may provide adequate fixation where rotational stability is ensured by the fracture configuration.(3,33,49) The pin is started in the intercondyloid notch cranial to the cranial cruciate ligament. It is then driven across the fracture site and allowed to exit through the intertrochanteric fossa proximally. The pin must be countersunk into the condyles to prevent knee damage from the cut pin.

Steinmann pins or Kirschner wires may be crossed through a fracture site and exit the opposite cortices proximal to the fracture site. This technique is usually done with pins of larger diameter than those used in a Rush pin-type technique.(17,58) The degree of stability achieved is directly proportionate to how far above the fracture the pins exit the cortex. This technique may result in some slowing of growth if placed through an open growth plate, but overall it works well.

Fractures that are comminuted or long oblique can be handled by any of the above methods with the addition of hemicerclage or full cerclage wires. The wires, probably hemicerclage wires, may be used to reconstruct the fracture fragments prior to pin insertion or following pin placement to ensure better interfragmentary compression, hemicerclage or full cerclage. The variety of combinations of pins and wires is infinite. Any bony defects that remain following the technique should be packed with cancellous bone graft.

Plate and screw fixation may be used for supracondylar fractures but is rarely indicated. Very comminuted fractures or fractures with significant bone loss are the main reasons for plate fixation. In this application the plates are used primarily as
buttress plates to hold the joint surface in proper alignment for proper articulation to occur. Either contoured straight plates or small angle blade plates can be used. They are bent to fit the lateral femoral surface and applied in typical technique. All bony defects are packed with autogenous cancellous bone graft. Plates should never span an open growth plate, since plate closure will occur and result in shortening and deformity.

The use of interfragmentary lag screws alone, without plates, has been suggested for fixation in simple supracondylar fractures. This technique is of questionable value and certainly is to be avoided if an open growth plate is present.

POSTOPERATIVE CARE
Animals in external fixation should be reexamined frequently to ensure proper fracture alignment. Immediately following union and splint removal, rehabilitation of the limb must start. Such animals may require analgesia to facilitate manipulation of the knee.

Animals that have had internal fixation should be encouraged to return to normal function. This will ensure return of a normal range of knee motion. The only exception is the case of comminuted fractures, which may require a period of limited exercise to prevent fixation failure in the first 2 to 4 weeks.

Pin removal is indicated when union has occurred. If the pins are in the trochanteric fossa, this is usually an easy procedure. Pins left in the joint capsule generally require arthrotomy for proper removal. Rush pins are usually not removed.

COMPLICATIONS
The most common complication in supracondylar fracture is lameness resulting from loss of motion in the knee. This can be due to poor reduction, muscle tie-down, prolonged external fixation, or poor pin placement. Occasionally the cut ends of pins will irritate soft tissues and result in joint pain.

Nonunion of supracondylar fractures is rare, since metaphyseal bone has adequate blood supply and cancellous bone and heals rapidly. Malunion may, however, result in deformity or functional disuse. Malunion may also result in degenerative arthritis of the knee.

Dehiscence of the lateral parapatellar arthrotomy incision- on many occasions results in medial patellar luxation. When dealing with fractures near joints, soft tissue complications resulting in loss of normal joint motion often cause more problems than do bone complications. Such is the case in supracondylar femoral fractures.

PROGNOSIS
When closed reduction and external fixation is used, a good result is the most one can expect. With proper alignment and adequate internal fixation, excellent results should be expected.

REFERENCES

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