

## 9

## Principles of Fracture Fixation

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### INTRODUCTION

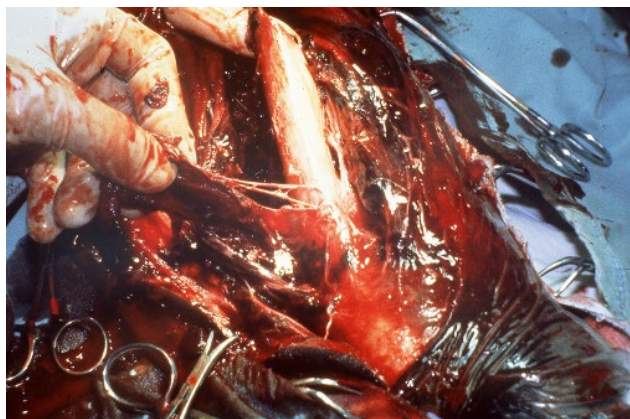
Fracture management in horses follows many of the same basic techniques used for fracture repair in humans and small animals. Techniques and equipment used in humans, particularly those developed by the Association for Osteosynthesis (AO; DePuy Synthes, West Chester, PA, USA), are used in equine fracture reconstructions, sometimes with modification and sometimes without.<sup>16,42</sup> Specific recent improvements are described in this chapter, including the 5.5 mm cortical screw, the limited-contact dynamic compression plate (LC-DCP), the locking compression plate (LCP), the dynamic condylar screw (DCS) plate and dynamic hip screw (DHS) plate, the equine intramedullary interlocking nail (IIN), and the equine external fixator. These implants and devices expand on prototypes developed to fill a need for immediate weight bearing of large animals, using implants able to withstand extraordinary stress, and yet capable of being applied expeditiously. Given the new implants entering use in equine fracture repair, the principles of fracture compression and rigid stabilization remain. Further, the care of adjacent soft tissues is critically important in the optimization of fracture healing. The increased application of the LCP has done more to preserve the soft tissues than most previous plating systems, and minimally invasive approaches to plate insertion are possible due to the reduced need for precise plate contouring and bone to plate surface contact. Detailed information on LCP application is provided in Chapter 10.

### MANAGEMENT OF SOFT TISSUE INJURY

Many fractures in horses involve considerable impact energy, which is transformed to both comminuted osseous fragmentation and extensive soft tissue injury. The additive effect of motion on an unstable limb can compound the soft tissue trauma of the initial fracture, reducing the prognosis for repair and increasing the cost. The possibility of disruption to the skin by the fracture ends depends on the energy of the fracture, the anatomic location of the break, particularly the amount of surrounding musculature, and the care of the limb in the postfracture phase. The classification of open fractures is described in Chapter 4. Injury can involve small skin wounds and increase to extensive skin wounds, muscle loss, and finally damage to the vasculature and peripheral nerves. Casting and splinting techniques are designed to prevent exacerbation of soft tissue injury following a fracture and are described in Chapters 5 and 6.

### Closed Fractures

Intact skin generally prevents skin-borne organisms from invading the fracture site. However, intact skin that has been extensively bruised or stretched or covers extremely swollen structures becomes pervious to bacterial invasion. Vascular compromise can often result from the stretching of vessels, such as with fetlock breakdown injuries, in which compromise of the digit is rapid unless hyperextension of the fetlock is corrected.



**Figure 9.1** High-energy fracture of the radius in a weanling showing massive muscle bruising and stripping of the periosteal sleeve for 10 cm.

The repair principles for closed fractures include:

- 1) Immediate preoperative stabilization to reduce swelling, to support the fracture, to prevent bone ends penetrating the skin or entrapping nerves and lacerating vessels, and to alleviate stretching of vessels that may promote vascular spasm or thrombosis.
- 2) Carefully planned surgical approaches to minimize the additional soft tissue damage. This becomes vital in high-energy fractures in which muscles are frequently macerated and the periosteum is stripped from the bone (Figure 9.1).
- 3) Stabilization techniques that minimally interrupt the soft tissue attachments and blood supply to the bones.

In many complex and comminuted fractures, such as unstable fractures of the proximal phalanx, avoiding surgical dissection and internal fixation by the use of external fixators has been recommended. In other circumstances, comminuted long bone fractures such as those of the third metacarpus in foals may be better managed by casts with transfixation pins. For fractures of the femur, tibia, and humerus, interlocking nails have been developed that can be inserted without extensive exposure of the entire bone. Similarly, LCP application requires less plate–bone contact, and thereby less plate contouring and soft tissue removal for an exact plate–bone fit. Where plating or screw insertion is required, the preservation of soft tissue attachments is critical in the maintenance of blood supply. Muscle attachments should be minimally disturbed, and plates should be applied to the surface of the bone after the periosteum has been dissected laterally only enough to allow full plate contact. Complete stripping of the periosteum should be avoided. Reduction of equine fractures can often be difficult and some associated trauma to adjacent structures is inevitable. The surgeon's experience and the methods or devices used

to assist in fracture reduction are important factors in minimizing the soft tissue damage.

Plate luting for improved plate–bone contact is a special compromise between more secure fixation and disturbed vascular supply. Use of bone cement as an interpositional material to improve plate–bone congruity has been shown to reduce screw loosening and implant failure by increasing the number of cycles to failure for plate application in horses.<sup>47</sup> Several studies in small ruminants demonstrate that cortical density is maintained beneath luted plates, although several other studies showed reduced vascularity and increased bone loss beneath the plates.<sup>47,53,56</sup> Regardless, carefully applied bone cement enhances frictional contact between implants and bone, and, provided that the bone cement is not allowed to penetrate the fracture line, improves the chance of bone union before implant failure. More detailed information on plate luting is available later in this chapter.

Intraoperative care of exposed muscle, fascia, and neurovascular structures should include careful padded retraction of tissues, use of soft Penrose drains to retract vessels and nerves, and frequent moistening of tissues with saline or lactated Ringer's solution. Addition of antibiotics to the saline or lactated Ringer's solution is also recommended. Air-borne organisms settle on exposed tissues in most surgical suites, despite precautions, and local lavage reduces bacterial numbers. Neomycin ( $4\text{ mg ml}^{-1}$ ) and potassium penicillin ( $5 \times 10^3\text{ IU ml}^{-1}$ ) are commonly added to the lavage. Application through a spray bottle efficiently wets the surfaces and minimizes solution waste.

## Open Fractures

High-energy fractures frequently result in comminuted configurations that have an increased tendency to penetrate the skin. Limited muscle coverage of the third metacarpus and metatarsus, and the medial aspects of the tibia and radius, makes fractures of these bones more prone to become open. Open fractures are classified into three types, as described in Chapter 4.

Repair of all open fractures commences with appropriate first aid and initiation of broad-spectrum antimicrobial therapy. The skin wound is cleaned of hair and debris and packed with antimicrobial gels. Small skin punctures may represent external wounds rather than penetrations from the fracture ends. Gentle probing after the initial cleansing may define a shallow subcutaneous wound rather than a path to the fracture. It should be assumed that deep wounds are made by fracture ends until proven otherwise at surgery.

Most equine open fractures are type I (skin laceration <1 cm) or type II (large skin laceration but little actual tissue loss). If repair is being considered, most horses will

already have been commenced on a course of penicillin or a cephalosporin, and gentamicin or amikacin. Supplementation with metronidazole for increased anaerobe coverage may also be warranted. Following induction of anesthesia, all hair is clipped for a wide margin, the wound edges and proposed incision site are shaved, and the skin is sterilely scrubbed. After the initial skin preparation, the skin opening and deeper wounds are draped and further explored using a separate set of instruments. All debris is removed by tissue debridement and rigorous pulsatile lavage of lactated Ringer's solution containing antimicrobials. Completely detached small fragments of bone can be discarded. When the wound is clean, it is packed with sterile gel or an antimicrobial gel, and the skin is partly apposed with several sutures.

The horse and limb are then positioned for the approach to the bone for fracture stabilization. The optimal approach avoids the previous skin laceration, but depends more on the fracture configuration and the tension band surface of the bone. The skin is aseptically prepared once again and then draped. New sterile instruments are used and the surgical team should rescrub and apply new gowns and gloves. Preservation of the vascular supply to the fractured ends of open fractures is critical. Fracture fixation by rigid internal fixation is still preferred in most open fractures; however, extensive skin loss or devitalization results in a tenuous vascular supply to the fracture, which increases the need for limited surgical interference and possibly the application of an external fixator, transfixation cast, LCP, or IIN.

During open fracture plating, any devitalized soft tissue remaining is gently debrided back to bleeding tissue, and the bone and soft tissues are thoroughly lavaged with solutions containing antimicrobials. Tissue samples or culture swabs are taken for identification of organisms and testing of antibiotic sensitivity. Reconstruction of the fracture must be fastidious to maximize cortical continuity and the chance of a persisting stabilization. Lag screw insertion is used to reconstruct comminuted fractures as two-piece units. The sites for plate application must be selected early and all lag screws inserted to avoid complicating the plate contact. A plate should always be positioned over any residual cortical gaps, so that the opposite side of the bone is left with full cortical contact.

Large butterfly fragments should be secured with lag screws and one of the plates should be applied over the fragment. Cancellous bone graft is always indicated in plate repair of open fractures. Harvested graft material is placed in the medullary cavity after debriding the fracture hematoma and foreign debris. Cortical defects are filled with bone graft, and plates are applied over them. After plating is completed, bone cement luting of each plate, other than LCPs, is indicated for added stability. The locked screw head design in the LCP obviates the need

for exact plate–bone contact and makes luting obsolete. For standard luting, the plates are loosened sequentially and polymethylmethacrylate (PMMA) applied beneath each prior to retightening. Some benefit is derived if only the heads of the screws are luted in the dynamic compression plate (DCP) slots.<sup>71</sup> Adding antibiotics to the PMMA used for plate luting in the repair of open fractures is always indicated. All excess methacrylate is removed before it polymerizes, and all fracture gaps must be carefully cleaned of residual bone cement.

Drain placement is indicated in many open fractures following plate repair. Hematoma and seroma formation are very dangerous developments in open fractures. Heparinized, fenestrated drains are placed in any dead spaces remaining at the time of soft tissue closure. Drains are exteriorized remote to the skin incision and must be firmly attached to suction devices. If a cast is to be applied following plating of a fracture, a drain is rarely indicated or productive, and often necessitates an early cast change.

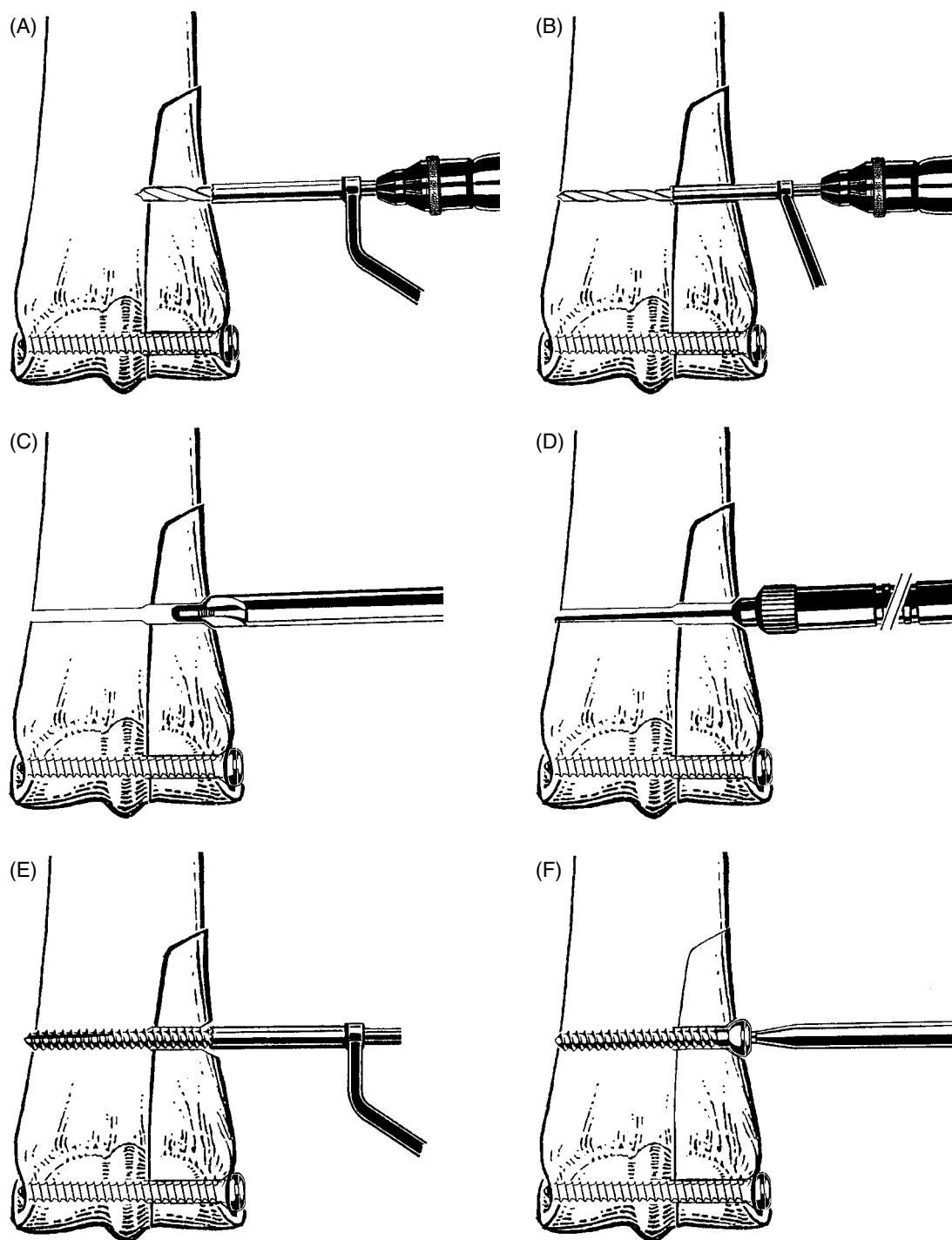
Antibiotics are continued in the postoperative period for several weeks. Regional limb perfusion of antibiotics for the initial five to seven days after surgery provides higher tissue levels of antibiotics compared to simple intravenous injection, and is always indicated for open fractures distal to the elbow or stifle. Topical cleansing of residual open wounds is done daily if a cast has not been applied, and if a suction device is used, culture of the drainage to monitor the condition of the interior of the wound is helpful. Additionally, culture of clots from the interior of the drain, following its removal, allows confirmation of the suitability of antibiotics. Radiographs are of little value in the detection of osteomyelitis until three weeks postoperatively. The status of the limb swelling, drainage, and level of pain are better indicators of progress.

## APPLICATION OF SCREWS (AUER)

Cortex screws may be applied as lag screws, as position screws, or as plate screws.

### Lag Screw Technique

The lag screw technique is the most frequent application of cortical bone screws in fracture repair.<sup>42</sup> It uses cortex screws applied in a lag screw manner rather than using actual lag screws. The near cortex is overdrilled through the large end of the double drill guide, with a drill bit the same size as the outside thread diameter of the screw (Figure 9.2A). During subsequent screw insertion the threads do not engage the bone surrounding the hole, but glide through, giving rise to the name *glide hole* for this portion. The smaller portion of the double drill guide is inserted into the glide hole to facilitate concentric drilling



**Figure 9.2** Lag screw technique demonstrated on a lateral condylar fracture of the third metacarpal bone. The distal screw is already inserted. (A) the glide hole is drilled with the large drill bit and the double drill guide; (B) the insert portion of the double drill guide is inserted into the glide hole and the concentric thread hole cut with the small drill bit; (C) the countersink depression is prepared on the surface of the near cortex; (D) the length of the screw needed is determined with the depth gauge; (E) the threads are cut in the far cortex with the tap through the double drill guide; and (F) a screw of the predetermined length is inserted and tightened with the hexagonal-tipped screwdriver.

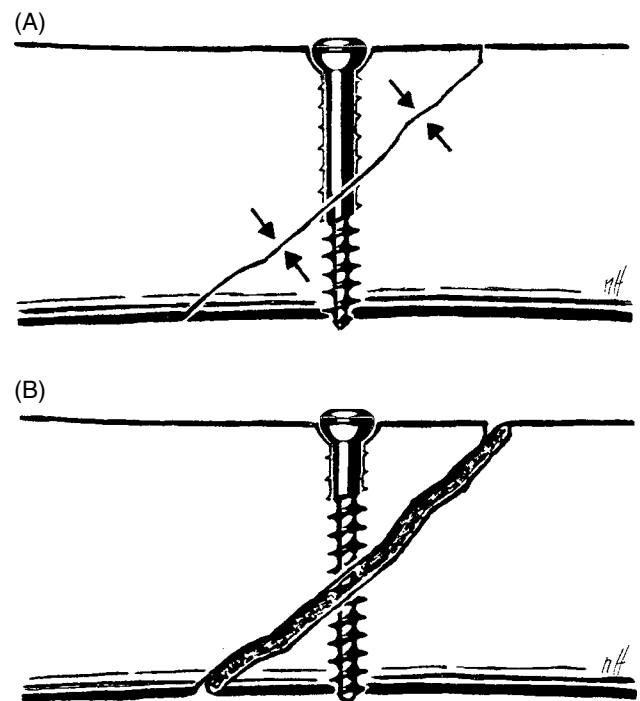


of the *thread hole*, the dimension of which matches the core diameter of the screw. This hole is drilled across the far cortex (Figure 9.2B). The drill bit and drill guide are subsequently removed. In most cases, a *countersink* depression is created to facilitate optimal seating of the screw head and provide an enlarged contact area between the head and the bone (Figure 9.2C). This results in decreased force per square millimeter of contact area. The cortex should be prepared carefully, especially if it is thin. Excessive countersinking can result in the screw head actually pulling completely through the cortex. The countersink should be used in a 360° motion. The *depth gauge* is subsequently used to determine the entire length of the screw needed (Figure 9.2D). The depth gauge has a small hook at the distal end, which can be engaged on the outer surface of the far cortex. The tapered barrel of the depth gauge is snugged gently down onto the near cortex and the shaft of the depth gauge tightened to allow direct reading of the exact screw length needed. In equine bone, the measured length is generally used, or occasionally 2 mm is subtracted to avoid irritation of soft tissues by the exiting screw tip. Where maximum screw purchase is necessary and the soft tissues are limited and not tightly adherent to the far cortex, 2 mm can be added to the measured length to ensure that the tapered tip of the screw is outside the bone, resulting in good contact of the entire threads and the cortex. Using the *tap sleeve* to protect the soft tissues and help guide the tip into the screw hole, the *tap* is inserted into the glide hole and the threads are cut in the thread hole (Figure 9.2E). The tap is continuously advanced until resistance increases, indicating that the tap has encountered dense cortical bone, in which case the tap is advanced two to three half turns followed by one half turn in the opposite direction. This action clears the threads of bone debris, which will subsequently accumulate in the three flutes cut into the tap. Through this action, clean cutting of the threads is assured. Once the hole has been tapped, the tap is withdrawn, the hole flushed, and the screw of predetermined length inserted. The hexagonal-tipped *screwdriver* is inserted into the screw head and the screw tightened (Figure 9.2F). Solid force should be used; however, over-tightening should be avoided, because it may break off the screw head, especially with 3.5 and 4.0 mm screws and occasionally with the 4.5 mm screw. The 5.5 mm screw is very difficult to break, and stripping of the hex socket in the screw head is more likely.

The lag technique is identical for all sizes of screw; only the sizes of the drill bits and instruments vary. In equine surgery, when many screws are inserted, it is advisable to use power equipment for tapping and inserting screws. This technique can be performed with the air drill and some battery-powered drills equipped with a reverse trigger. Power tapping should be practiced extensively prior to applying it during surgery.

## Lag Screw Application

From a functional point of view, a lag screw contains a portion without threads. Therefore, it is a partially threaded screw. Most lag screws are cancellous screws, but a partially threaded cortex screw, referred to as a *shaft screw*, has been available in the past. To use lag screws, a hole of only one size, the thread hole, is drilled across the entire bone. In soft bone, the cancellous screw is then simply inserted, cutting its own threads as it penetrates. In more dense bone, particularly adult cortical bone, threads are cut along the total length of the hole with the *cancellous tap* and the lag screw is inserted. The threads in the near cortex are not filled by the partially threaded screw, because the screw threads are located toward the screw tip and engage the far cortex or on the far side of the fracture plane, allowing solid interfracture compression (Figure 9.3A). If the threads are partially located in the near cortex as well as in the far cortex, no compression can be achieved (Figure 9.3B). Only the partially threaded 4.5, 7.0, and 7.3 mm cannulated screws and the partially threaded 4.0 and 6.5 mm cancellous screws can be used as lag screws. All other screws have to be applied using lag technique if compression is to be achieved.



**Figure 9.3** Lag screw application using a partially threaded cancellous lag screw. (A) A cancellous screw of correct thread length is inserted into the tapped thread hole. Note that all the threads are located beyond the fracture plane, allowing the fracture line to be compressed. (B) Selection of a cancellous screw with too long a thread length; threads are located on both sides of the fracture plane, preventing interfracture compression.

## Position Screw Technique

Position screw technique is applied to cortex screws if a fragment has to be maintained at a certain distance, especially where compression would pull the fragment into the medullary cavity. Therefore lag technique is avoided. With position screw technique, only a thread hole is drilled. The entire hole is tapped, and because the threads engage the near cortex as well as the far cortex, no interfragmentary compression is achieved when the screw is tightened. It should be noted that in position screw technique no countersinking can be performed, except for the 3.5 mm screw, because the centering tip of the countersink is too wide to fit into the thread hole. An alternate technique would involve the use of a washer under the screw head to distribute the forces applied to the bone. Position screw technique may be desirable in certain situations, for example if a small fragment is kept in place and subsequently protected by a neutralization plate.

## Plate Screw Technique

Insertion of a plate screw in most instances requires the same technique as that described for the position screw. The plate screw, as the name suggests, is used only through plates and a thread hole is drilled across the entire bone. Since the hole or slot in the plate is larger than the thread diameter, the threads do not catch in the plate, and by tightening the screw the plate is pressed onto the bone. This is true for all plates except the LCPs (see Section 9.7).

## Cannulated Screw Technique

Cannulated screws are inserted over a guide pin. The fracture is reduced and the location for screw insertion selected. A guide wire may be placed adjacent to the desired location and its position and angle evaluated with the help of an image intensifier or intraoperative radiographs. Once the guide wire is correctly placed, a 2 mm hole is drilled parallel to the guide wire in the correct location. The hole is advanced to the desired depth. Subsequently, the 2 mm drill bit is exchanged for a guide pin. The direct measuring device is placed over the guide pin. A cannulated screw approximately 5 mm shorter than the measured length is selected. Care is taken to also select the correct thread length, to ensure lag effect during tightening. The cannulated drill bit is placed over the guide pin and the hole prepared to the desired depth, which is verified using an image intensifier or intraoperative radiographs. The thread hole is subsequently tapped over the guide pin using the cannulated tap. The selected screw is then inserted with the cannulated

hexagonal-tipped screwdriver. A special set has been assembled for the cannulated screws containing various sizes of screws and the instruments needed for their insertion (described in Chapter 8). Mechanical characteristics of the 7.3 mm cannulated screw are similar to the 6.5 mm cancellous screw,<sup>25</sup> although the cannulated screws are known to be weaker in shear.

## Locking-Head Screws

Locking screws are only applied through LCPs. The technique is described later in this chapter and their application is covered in Chapter 10.

## Screw Sizes

The various sizes of screws employed in equine surgery, with all the pertinent data, such as screw type, screw diameter, gliding hole diameter, thread hole diameter, relevant tap diameter, and the screw shape, are summarized in Table 8.1 in Chapter 8. Generally, the outside thread diameter of the various types of screws is responsible for the name of the screw. For example, the 5.5 mm cortex screw has an outside thread diameter of 5.5 mm. Screws are classified as large, small, and mini. Large screws include the 4.5 and 5.5 mm cortex screws, the 4.5, 7.0, and 7.3 mm cannulated screws, the 6.5 mm cancellous screw, and the 4.0 and 5.0 mm locking-head screws. The small screws include the 4.0 cancellous screw, the 3.5 mm cortex screw, and the 3.5 mm locking-head screw. The smaller screws available for small animals and humans are not described here. For information on these and other implants, the reader is referred to the Association for Osteosynthesis (AO) manuals and DePuy Synthes catalogs.<sup>42</sup>

The 5.5 mm cortex screw has been shown in equine adult bone to have greater strength than the 4.5 mm cortex screw.<sup>77</sup> In foal bone it is comparable to the 6.5 mm cancellous screw.<sup>78</sup> Therefore the 5.5 mm screw has become very popular in equine fracture repair. It is mainly used in critical locations where potential increased strain and movement may occur during healing.

## Screw Removal

Cortex screws, locking-head screws, and fully threaded cancellous screws are easily removed because they are fully threaded. However, after a fracture has healed, a partially threaded screw may be impossible to remove from the hard equine bone. During fracture healing, the pre-cut threads in the near cortex fill with solid bone, which surrounds the shaft of the screw. Removal of the screw would require that the threads cut their own way backing out

through the bone, for which most screw threads are not designed. This can result in screw breakage, usually at the head–shaft junction. Therefore, the surgeon has to be very careful in using cancellous screws in hard equine bone, especially in cases where implant removal might be necessary at a later stage. For the cannulated screws this problem has been corrected by manufacturing a self-cutting device in the proximal-most threads, which allows removal of the screws. However, it is questionable whether these devices will be sufficient to cut threads in the hard equine bone. To date, no experimental evaluation of these screws has been performed in the horse.

## CERCLAGE WIRE APPLICATION

Cerclage wires are used frequently for fracture stabilization in humans and small animals, where they are applied around oblique long bone fractures. This type of fixation has not been popular in the horse because of its lack of stability and the ease of breakdown of fixation under the extreme loads placed on the equine limb. However, cerclage wires are still applied in a few situations. Several studies describe cerclage wire application for repair of proximal sesamoid fractures.<sup>32</sup> Perhaps the most frequent application of cerclage wire is physeal growth retardation surgery. Additionally, there have been reports on the use of cerclage wires in the treatment of apophyseal and nondisplaced ulnar fractures in foals.<sup>33,40,52</sup> A distinct advantage to the use of wires is the elimination of the possibility of a plate repair bridging the ulna and radius with screws. Cerclage wire is also used in arthrodesis of the metacarpophalangeal joint following breakdown injuries due to comminuted fractures of the proximal sesamoid bones.<sup>5</sup> In such a case a cerclage wire tension band is inserted through the palmar/plantar aspect of the metacarpophalangeal joint, in addition to the application of the dorsal plate. Cerclage wires also occasionally still have a use in temporary stabilization of fracture fragments while plates and other implants are applied to the bone.

## DYNAMIC COMPRESSION PLATES

The pertinent specification data on the most frequently used plates in equine fracture repair is collated in Table 8.2 in Chapter 8.

### Dynamic Compression Plating

#### Plate Application

After a fracture is reduced and stabilized by reduction forceps or independent 3.5 or 4.5 mm cortex screws

placed in lag fashion, the plate is contoured and subsequently attached to the bone by means of screws. The first screw hole is drilled in a neutral position (green DCP drill guide or the universal drill guide) through one of the plate holes toward the end of the plate. The screw is inserted, but not completely tightened. This allows displacement of the plate to a loaded position, if so desired. The same effect can be achieved by drilling the initial hole with the use of the load (yellow) DCP guide and maintaining the plate in the same position. When additional axial compression is needed, the hole for the second screw is drilled on the other side of the fracture line, again toward the end of the plate, using the load drill guide (Figure 9.4). Care is taken to ensure correct plate position prior to drilling of the second hole. By initially applying a screw toward each end of the plate, the surgeon can be sure that the entire plate is correctly positioned along the bone surface, especially when long plates are used. If the initial screws are inserted near the center of the plate, only a minor abaxial malalignment of the plate may result in the plate ends being displaced off the bone and into the soft tissues. The drilled hole is then measured for screw length and tapped for the screw, which is subsequently inserted. Fracture line compression is achieved through alternately tightening the two screws. One additional screw may be applied in load position on either side of the fracture line. Should an additional screw be placed under load, the screw initially inserted on that half of the bone has to be slightly loosened to allow motion of the plate relative to the bone as the additional axial compression is applied. The remaining screws are then inserted in neutral position throughout the plate. Any screw placed through the plate across a fracture line is introduced using lag technique, if possible. Obviously, for this technique the double drill guide or the universal drill guide has to be used and not the DCP drill guide.

The screws in a DCP can be applied in neutral, in load, or in buttress position. Under loading conditions, the arrow on the yellow drill guide must point toward the fracture line. This results in 1 mm of compression. If the arrow points away from the fracture line, the screw is placed in buttress position and does not provide fracture axial compression. During double plating, only two screws are placed in load position in the second plate, which is usually arranged at 90° relative to the first. Plates have to be contoured to fit the surface of the bone. For large plates, the bending press is preferred over bending irons. If the plate is perfectly contoured to the bone surface, only the near cortex will be under compression, whereas the far cortex will be spread apart. Therefore, the plate is minimally overbent at the fracture site, which provides a slight space under the plate near the fracture line and places the far cortex under compression as well.

## Plate Luting

Stability of the fixation is derived from friction between the plate and the bone. There is a direct proportional relationship between the amount of plate contact and the stability of the fixation. A technique developed to obtain 100% plate–bone contact, through interfacing bone cement between the plate and the bone, has been termed plate luting.<sup>45,47</sup> This is done after all screws in the plate are inserted. The screws of one plate are subsequently loosened, the plate is lifted off the bone, and PMMA in a doughy consistency placed between the bone and the plate. All the screws are immediately retightened using power equipment. Penetration of bone cement into the fracture line must be prevented, because it prevents bony union in that region. Once the screws are tightened, the excess soft cement is removed. The procedure is repeated with the second plate. To assure effective local tissue concentrations of antibiotics, the selected drug may be incorporated into the PMMA (see Chapter 48). The hardening process of the PMMA is an exothermic reaction, requiring cooling of the bone and metal with sterile saline solution. The soft cement also enters the oval hole of the DCP or LC-DCP and provides additional support to the screw head, making the fixation extremely rigid. Plate luting increases the area of plate–bone contact and the congruency of plate fit to the bone.<sup>62</sup> A study on unstable equine limb specimens revealed that plate luting results in increased stress protection for repaired third metacarpal and metatarsal bones.<sup>69</sup> A subsequent study in which only the plate holes were filled with PMMA demonstrated a similar increase in stress protection.<sup>71</sup> It is therefore most likely that the main effect of plate luting is achieved through addition of stability to the screw heads by filling the plate hole around them. The concept of plate luting is not applicable in humans and small animals because of the danger of bone avascularity under the plate, possibly inducing a pathologic fracture

following implant removal.<sup>56</sup> These complications have not been evident in the horse.

## Screw Positioning and Direction

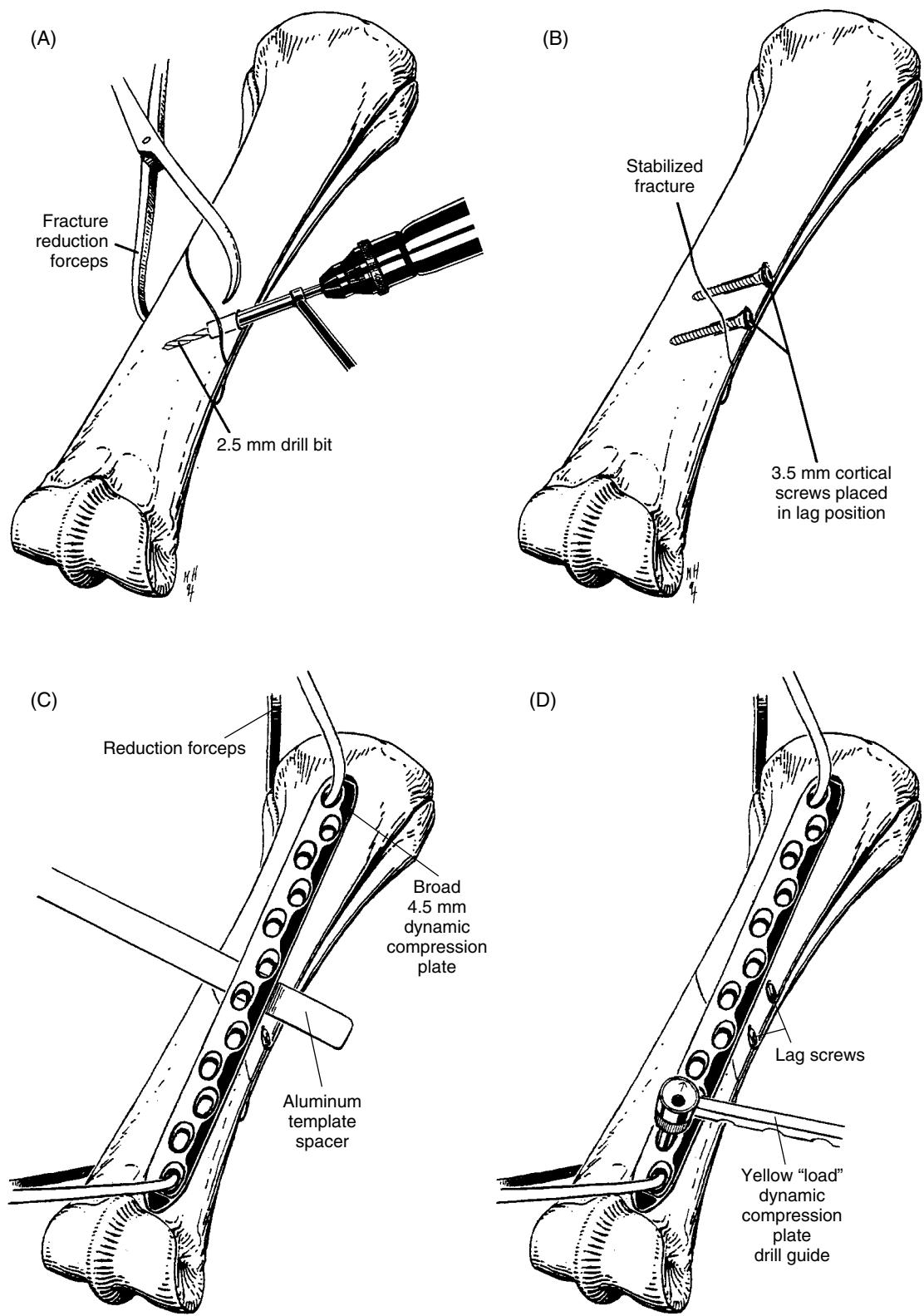
Whenever possible, plate screws should be inserted perpendicular to the plate or the long axis of the bone. This is of particular importance if two plates are applied at 90° angles relative to each other.<sup>2,3,6</sup> Applying the screws in this way reduces the possibility that screws from each plate will connect or touch within the bone. Every hole in the plate should be filled with a screw. Should a hole be located over a fracture line after all other screws have been tightened, lag technique is applied and the screw directed in such a way that it engages the opposite cortex next to the fracture line. Application of 4.5 mm screws through the 4.5 mm plate allows 20° of angulation in either longitudinal direction and 7° in the lateral direction. If 5.5 mm screws are used through a 4.5 mm DCP hole, angulation of only 10° in each longitudinal direction is possible and 3–4° to either side.

## Plate and Double Plate Positioning

Ideally, plates applied for fixation of a long bone fracture should extend over the entire length of the bone. Shorter plates must be staggered to ensure plate coverage over the total length of the bone.<sup>6</sup> The distal-most end of the proximal fragment in an oblique bone fracture should be wedged between a plate and the opposing distal fragment. Therefore, the configuration of a fracture may also dictate the location of the plate to be applied, not just the tension side of the bone.<sup>2</sup> Additionally, implants should be applied to avoid severely bruised skin or discrete skin defects, and, whenever possible, plates should not be applied to areas where the bone is covered only by skin. Plate application is easier in such regions, but the risk of developing a surgical site infection is much higher.

**Figure 9.4** Repair of a simple oblique third metacarpal fracture with two cortex screws applied in lag technique and a broad limited-contact dynamic compression plate (LC-DCP). (A) The fracture is reduced and temporarily maintained in reduction with the large pointed reduction forceps. Two 3.5 mm cortex screws are then applied across the fracture plane using lag technique. After drilling the 3.5 mm glide hole across the fracture line, the 2.5 mm insert portion of the double drill guide is inserted into the glide hole and the 2.5 mm thread hole drilled through the opposite cortex. (B) The remaining steps of the lag technique are completed and the two 3.5 mm screws inserted. It is important to preplan the screw location to avoid later interference with the plate. The large pointed reduction forceps can now be removed. (C) The 12-hole broad LC-DCP is contoured to the shape of the bone surface, and applied and maintained temporarily with two large pointed reduction forceps. The plate is slightly overbent at the fracture site, sufficient to allow an aluminum template to be inserted between the plate and the bone, to facilitate compression of the far cortex following screw tightening. (D) The yellow load drill guide is placed into the second most distal plate hole for drilling of the first thread hole. The arrow on the top of the drill guide should point toward the fracture line. (E) The hole is tapped and the screw is inserted but not tightened, allowing the screw head to protrude above the plate. On the opposite end of the plate a second screw hole is prepared using identical technique. The screw is inserted and subsequently both screws are completely tightened, which places the two fracture fragments under compression. The two large pointed reduction forceps are now removed. (F) The remaining screw holes with exception of the one crossing the fracture line are prepared using the green neutral drill guide and the screws inserted and firmly tightened. (G) The last screw is applied using lag screw technique across the fracture line. (H) After the final screw is inserted and tightened, all other screws are checked for tightness.





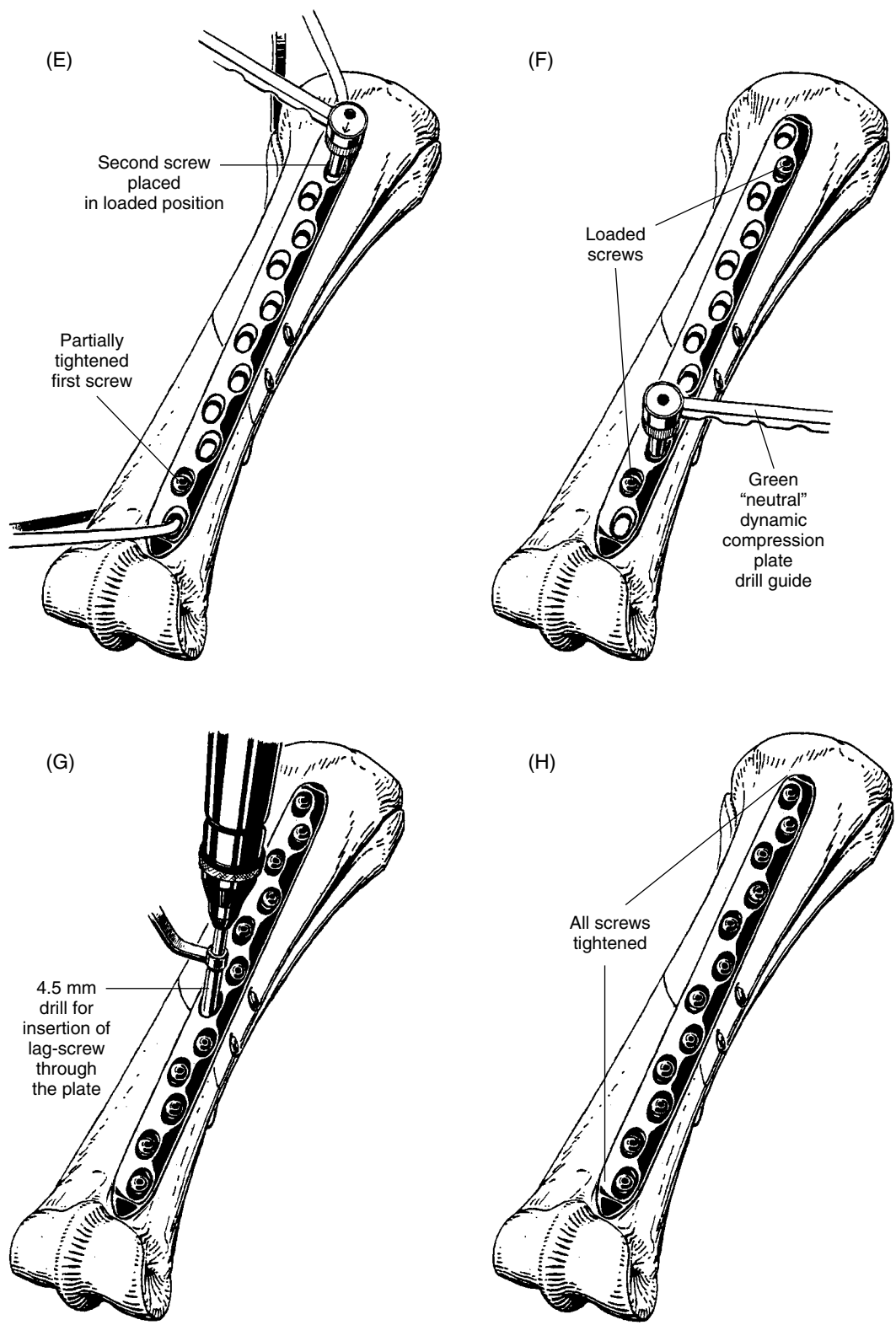


Figure 9.4 (Continued)

## Neutralization Plating

A neutralization plate is applied after reconstruction of a multifragment fracture with cortex screws inserted in lag fashion. Through this technique, compression is developed between the various fracture fragments. However, such a configuration is not able to withstand significant axial loading forces. To allow stress continuity, a plate is applied over the entire length of the bone. This plate is applied without axial compression, neutralizing the various diverging shear, bending, and rotational torque forces; it effectively bridges the long axis of the entire bone. It is important to plan the entire fixation to prevent interference of the independent lag screws applied in various planes across the bone fragments with the eventual plate screws.

## Buttress Plating

If a cortical defect persists after the fracture has been reduced, a weak area is created in that region. It is imperative that the defect is bridged by a plate to prevent collapse of the fracture into the defect. In such a case, no compression is applied because compression would result in an altered bone axis and possibly alter the axis of associated joints. Therefore, the screws are placed through the plate in buttress position, with the screw head down in the extreme end of the plate hole closest to the fracture and unable to provide compression. Such an application prevents collapse of the bone and maintains the axis while healing occurs. The cortical defect should be filled with a cancellous bone graft or a bone substitute. Any screw placed through the plate in the region of the defect should engage the opposite cortex. All the other principles of fixation have to be maintained.

## Cobra-Head Plating

The cobra-head plate is a modified DCP with an expanded end designed to improve fixation of long bone extremities.<sup>27</sup> The plate has improved application if it is custom ordered with the underside milled for screw insertion, rather than standard milling (see Chapter 8). The curvature of the reverse-milled plate fits the contour of the distal femur and proximal radius more accurately, reducing the need for extensive plate contouring. The round holes of the expanded end accept 4.5, 5.5, or 6.5 mm screws. After fracture reduction and preliminary screw insertion, additional screws are placed in the expanded plate end. Compression can be applied in the DCP holes of the plate shaft, which all compress toward the expanded end. The cobra-head plate is designed for metaphyseal fractures and other

fractures at the ends of long bones. It has also been applied for carpometacarpal and tarsometatarsal fracture/luxation and arthrodesis stabilization.<sup>44</sup> Application requires only DCP instrumentation, without additional specialized tools. Intraoperative radiographic monitoring is required in most cases, given the proximity to articulations during most applications.

## LIMITED-CONTACT DYNAMIC COMPRESSION PLATE

The basic application of the LC-DCP as well as the self-compressing function is identical to the DCP. Minor differences include the dynamic compression unit (DCU) plate hole design, which provides the capability of compression from either end of each plate hole and therefore axial compression of a fracture anywhere along the plate. Additionally, there is no center to the plate. The recessed underside of the plate also allows increased axial deviation of the cortex screws in the bone. This provides up to 40° of angulation along the axial plane of the plate when using 4.5 mm screws. Because there is the same amount of plate material at any given location, there are no stress concentrators located at the plate holes, and the plate bends more evenly in the bending press than a DCP.

A comparison between the broad 4.5 mm DCP and the broad 4.5 mm LC-DCP showed that the broad LC-DCP provided increased stability in static overload testing; however, it was significantly less stable in cyclic fatigue testing.<sup>58</sup> A special 5.5 mm LC-DCP was developed for equine fracture repair. An *in vitro* comparison between the 5.5 and the 4.5 mm LC-DCP revealed that the 5.5 mm LC-DCP fixation was superior to the 4.5 mm LC-DCP fixation in resisting the static overload forces of palmarodorsal four-point bending.<sup>59</sup> There was no significant difference between the 5.5 mm LC-DCP fixation and 4.5 mm LC-DCP fixation in resisting static overload forces under torsion. However, the 5.5 mm LC-DCP provided significantly less stability (80% of that of the 4.5 mm LC-DCP) in cyclic fatigue testing.<sup>59</sup> Additionally, the 5.5 mm LC-DCP was not pursued to market due to the development of the LCP. In general, the LC-DCP provides an advantage in screw angulation and bidirectional fracture compression that makes it a versatile plate for equine fracture repair.

The double-ended LC-DCP drill guide provides neutral and load configuration, but must be positioned in the DCU slot with the arrow oriented toward the relevant fracture line, to provide appropriate directional compression. The handle of the drill guide has an undercut

surface to alert the surgeon to the LC-DCP guide rather than the DCP drill guide.

## LOCKING COMPRESSION PLATE

The LCP was developed to incorporate the axial loading capabilities of the DCP and LC-DCP, the decreased plate–bone contact of the LC-DCP, and the rigidity and stiffness of the Less Invasive Stabilization System (LISS), where locking-head screws were first used.<sup>19,20</sup> The goals were met by designing a “combi hole” where either a standard screw or a locking screw could be inserted. It is not necessary to only apply locking-head screws. A study comparing the application of two LCPs at right angles relative to each other, with identical constructs using DCPs, LC-DCPs, and clamp-rod internal fixators (CRIFs) in four-point bending, showed that implanting two locking-head screws on either side of an oblique saw cut across an artificial bone composite (Canevasit™, Erhard Hippe, Spremberg, Germany) provided significantly increased stiffness to the construct.<sup>17</sup> Substituting cortex screws for locking-head screws in several holes in the LCP significantly reduces cost without jeopardizing the stability and stiffness of the construct. Without application of the push–pull device or standard cortex screws, both of which compress the plate onto the surface of the bone, a gap of 2 mm or more will be present between the plate and the bone after application of the LCP. Therefore an early basic decision in LCP application hinges on whether there is a necessity to apply the LCP close to the bone. For most open repairs in horses, the stability of fixation in the LCP construct is enhanced by additional bone–plate friction. This supplements the rigidity provided by the locking-head screws.

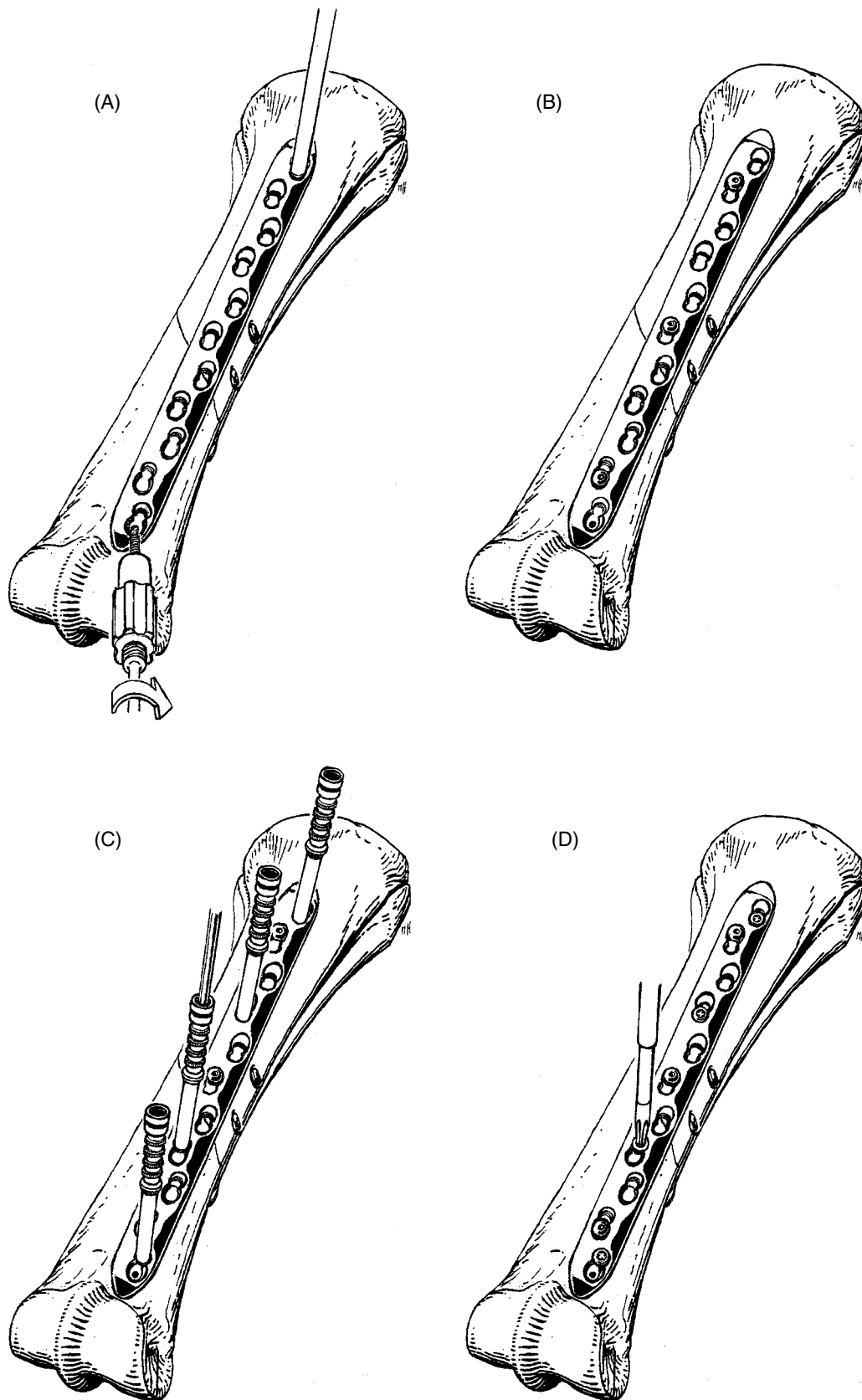
The LCP is positioned with the plate holder and the push–pull device inserted at a slight angle through the DCU portion of the combi hole (Figure 9.5A). By turning the collet in a clockwise direction, the plate can be pressed onto the bone surface. At the same time, it temporarily fixes the plate to the bone and maintains fracture alignment. A second push–pull device can also be applied through the stacked combi hole on the other end of the plate if desired. The strategic cortex screws are then inserted and tightened to facilitate solid bone–plate contact (Figure 9.5B). A second plate can be positioned and similarly fixed to the bone with several cortex screws. After removal of the push–pull device and the plate holder, the locations for the locking-head screws are selected to avoid contact with the cortex screws and any other interfragmentary screws. The planning of screw insertion is a vital part of LCP application. Planning screw position and angles becomes even more important

when two LCPs are applied, because the locking-head screws *must* be inserted perpendicular to the plate. The fact that the screw position differs if a locking-head screw or a cortex screw is used through a combi hole represents an additional difficulty in the planning of the surgery. This fact is further compounded if a combination of a DCS, with mainly DCP holes, and an LCP is used, because the lengths of the DCP hole and the combi hole are different. Once locking-head screws are applied, the plate is solidly fixed in its position, and cannot be further compressed to the bone.

The LCP drill guide is carefully twisted into the threaded part of the combi hole. To facilitate perpendicular insertion and solid engagement of the threads in the plate hole, the drill guide is placed into the combi hole and then twisted backward until a click generated when the drill guide slips from the upper thread onto the one located just below is heard. Then the drill guide is twisted clockwise to engage the threads of the combi hole. When solidly seated, its position relative to the plate is evaluated once again, assuring its perpendicular orientation. All the LCP drill guides provided in the set can be fixed to the plate to speed up the procedure, followed by drilling all the holes (Figure 9.5C). The drill guides are removed and the screw lengths are determined using the depth gauge. The 4 N torque-limiting device is attached to the power drill, followed by insertion of the power attachment for the star drive. By pressing the screwdriver into the star drive indentation of the LCP screw in the rack, the screw is selected, secured by friction, and withdrawn from the rack, and then advanced into the predrilled hole using the power-tapping technique. The screw is fully inserted until the torque-limiting device releases, indicating that the 4 N maximum insertion force has been reached. This precautionary step was initially introduced in human surgery to prevent cold welding between the titanium plate and screws. Most equine LCP application uses stainless steel implants, which minimizes the danger of cold welding. Nevertheless, the use of the torque-limiting device is recommended, at least in soft bone. Adult equine bone is quite hard, and for long screws the 4 N threshold may be reached prematurely, before complete tightening of the screw head threads in the plate. It is therefore prudent to provide final tightening with the hand screwdriver (Figure 9.5D). Once all locking-head screws are implanted, any empty plate hole should be filled by applying a cortex screw through the DCU portion of the combi hole at the angle necessary to avoid contact with a screw in the other plate.

The finely machined threads in the locking screw head and plate form a tightly bonded unit, which prevents the screw head from moving within the plate and thereby provides significant stiffness to the construct. Locking-head screws inserted into the plate feel very solid,





**Figure 9.5** Application of a locking compression plate to an oblique third metacarpal fracture. (A) After reducing and temporarily stabilizing the fracture with two 3.5 mm cortex screws, the plate is applied to the desired bone surface with the plate holder and temporarily fixed in place with the push-pull device. By turning the collet on the push-pull device in a clockwise direction (arrow), the plate is pressed onto the bone surface. (B) To facilitate good plate-bone contact along the entire plate, cortex screws are inserted and tightened using plate screw technique in the self-compressing portion of each combi hole at both ends and in the center of the plate. (C) The holes where locking-head screws are to be inserted are selected and the drill guide twisted into the threaded portion of the combi hole. Because the plate is solidly fixed to the bone, and no further compression of the fracture or plate to the bone is required, all four drill guides provided in the set are applied, followed by drilling all four holes. (D) The locking-head screws are inserted with the power drive with the torque-limiting device interconnected between the drill and the power screwdriver. The screws are subsequently hand tightened, followed by insertion of the remaining cortex or locking-head screws through the empty plate holes.

because the threads in the screw head engage the corresponding threads in the plate. This does *not* mean that the screw is solidly inserted into the bone beneath the plate. This is a new experience for the surgeon and must always be kept in mind. When inserting locking screws through significant soft tissue overlying an LCP, it may be difficult to twist the drill guide perpendicularly into the threaded portion of the combi hole. Separate stab incisions through the overlying muscle bellies may be required to provide access to the combi hole at a right angle. The drill guides can be lengthened by threading several guides end to end to facilitate engagement in the plate and subsequent correct drilling of the hole.

The LCP has quickly established itself as the preferred plate for many equine fracture fixation applications, despite the additional cost of both plates and screws.<sup>10,24,31</sup> A recent study comparing 4.5 mm LCPs with 4.5 mm LC-DCPs confirmed the superior strength and stiffness of the LCP.<sup>60</sup> Recently a 5.5 mm LCP designed specifically for equine fracture repair has been developed, replacing the 5.5 mm LC-DCP (see Chapter 8).<sup>61</sup>

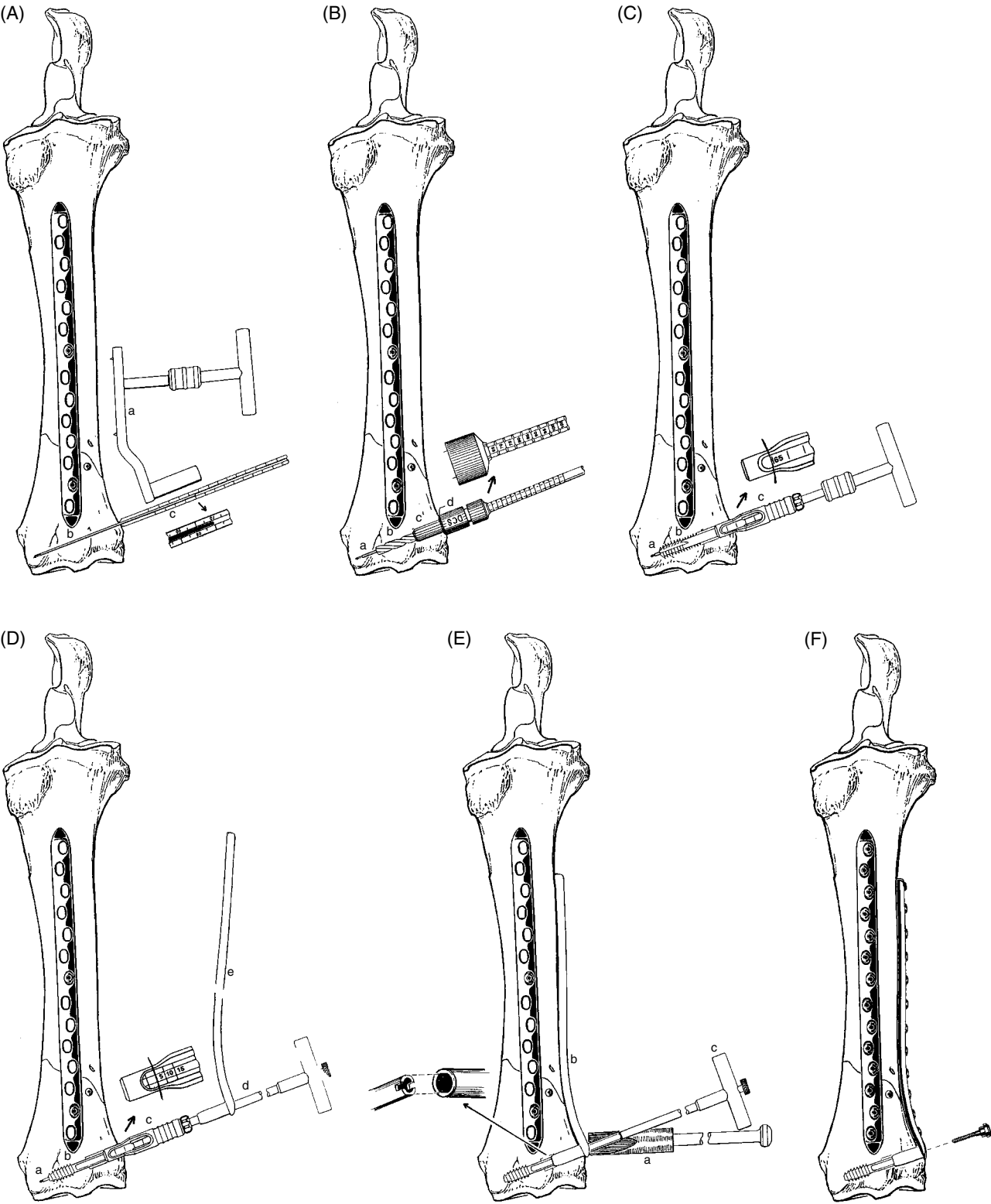
## DYNAMIC CONDYLAR SCREW AND DYNAMIC HIP SCREW APPLICATION

The DCS plate has established itself as a very useful implant in the treatment of equine long bone fractures,<sup>2</sup> more so than the DHS system.<sup>1,4</sup> The primary application of the DCS plate is in metaphyseal fractures, where only a few screws can be secured in the smaller fragment. The DCS plate has replaced the angled blade plate for application in long bone fractures with a short metaphyseal fracture fragment.<sup>18</sup> The DHS plate has been applied in femoral capital physal fracture repair,<sup>23</sup> but alternative fixation methods such as cannulated 7.3 mm screws or diverging 5.5 mm cortex screws have reduced the use

of the DHS plate for proximal femur fixation. It is still used on occasion for plating repair of distal femoral fractures.

The most important step in the application of the DCS and DHS plate systems is the correct placement of the 2.5 mm guide pin (Figure 9.6A).<sup>1</sup> Drill guides for the different angles of the DCS and DHS plates ensure exact placement of the guide pin, which is verified with an image intensifier or intraoperative radiography. Once correct placement of the guide pin is confirmed, the subsequent steps are carried out swiftly, because all instruments contain a central canal to accept the guide pin. The triple reamer is placed over the guide pin, to allow drilling of the thread hole for the large lag screw, drilling of the 12.5 mm hole for the plate barrel, and beveling of the cone shaped plate–barrel interface (Figure 9.6B). The threads for the DCS lag screw are prepared using a suitably sized tap (Figure 9.6C) and the screw of appropriate length is introduced, followed by the plate (Figure 9.6D). Once the shaft of the screw and the barrel are aligned, the barrel slides easily over the shaft and the plate position can be adjusted before impacting it onto the bone (Figure 9.6E). The barrel has the same inside configuration as the screw shaft cross-section (8 mm and flattened at two opposite sides). This prevents screw rotation within the barrel after the plate is attached to the bone, making loosening impossible. The DCS plate has a barrel length of 25 mm, whereas the DHS is supplied in versions with a barrel length of 25 and 38 mm.<sup>23</sup> After their implantation, the lag screw and the plate are joined with a connecting screw, uniting the two separate components (Figure 9.6F). Tightening of the set screw creates interfragmentary compression, provided that the lag screw threads have passed beyond the fracture line. Remaining screw holes in the DCS and DHS plates are filled by 4.5 or 5.5 mm screws placed under load or in a neutral position. The two holes adjacent to the lag screw can only be placed in a neutral position.

**Figure 9.6** Application of the dynamic condylar screw (DCS) plate to the distal radius. (A) The distal radius fracture is reduced and temporarily fixed with two 3.5 mm cortical screws, applied in lag fashion across the fracture plane. Subsequently, a 14-hole limited-contact dynamic compression plate is applied to the cranial bone surface (tension side) with two cortical screws providing axial compression. The guide pin (b) is applied through the special drill guide (a). The measuring device (c) applied over the guide pin allows the determination of the pin length inserted in the bone in this instance (70 mm). (B) The DCS triple reamer is assembled and set for the drilling depth desired (65 mm), which is 5 mm less than the pin length in the bone and assures maintenance of the pin during DCS screw insertion. The triple reamer is placed over the guide pin (a) and the shaft hole for the DCS screw (b), the barrel hole for the plate (c), and the barrel–plate junction (d) are prepared. (C) The DCS centering sleeve (c) is placed over the tap (b), which is subsequently placed over the guide pin (a). After inserting the centering sleeve into the barrel hole, the tap is advanced to the desired depth (65 mm). (D) The DCS coupling screw (d) is placed through the T-handle and the DCS plate (e) of selected length (12-hole) and connected to the DCS screw (b) of desired length (60 mm). The centering sleeve (c) is applied over the coupling screw. After placing the assembly over the guide pin (a), the screw is inserted to a depth of 65 mm, which is marked on the centering sleeve as 5 mm. (E) After tightening the screw and adjusting the horizontal bar of the T-handle (c) parallel to the long axis of the bone, the DCS plate (b) is seated over the shaft of the DCS screw with the help of the DCS impactor (a) and a mallet (not shown). Orientation of the instruments and implants is important, because the DCS screw (left insert) and the plate barrel (right insert) contain complementary parallel contours, which have to be aligned to allow sliding of the barrel over the screw shaft. (F) The DCS compression screw is inserted through the plate barrel and tightened into the back end of the DCS screw. This unites the three components (DCS screw, DCS plate, and connecting screw) to one. Insertion of the remaining cortical screws and final tightening of all screws completes the procedure.



## INTRAMEDULLARY FIXATION (WATKINS)

Intramedullary fixation has been used sparingly in large animal orthopedics. Few reports advocate this method of fixation for repair of diaphyseal fractures, but success has been reported in femur fractures in foals and calves and humeral fractures in foals.<sup>6,63,64</sup> Other reports advocate intramedullary (IM) fixation techniques for repair of physeal fractures of the proximal tibia, femoral capital physeal fractures, and fractures of the olecranon.<sup>40,52,70,75</sup>

### Intramedullary Pins

#### Steinmann Pins

Veterinarians are most familiar with traditional IM fixation, which uses a single smooth Steinmann pin with a diameter of approximately 60% of the diameter of the medullary canal.<sup>13</sup> Intramedullary pinning alone, as well as in conjunction with cerclage wires or an external fixator, is commonly utilized for management of long bone fractures in small animal veterinary practice. A number of general guidelines have been formulated to improve success rates, including recommendations on fracture location, configuration, and implant selection. In general, mid-diaphyseal fractures which are stable in compression and rotation are best suited for IM fixation alone. Transverse or short oblique fractures with substantial interdigitation between fracture fragments are ideal candidates. Long oblique fractures require the use of supplemental fixation in the form of cerclage wires to prevent telescoping and to provide rotational stability during weight bearing. Significant comminution, particularly when there is less than 50% contact between the proximal and the distal cortices at the fracture site, precludes adequate fixation with traditional IM techniques.

Intramedullary fixation with a single pin relies on load sharing between the implant and the intact cortical bone of the major proximal and distal fracture fragments. The implant serves primarily to maintain alignment at the fracture site, with contact between fracture fragments providing axial and rotational stability. Resistance to bending forces is provided by contact of the pin with the medullary canal. Because absolute stability is not achieved, indirect bone healing with periosteal callus is responsible for fracture union.

In many cases in which a single IM pin is utilized, the fracture is reduced and stabilized using closed-fracture techniques. This approach results in minimal additional trauma to the soft tissue envelope, which reduces the potential for infection and promotes early revascularization and fracture healing. Closed fixation, combined with the ability of most small animal patients to ambulate effectively while protecting the fractured limb from full

weight bearing, undoubtedly contributes to the success of IM single-pin fixation in small animal practice. Unfortunately, equine fracture fixation can only rarely be accomplished using closed techniques. Furthermore, a single IM pin is not likely to provide the stability necessary for substantial postoperative weight bearing. The severity of complications related to the lack of weight bearing on the fractured limb dictates that the fixation provide adequate strength and stability at the fracture site for an early return to unprotected weight bearing; otherwise complete restoration of function is unlikely.

Application of multiple parallel pins across capital femoral physeal fractures has been advocated and has resulted in some success.<sup>70</sup> Steinmann pins have also been used in the treatment of olecranon fractures in the very young foal, in combination with a tension band such as cerclage wire.<sup>52</sup>

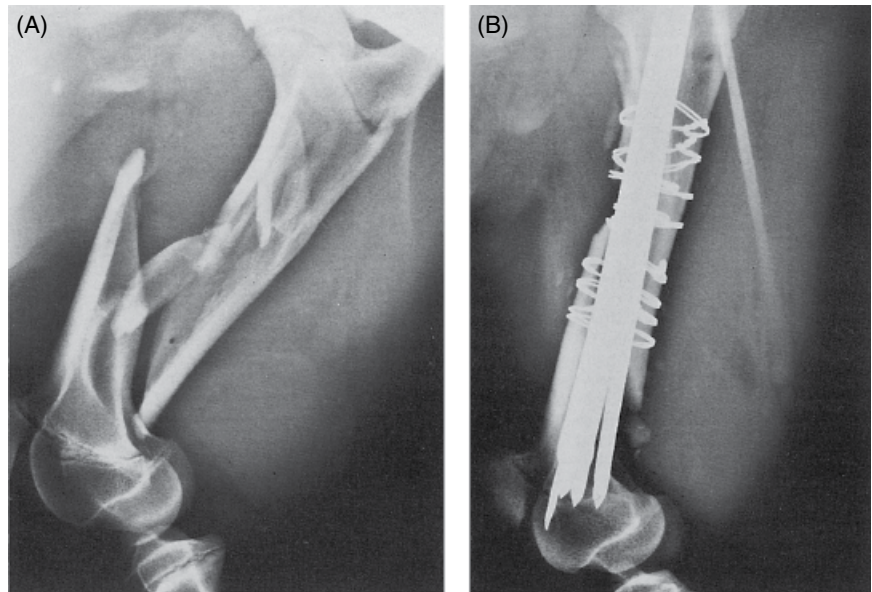
In most equine fractures, the goals of strength and stability at the fracture site are best achieved by accurate anatomic reconstruction of the fractured bone and stabilization with one, or preferably two, DCPs or LCPs. When this is not possible and the fractured bone is either the humerus or femur, or occasionally the proximal aspect of the tibia, IM fixation should be considered as a potential alternative. However, traditional IM fixation with a single Steinmann pin, as previously discussed, is inadequate in most cases. Several methods are recommended to increase the strength and stability of the fixation over that provided by a single IM pin, and include stacked pin fixation, or preferably an IIN.

#### Stacked Pin Fixation

Stacked pin fixation fills the medullary canal with multiple IM pins. When the entire medullary space throughout the narrowest portion of the diaphysis (the isthmus) is filled, frictional forces between the implants and medullary cortical bone are increased. *In vitro* studies performed on transverse fractures in dog femurs showed that stacked pin fixation provided up to three times more rotational stability than a single IM pin.<sup>12,72</sup> As with single IM pin fixation, axial and rotational stability depends predominantly on the location and configuration of the fracture. Although stacked pin fixation increases resistance to torsional forces, significant rotational instability remains. Transverse and short oblique fractures in the mid diaphysis are best suited to stacked pin fixation. Mid-shaft fractures develop maximal contact between the implants and the medullary cortex of the bony cylinder on either side of the fracture. When the medullary canal is filled by implants, translation, telescoping, and overriding of the fracture fragments are prevented. Although rotational stability relies heavily on fracture interdigitation, friction between the medullary cortical bone and stacked IM pins will resist rotational forces significantly better than



**Figure 9.7** (A) Comminuted femur fracture in a miniature foal. (B) Treatment of the fracture by the use of stacked-pin fixation in conjunction with multiple cerclage wires.

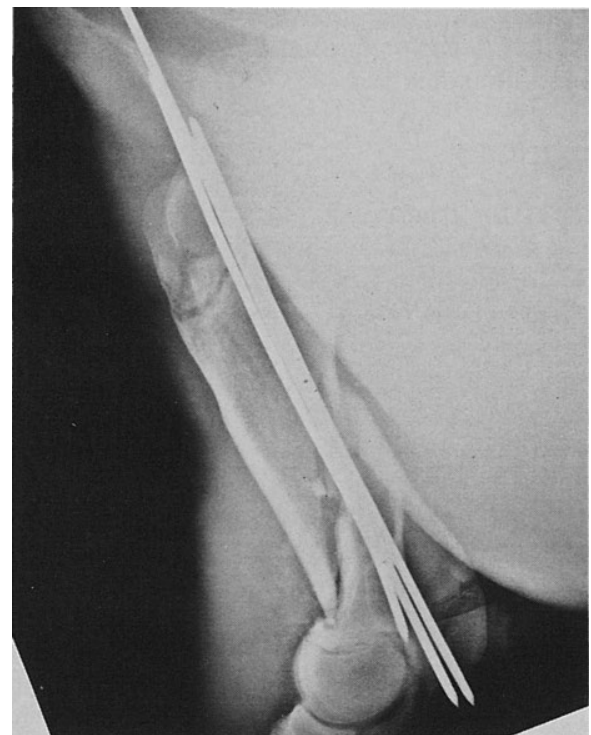


a single IM pin. In fractures with significant obliquity, the addition of a cerclage device substantially improves stability. Unfortunately, cerclage wiring in large animals is frequently inadequate to provide stability.

Stacked pin fixation has been used successfully in the management of short oblique and transverse fractures of the mid-humeral diaphysis in foals.<sup>6</sup> Other applications have included femoral fractures in calves and foals (Figure 9.7).<sup>64</sup> As many 1/4 in. Steinmann pins as possible are inserted into the diaphysis. Usually four or five pins can be placed in a foal's humerus or femur. The space between the 1/4 in. pins is then filled with pins of smaller diameter such as 5/32 in. Steinmann pins, to ensure maximal contact of the IM pins and the cortical bone of the diaphyseal medulla.

Placement of the multiple IM pins is accomplished in normograde fashion. Exposure of the fracture is generally necessary to allow realignment and temporary stabilization of the fracture fragments with a bone clamp or a similar device. In addition, adequate exposure of the proximal long bone is needed to allow pin placement. Driving several IM pins the length of the diaphysis can be difficult even with power equipment. Preferably, the medullary canal can be reamed prior to pin placement (see the discussion of IIN fixation later in this chapter). Medullary reaming simplifies pin placement and increases the degree of contact between the IM pins and the medullary cortical bone. Following reaming of the medullary canal, the fracture is aligned and stabilized with a bone clamp, and pin placement commences as previously described.

Complications associated with stacked pin fixation include those associated with any form of open reduction and internal fixation. In addition, because of the inherent



**Figure 9.8** Humeral fracture in a foal stabilized by multiple intramedullary pins. Overriding of fracture fragments has resulted in pin migration.

instability associated with IM pinning, implant migration is a major concern. Motion at the fracture site during use of the repaired limb often initiates pin migration (Figure 9.8). Pin migration tends to be retrograde, particularly if axial collapse is occurring at the fracture site. As the

pins migrate, stability is compromised, which allows more motion at the fracture site and perpetuates the cycle of further implant migration and instability. Eventual success or failure is a race between the increasing ability of the healing fracture to sustain the forces of weight bearing and the decreasing ability of the fixation to provide stability at the fracture site. An additional concern is the tendency for migrating pins to penetrate the skin. Environmental contaminants can follow pin tracts, gaining access to the medullary cavity, and osteomyelitis can result. Instability, when complicated by infection, seriously compromises the healing capacity of the affected bone. The time to fracture union is substantially prolonged, and in some cases an infected nonunion may result.

### Rush Pins

The Rush pin method of fracture treatment was popular before bone plating was introduced. Fracture fixation using these devices is an art. The slightly prebent pins are introduced obliquely into the distal fragment and advanced toward the opposite cortex. The tip of the pin, which is flattened on one side, slides off the opposite cortex and is redirected toward the near cortex. The length of the pin has to be predetermined to allow the tip to engage in the near cortex proximal to the fracture, providing four-point contact. Usually, two pins are introduced, one from each side of the bone. If the technique is performed correctly, good rotational stability is achieved, with a minimum of implants and surgical trauma. The Rush pin fixation technique is not applicable in comminuted or open fractures. With the better stabilization and early mobility afforded by the numerous plating and interlocking nail techniques in horses, the use of Rush pins is only of historical interest.

## Intramedullary Interlocking Nail Fixation

Transfixation of the major proximal and distal bone fragments to an IM rod was first described by Kuntscher, who termed it “centromedullary pegging” and named the device a “detensor nail.”<sup>29</sup> Modifications by Klemm and Schellmann<sup>28</sup> were later incorporated, and the device was renamed the intramedullary interlocking nail. In human orthopedics, interlocked nailing is currently the preferred method of fixation for a variety of complex fractures of the femur, and is becoming more frequently used in humerus and tibial fractures.<sup>7,8,11,14</sup>

### Interlocking Nail Technique

In most human fractures, IIN fixation is accomplished using closed surgical techniques.<sup>14</sup> Closed interlocking nail fixation provides excellent stability at the fracture site and, because of the minimal operative trauma to the

overlying soft tissues, results in a biologic and mechanical environment which supports fracture healing while also allowing early mobilization of the fractured limb. Additionally, many of the complications associated with open reduction and fracture fixation by plating methods are avoided.

Intramedullary nailing in humans currently utilizes a slightly flexible nail passed normograde down the prereamed medulla. Interlocking nails have recently been introduced which eliminate the need for medullary reaming prior to fracture fixation.<sup>8,14</sup> Once the nail is in the medulla, interlocking is accomplished in the proximal fragment using a targeting jig attached to the nail, which positions the cortical drill hole to coincide with a prefabricated hole in the nail through which a screw of appropriate size is placed. The slight flexibility of the nail, while allowing it to fit the contour of the medullary cavity, also requires the use of image intensification and sophisticated targeting devices to interlock the nail in the distal fragment.

Interlocking the IM device to the major proximal and distal bone cylinders provides a static form of fracture fixation that resists compressive and rotational forces and provides bending stability. Fixation positioned in the medullary cavity near the center of the bone, close to the neutral axis of the diaphysis, imparts a significant mechanical advantage over plate fixation, particularly when the bony cylinder cannot be reconstructed. *In vitro* tests, using a comminuted subtrochanteric femoral fracture model, showed that in combined bending and compression, interlocking nails supported the highest loads to failure.<sup>68</sup> In that study, interlocking nails supported 300–400% of body weight, whereas plate systems failed at loads equivalent to 100–200% of body weight. Intramedullary interlocking nail constructs rely less on the reconstructed fracture to resist the forces of weight bearing. This reduces the necessity for anatomic reduction and rigid fixation of all fracture fragments that are specifically recommended for most forms of plate fixation.<sup>50</sup>

### Equine Application

Interlocking nail systems for use in large animal fracture fixation are not yet commercially available.<sup>22,35,37,38,51</sup> The implants used in human orthopedics are for the most part slotted, tubular designs, which compromise the strength of the fixation and mitigate against their use in equine fracture repair. A recent equine investigation of an interlocking nail designed for use in the human tibia found that the yield torque for the IIN constructs was less than that associated with strains measured *in vivo* in the tibia of a horse at the walk.<sup>39</sup> The slotted design of human nails substantially reduces the stiffness of the implant and results in a drop in the torsional moment of inertia to

approximately 1/50th of the value of a nonslotted nail of equal dimension and wall thickness.<sup>66</sup> Furthermore, the slot must be oriented toward the tension surface of the bone to achieve maximal bending stiffness. If the slot is oriented in another direction, buckling of the nail is likely to occur secondary to bending forces.

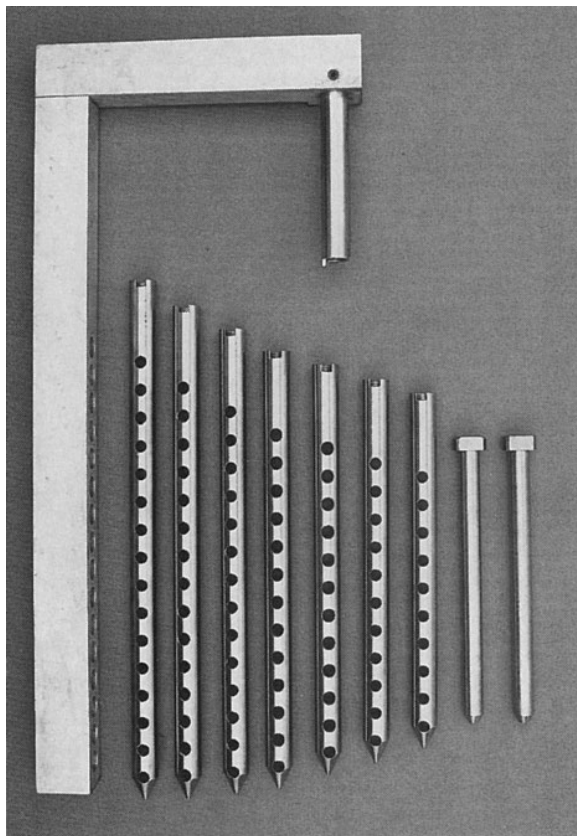
A study of an intramedullary AO nail for third metacarpal and metatarsal fractures has been published.<sup>21</sup> Introduction of the nail into the bone was achieved through an osteotomy of the attachment of the extensor carpi radialis tendon and an arthrotomy of the carpometacarpal joint. After introduction of the nail into the medullary cavity of the third metacarpus, the osteotomy fragment was reattached to the metacarpus using lag screws, in conjunction with an arthrodesis of the carpometacarpal joint using screws and cerclage wire. Extensive reaming was necessary to introduce the nail. Once in place, the nail was very functional; however, the mode of introduction proved to be impractical.

An equine interlocking nail (Prototype manufactured by IMEX Veterinary, Longview, TX, USA) for use in the humerus and femur of foals and calves has been developed (Figure 9.9).<sup>35,51,73,74</sup> The IM implant is constructed from implant grade 316L stainless steel rod  $\frac{1}{2}$

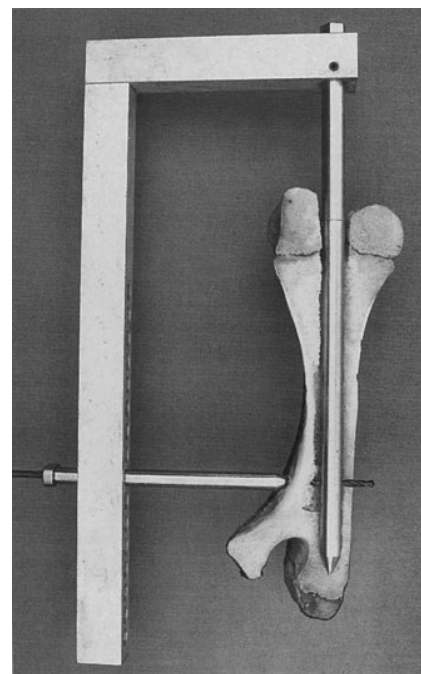
in. in diameter. The holes for interlocking accept 5.5 mm cortical bone screws (DePuy Synthes) and are positioned throughout the length of the nail to allow the use of many transcortical bone screws for interlocking the major fracture fragments. Targeting of the screw holes is accomplished by the use of a jig, which accepts drill guides as well as other instrumentation necessary for hole preparation (Figure 9.10). The rigid nature of the nail allows use of an attached rigid targeting device for locating screw holes, obviating the need for specialized targeting systems using image intensification.

### Technique in the Horse

Techniques for fracture fixation using the interlocking nail system are similar to those for stacked pin fixation. Initially, the fracture is exposed and debrided. The medullary canals of the bony cylinders proximal and distal to the fracture are reamed. In most instances, the distal cylinder is reamed retrograde, commencing from the fracture and advancing distally. Rigid medullary reamers of increasing size are used to reach a final diameter of 13 mm. The proximal bony cylinder is subsequently reamed, usually in normograde fashion, beginning from the proximal end of the bone and progressing to the fracture site. Once both cylinders are reamed, the fracture is reduced and temporarily stabilized with a bone clamp. A nail of appropriate length is selected and, with the targeting jig attached, the nail is passed into the

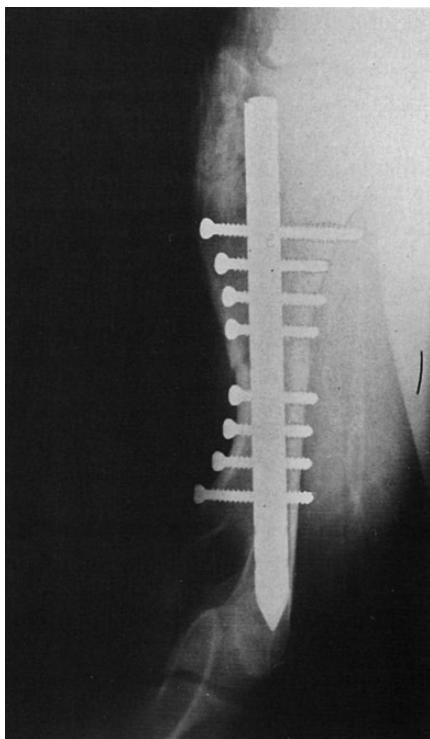


**Figure 9.9** A large animal intramedullary interlocking nail system showing targeting jig, various length nails, and drill guides.



**Figure 9.10** Cross-section of foal humerus demonstrating the procedure for drill hole preparation with the targeting jig and drill guide.





**Figure 9.11** Caudal to cranial radiograph, demonstrating intramedullary interlocking nail in 4/4 fixation of humeral osteotomy.

reamed medullary canal. Screw holes are drilled with guidance from the targeting jig and the screws interlocked (Figure 9.11). When possible, at least three 5.5 mm cortical bone screws are interlocked on both sides of the fracture. This fixation is described as an IIN-3/3 construct, a designation that delineates the number of interlocking screws proximal and distal to the fracture. If possible, fractures with significant obliquity are afforded additional stability by placing one or two interlocking screws across the fracture in lag fashion. If this is not feasible, then some form of cerclage wire fixation is recommended. In addition, washers (DePuy Synthes) are recommended to prevent the conical head of the interlocking screws penetrating the cortical bone. This fixation device has been evaluated by *in vitro* and *in vivo* controlled studies.<sup>35,73,74</sup> An *in vitro* study, using a foal humerus fracture model, showed that IIN fixation provides significantly more rotational stability than stacked pin fixation.<sup>74</sup> In addition, *in vivo* studies have shown there are no detrimental effects of medullary reaming alone or in conjunction with IIN fixation on the growth and development of the normal foal humerus.<sup>73</sup> More recent studies document that healing of transverse humeral and femoral osteotomies will occur within four to six months after IIN fixation.<sup>35</sup>

Although the number of clinical cases in which IIN fixation has been used is limited, the deficiencies and

benefits of interlocking nail fixation are apparent.<sup>4</sup> As with all forms of fixation, the location and configuration of the fracture significantly affect the surgeon's ability to achieve stability and subsequent healing of the fractured bone. For ideal fixation of fractures in foals, three interlocking screws should be positioned on either side of the fracture, and the distance between the two screws inserted nearest the fracture should be as short as possible. Fractures located near the epiphysis are less readily stabilized using interlocking nail fixation, and the epiphyseal segment is at an increased risk for secondary fracture through the interlocking screw holes. In these instances, some form of supplemental fixation is necessary to decrease the potential for catastrophic failure of the fixation. Long oblique fractures, particularly those in which the plane of the fracture interferes with screw placement adjacent to the fracture line, appear to be at increased risk for implant failure. Although three interlocking screws can be positioned in the proximal and distal fracture segments, if the length between the two screws on either side of the fracture is great, cyclic bending forces put the implant at risk for fatigue failure. In these instances, the implant is best positioned to allow one or two additional interlocking screws to be placed in lag fashion across the fracture plane. If this is not feasible, then some form of cerclage must be relied on to neutralize the bending forces. Unfortunately, standard cerclage wire fixation is unreliable for this purpose. Alternative devices such as stainless-steel cables are currently being evaluated to identify an implant for this purpose. Supplementing the interlocked nail with a DCP or LCP applied using a unicortical technique to the cranial aspect of the humerus has enhanced the stability of repair in oblique fracture configurations and improved success in clinical cases.<sup>76</sup>

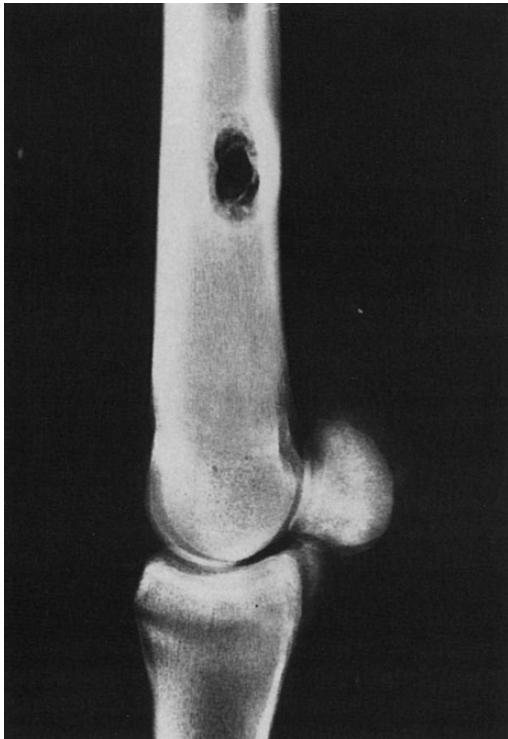
## EXTERNAL SKELETAL FIXATION

In principle, external skeletal fixation (ESF) offers an attractive method for fracture management, particularly in those fractures accompanied by substantial soft tissue trauma. The ability to stabilize a fracture without surgically invading the overlying soft tissue envelope, stripping the bone of remaining soft tissue attachments, and implanting large quantities of foreign material into the wound is a distinct advantages when considering the biology of fracture healing.<sup>49</sup> However, the mechanical limitations of most devices used for ESE, particularly in large animal practice, markedly limit their application. Fracture healing relies on the fixation method to provide adequate stability to create and maintain a mechanical environment suitable for new bone formation. In addition, the fixation must provide adequate strength to protect



the fracture from the forces of weight bearing throughout the healing period. One of the major limitations of ESF in equine patients is the inability of conventional ESF techniques to neutralize the forces associated with full weight bearing.<sup>48</sup> Mechanical failure of the devices is highly probable, with the clamps used to connect the transfixation pins to the sidebars at greatest risk.

ESF devices with adequate strength to support weight bearing in large animals are still at risk for implant loosening, just as they are for ESF applications in all animal species. Implant loosening is primarily the result of bone resorption at the interface of the transfixation pin and the cortical bone. Although a number of factors contribute to loosening at the bone–pin interface, the strain environment at this interface is probably the most important factor.<sup>49</sup> If pin stress secondary to the forces of weight bearing results in substantial pin deflection and therefore significant strain at the interface, then bone resorption is initiated. Bone resorption leads to increased pin motion, and a vicious cycle of resorption and motion is perpetuated (Figure 9.12). This complication is particularly common in equine ESF because of the extremely large loads placed on the transfixation pins during full weight-bearing activity.

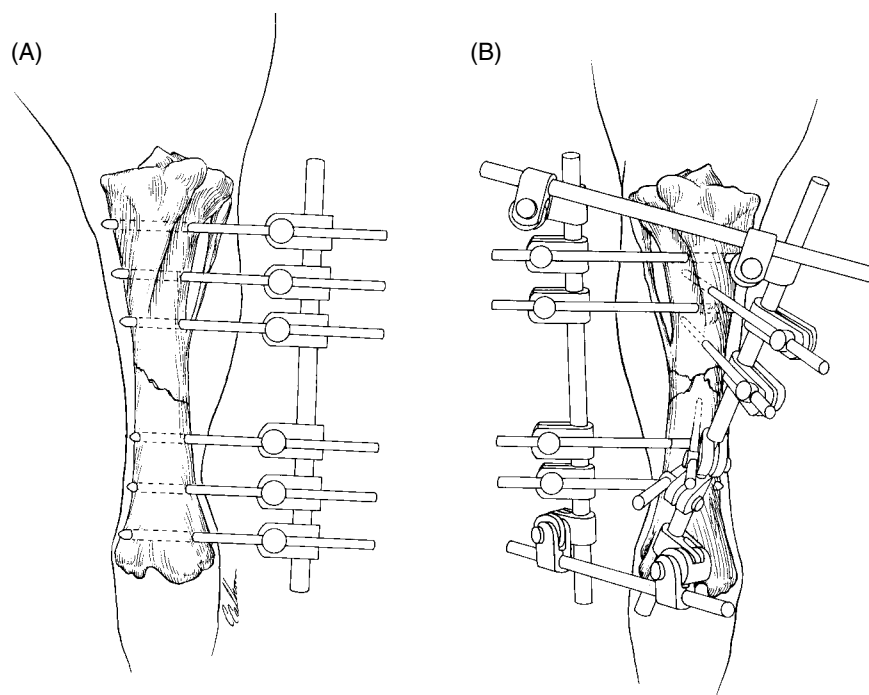


**Figure 9.12** Radiograph showing substantial bone resorption at the site of a transfixation pin utilized for transfixation cast stabilization of a distal limb injury. In this case a single transfixation pin was utilized, which may have contributed to the degree of resorption.

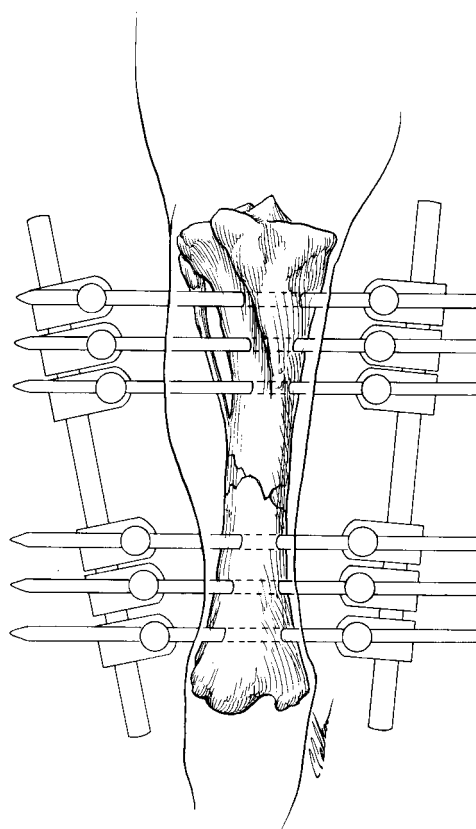
The strength and stiffness of a fixation after application of external skeletal fixators are determined by a variety of mechanical factors. As with all treatment modalities, the configuration of the fracture significantly influences the ultimate mechanical properties of the surgical construct. This is especially true with ESE, where there is usually no attempt to reconstruct and internally stabilize the fractured bone. The ESF frame must be able to neutralize all forces acting on the fracture until the healing bone can begin to accept some of the load. In the equine patient, these forces are great and are likely to promote premature loosening of the transfixation pins, with resultant instability. The race between the gradually increasing load-carrying capacity of the healing bone and failure of the fixation modality is particularly important in equine ESF. The more initial strength and stiffness the ESF device has, the longer the expected duration of fracture fixation. Strength and stiffness of the assembled ESF device depend on the frame configuration and the distance separating the bone from the sidebars, as well as the size, number, location, and arrangement of the transfixation pins.<sup>49</sup>

### Mechanical Characteristics and Classification of Devices

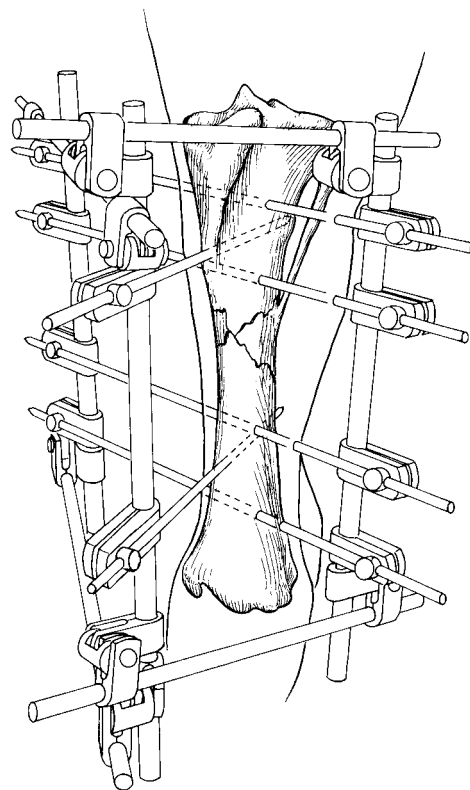
External skeletal fixators are classified according to the configuration of the assembled frame.<sup>15</sup> Unilateral frames are classified as type I fixators (Figure 9.13) and can be either uniplanar (type Ia) or biplanar (type Ib). Also known as half-pin splints, these fixators utilize connecting bars on only one side of the bone. Type I frames provide the least resistance to compressive forces and are the least rigid in bending and torsion. Type II frames are bilateral and constructed using transfixation pins passed perpendicular to the long axis of the bone (Figure 9.14). The transfixation pins are affixed to connecting rods on both sides of the bone, and are also termed full-pin splints. In practice, the pins are parallel and coplanar in arrangement. These frames are significantly more rigid than type I frames in compression and in bending, when the bending forces are parallel to the pins. However, when the bending forces are perpendicular to the pins, a type Ib frame provides more stability than a type II frame. Type III frames are constructed by combining a type I frame at 90° to a type II frame (Figure 9.15). The type III frame offers the most strength and stiffness of all traditional ESF devices in use today. Recently, there has been growing interest in circular and semicircular external frame configurations. They are currently used in human orthopedics for a number of reconstructive procedures and have been introduced into clinical orthopedics in small animal practice. However, their use



**Figure 9.13** External skeletal fixators. (A) Type Ia external skeletal fixator consisting of a single connecting bar in a uniplanar configuration. (B) Type Ib external skeletal fixator utilizing two frames, each using a single connecting bar but positioned in a biplanar configuration.



**Figure 9.14** Type II external skeletal fixator configuration using transfixation pins and two connecting bars in a coplanar configuration.



**Figure 9.15** Type III configuration of an external skeletal fixator in which type I and type II frames are combined to achieve maximal frame strength and stiffness.

in large animal fracture management has been limited, although transfixation casting offers some of the advantages of circular ESF techniques.

Pin stiffness is another important factor in determining the rigidity of the ESF device. The relationship is geometric, with stiffness of the pin proportional to the fourth power of the pin radius. Therefore, the use of pins of larger diameter can substantially decrease pin deflection when loaded, and thereby increase frame stiffness within certain limits. These limits are determined by the corresponding decrease in bone strength that results from the larger holes created by pin placement. Although data for equine bones are somewhat conflicting, it appears that hole diameters up to 20% of the bone diameter do not significantly decrease the strength of the bone in torsional failure, beyond that decrease produced by the stress-concentrating effect of the defect.<sup>36</sup> However, as hole size is increased beyond this level, there is a linear decrease in torsional strength. This will increase the potential for secondary failure through the pin hole. Further, bending strength is proportionally decreased as the size of the cortical defect increases.<sup>36</sup> *In vitro* tests in the equine metacarpus confirm that large-diameter pins result in a stiffer frame and less strain on the surface of the metacarpus.<sup>34</sup> However, the incidence of catastrophic failure of the transfixed bone through the pin hole is increased as the size of the pin increases.<sup>57,67</sup>

The distance spanned by the transfixation pin between the cortical bone interface and the sidebar is termed the working length. Pin stiffness and therefore pin deflection during loading are inversely proportional to the third power of the working length. Therefore, stiffer frames can be assembled by minimizing the working length. In addition, as the working length decreases in type II frames, the resistance to perpendicular bending forces correspondingly increases. Stiffer constructs, attained by maximizing pin size and minimizing working length, will result in less pin stress. Decreasing pin stress preserves the bone–pin interface and decreases the potential for cyclic fatigue failure of the pins.

## Pin Insertion

Mechanical properties of traditional ESF frames are also affected by the number and arrangement of the transfixation pins. In general, increasing the number of pins to a maximum of four on either side of the fracture increases the stiffness and strength of the surgical construct and decreases the cyclic stress applied to each fixation pin. Pins should be positioned to minimize the distance between pins adjacent to the fracture, as well as to maximize the distance between pins within the same major fragment.

The importance of pin design on maintenance of the bone–pin interface has become increasingly apparent. Threaded pins have substantially more holding power than smooth pins, particularly after the pins have been in place for a period of time. However, pins that have had threads cut into them (negative thread profile) are substantially weakened, and failure typically occurs at the junction of the shaft and the threaded portion. Pins in which the thread diameter is greater than the shaft (positive thread profile) provide the increased holding power of threaded pins while maintaining pin stiffness and resistance to fatigue failure.

The technique of pin insertion also contributes to premature pin loosening. This is particularly important when using ESF or transfixation casts in the horse, because of the density and thickness of equine cortical bone. Pin placement should result in minimal trauma and thermal injury to the cortical bone surrounding the pin hole. Predrilling the pin holes to a diameter nearly equal to that of the fixation pin is required.<sup>30</sup> Sharp drill bits that are lubricated by constant saline application during drilling should be used. If threaded pins are utilized, they should be self-tapping or, better yet, an appropriate-sized tap should be used to cut threads into the cortical bone. Self-drilling and self-tapping positive-profile pins result in increased thermal necrosis and better designs are still required before they can be safely utilized in equine cortical bone.<sup>9,41</sup> The pin should be carefully inserted using every precaution to minimize trauma and thermal injury. Improper pin hole preparation and pin placement invariably result in bone necrosis and formation of a ring sequestrum surrounding the pin hole (Figure 9.16). Not only is fixation compromised when this occurs, but the increased size of the cortical defect may predispose to secondary fracture through the pin hole.

Two of the various ESF configurations designed for humans and small animals were used in an experimental *in vivo* study in foals, in which healing of transverse and oblique tibial osteotomies was evaluated.<sup>65</sup> A full-pin splint (type II), consisting of four or more Steinmann pins inserted across the bone and soft tissues in a frontal plane, and attached through clamps to one vertical bar on each side of the bone, was compared to a three-dimensional tent configuration (type III), which consisted of a full splint, whose vertical bars were connected to a third bar oriented at 90° axial rotation either cranially or caudally. The third vertical bar was also connected to the bone with Schanz screws, collectively representing a three-dimensional tent fixation. The study showed that the animals treated with the three-dimensional tent configuration did not bear weight on the limb, developed additional problems, and had to be euthanized early. Conversely, full-splint external fixation resulted in



**Figure 9.16** Ring sequestrum at the transfixation pin site secondary to faulty pin insertion technique.

complete healing in 67% of the animals. The investigators concluded that a type II splint was a viable alternative for fracture fixation in foals weighing less than 150 kg. Half-pin splints (type I) applied in the horse were only marginally successful.

### Surgical Technique

The ESF repair is started by drilling a 4.5 mm diameter hole perpendicular to the long axis of the bone, 2 cm away from and on either side of the fracture line. A Steinmann pin is inserted in each hole. The fracture is reduced and the vertical bars are attached to the medial and lateral end of each of the Steinmann pins. Additional Steinmann pins or Schanz screws are placed further away and may be introduced at different angles. A special guide, allowing exact drilling and aiming toward the opposite clamp on the vertical bar, facilitates precise construction of the full splint frame. Biomechanical studies have shown that axially preloading the pins against each other within one fragment, combined with compression of the fracture using temporary compression clamps, achieves the greatest stability.

Preloading of the pins also delays eventual loosening of the Steinmann pins. Radially preloaded Schanz screws (through a conical pin geometry) have also been compared to axially preloaded Steinmann pins, and the radially preloaded conical pin was found to be superior to axial preload in every aspect.

To ensure the greatest stability, the vertical bars should be positioned as close as possible to the skin. This reduces the working length of the pin and increases stability. A minimal distance of about 1 cm should initially be established between the skin and the clamps connected to the vertical bars, to allow soft tissue swelling to occur without the tissues making contact with the Steinmann pin-clamp interface. If pressure necrosis does occur, the vertical bars can be moved further away from the skin by simply loosening the clamps while the limb is supported in a non-weight-bearing position.

Fracture healing with external fixation occurs at a slower pace than healing after internal fixation, and is associated with callus formation, which indicates motion at the fracture site. A mechanical study that compared *in vitro* models of external fixator configurations for the horse, testing to 5000 Nm in compression and four-point bending, revealed that a three-dimensional configuration containing four radial preload 5 mm Schanz screws, together with six Steinmann pins of 5 mm diameter, withstood the load with only minimal movement at the 1 cm osteotomy gap.

## EQUINE EXTERNAL SKELETAL FIXATION DEVICE

A type II frame utilizing full-pin splintage has been developed by Nunamaker et al.<sup>48</sup> The equine external skeletal fixator originally used large, partially threaded fixation pins which were self-tapping and had a core diameter of 8.6 mm in the threaded portion and 9.6 mm in the nonthreaded portion. The sidebars were fashioned from a composite polyurethane reinforced with steel rods. Designed for injuries of the distal limb, the sidebars connect the transfixation pins placed proximal to the fracture to a foot plate. The foot plate is rounded to reduce ground contact and angled 15–25° from the ground surface. The foot plate is bolted to a bar shoe, which is individually fashioned for each horse. A tapered sleeve has been added over smooth 7.94 mm pins with finely threaded ends in recent years to add to the mechanical integrity by improving bone-pin strain transition (Figure 9.17).<sup>46</sup> The sleeves are compressed against the bone cortices by nuts tightened onto the machined threads on the pin ends.

Mechanically, the original and new versions of this fixator are extremely strong. The overall construct





**Figure 9.17** Equine external skeletal fixator, version III. Source: Designed by Nunamaker and coworkers.<sup>46</sup>

has stiffness and strength characteristics that allow immediate full weight bearing by adult horses. Mechanical testing of the original fixator indicated that the bones within the lower limb were shielded from strain with loads equivalent to 1758.4 kg, at which time plastic deformation of the device occurred. At this load, stress in the most proximal pin was over 350 MPa. *In vivo* strain measurements in a single clinical case resulted in calculated maximal stress in the same pin to be less than 92 MPa. This pin is subjected to the greatest stress during weight bearing, and from these studies there is clearly a large margin of safety between *in vivo* loads imposed when a horse is walking, and loads necessary to cause mechanical failure of the device.

The equine external skeletal fixator allows complete immobilization of unstable comminuted fractures, provides ready access to local wounds or soft tissues, and provides a mechanism to deal with severely traumatized soft tissues without further tissue disruption through surgical intervention. In the initial description of the device, reasonably good success was reported for a number of severe orthopedic injuries in adult horses.<sup>48,54</sup> These injuries included highly comminuted fractures of the distal metacarpus and proximal and middle phalanges, as well as traumatic disruption of the suspensory apparatus. Some of these injuries were open. In most cases the patients were stable in their frames for eight or more weeks. For the 15 horses treated, healing of the original injury was achieved in 7.<sup>48</sup> Complications related

to the use of the equine external skeletal fixator included secondary fracture through the pin holes in four patients. Two of these fractures occurred through the proximal pin hole with the device in place, and the remaining two occurred following removal of the frame. One of the latter was associated with the development of a ring sequestrum due to faulty pin design (self-threading vs. self-tapping). Modifications to the foot plate decreased the incidence of fracture during treatment, and removal of the frame with the horse standing has reduced fracture following device removal.

### Surgical Technique

Application of the original frame commenced with a stab incision in the skin over the mid-portion of the third metacarpus or metatarsus and a 5.5 mm hole was drilled across the bone, perpendicular to the long axis of the bone and in the frontal plane. Additional holes are drilled parallel to the first, 6–7 cm proximally and distally. The holes are enlarged with a hand chuck and 8.73 mm diameter drill. Using manual insertion, self-threading pins with a core diameter of 8.6 mm and an outside thread diameter of 9.6 mm are introduced into the holes. The pins are centered within the third metacarpus or metatarsus. Occasionally, limited internal fixation of the fracture with several lag screws is used to unite major bone fragments and provide some interfragmentary compression. This type of surgery also allows introduction of a cancellous bone graft and removal of articular cartilage, where indicated. The foot plate is screwed onto the horseshoe, and the vertical connecting bars are aligned next to the transfixation pins. The pins are cut to extend 1 cm beyond the vertical bar. Soft insulation tubing is subsequently placed over each vertical bar extending up from the foot plate, and tied off around the bar at the level of the coronary band. A steel wire grid, providing additional reinforcing support, is introduced inside the entire length of the soft tubing, parallel to the vertical bar. The cross pins are then carefully pushed through the axial wall of the tubing and allowed to protrude into its lumen. The tubing should extend well proximal to the most proximal pin, e.g., to the carpal area for a problem involving the proximal phalanx. A distance of about 2.5 cm should be allowed between the inside of the tubing and the skin. When the vertical bars are appropriately lined up and contacting the horizontal transfixation pins, a two-component acrylic is prepared and poured into the tubes. The acrylic sets in 5 minutes, and during that period of time adjustments in alignment can be made and reduction of the fracture achieved. The acrylic is poured into one tube and allowed to set before more acrylic is poured into the second tube. After the acrylic

has hardened, the proximal portion of the tubing can be shortened to the appropriate length using a hacksaw. The entire device is incorporated into a bandage, and recovery from anesthesia is assisted to allow the horse to rise without undue trauma. Owing to the frame's considerable weight and the animal's resistance to it, such trauma is not uncommon, and may lead to catastrophic failure of the bone containing the large transfixation pins.

A modified version of the equine skeletal fixator has been developed (see Figure 9.17).<sup>43,46</sup> The tapered-sleeve transcortical pin device uses 7.94 mm diameter smooth pins with machine threads cut into either end to allow a nut to be applied. Tightening of the nut inside the tapered sleeve on either side of the limb tensions the pin and provides a broader area for transition of force from bone to pin. As a result, pin loosening is far less likely. Application in seven horses with severely comminuted fractures distal to the third metacarpus, including six with comminuted proximal phalanx fractures (Figure 9.18), resulted in survival of five of the seven horses.<sup>46</sup> The tapered-sleeve concept and reduced pin size compared to the initial ESF resulted in a device that supports approximately 10 times the horse's weight, which significantly improves upon the previous version, which supported 3 times the body weight.<sup>46</sup> Further case evaluation is required to determine the value of the equine skeletal fixator compared to transfixation casts, which have resulted in survival rates of



**Figure 9.18** External skeletal fixator (III) with tapered conical sleeves applied to case with comminuted phalangeal fracture.

70% (14 of 20 horses) when applied to comminuted proximal and middle phalanx fractures in one study,<sup>26</sup> and 82% (9 of 11 horses) in a more recent study using a combination plaster/fiberglass transfixation cast.<sup>55</sup>

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