2.1   Screws and plates

1   Introduction

In the early 1960s, interfragmentary compression techniques, leading to direct bone healing, were the gold standard for treating long bone fractures in small animals. Absolute stability was achieved by the application of compression devices such as lag screws and compression plates. However, this conventional method of treating fractures requires an extensive surgical approach and demands skill and expertise to minimize biological complications such as iatrogenic soft-tissue damage, early bone necrosis underneath the plate and late stress protection of the bone.

Recent developments have led to the principle of biological fracture healing in long bone fractures. This is characterized by minimal biological damage during the repair together with flexible fixation. Minimal damage is achieved by eliminating anatomical reduction, by practicing indirect reduction techniques and by concentrating on axial alignment of the fragments. Less surgical trauma is therefore created. Flexible fixation is achieved by wide bridging of the fracture zone using locked nails, bridge plating, or internal or external fixators. It leads to indirect bone healing with callus formation. Healing will occur under optimal biological conditions rather than absolute stability [1].

The issue of implant–bone contact has been addressed in a number of ways. Limited contact devices such as the LC-DCP (limited contact dynamic compression plate) reduce the plate–bone contact without loss of friction between the implant and bone to transmit forces. This friction is further avoided by the locked-screw technique (LCP, UniLock), which in turn reduces bone necrosis.

2   Instrumentation

Instruments are required to facilitate the surgical approach to a fracture, to assist fracture reduction, and to create osteosynthesis.

2.1 Instruments to assist the surgical approach

Special instruments for the surgical approach include retractors, levers, and elevators. Self-retaining retractors or soft-tissue retractors with smooth or pointed ends can be carefully placed underneath musculature or into joint capsules. Gelpi retractors are particularly useful and may be used in a wide variety of situations. Bone levers, such as Hohmann retractors, may be used for retracting muscles by placing their tips under a solid structure and depressing the muscle under their arm. Periosteal elevators may be carefully used to separate soft tissues from bone to reveal the major bone fragments.

2.2 Instruments for reduction

Reduction reverses the process that created the fracture. It calls for forces and moments opposite to those that resulted in the fracture. These methods may be operative or nonoperative, open or closed. Meticulous preservation of blood supply has to be weighed against perfect fracture reduction. Indirect methods have the advantage that the fracture area remains covered by surrounding soft tissue, but they are technically demanding. Direct reduction implies that the fracture is exposed surgically. The fragments are grasped by instruments and apposed by applying forces close to the fracture zone. In simple diaphyseal fracture patterns, direct reduction is technically straightforward and the result is easy to control. **In more complex fractures, the repeated use of bone clamps and other**

reduction tools or implants may devitalize the fragments, with disastrous consequences for the healing process [2].

The standard pointed reduction forceps is an instrument well suited for direct fracture reduction since the points minimize damage to the periosteum. In some oblique midshaft fractures, one reduction forceps may be sufficient to maintain fracture reduction (**DVD | Video 2.1-1**). In most cases, however, two are required for the manual distraction of the main fragments, followed by proper axial alignment and controlled reduction (**DVD | Video 2.1-2**). In cortical bone, the small-tipped Hohmann retractor can be used as a lever to achieve reduction (**DVD | Video 2.1-3**). An intramedullary nail may temporarily be used as a reduction device, along which the fragments are aligned. In bones that are difficult to approach (eg, the pelvis), pins may be placed away from the fracture site in order to manipulate the fragments (**DVD | Video 2.1-4**). Temporary cerclage wire may also be used, but care must be taken not to denude bone during its application (**DVD | Video 2.1-5**). Special reduction clamps have been developed for acetabular fractures (**DVD | Video 2.1-6**).

2.3 Instruments for osteosynthesis

Instruments are designed for the proper application of implants. Plate osteosynthesis is performed using the following standard instrumentation: drill machine with coupling devices for the drill bit and for K-wires, suitable sized drill bits and taps, sleeves for drill bits and taps, depth gauge, double drill guide for screws, plate-holding forceps, bending irons, aluminum template, and screw driver. The equipment differs according to the size of the implant and the type of plate fixation. If an oscillating mode of drilling is desired, drills with three flutes are chosen rather than the more conventional two.

3 Screws

A screw is a very efficient implant for repairing a fracture using interfragmentary compression, or for fixing a splinting device such as a plate, nail, or fixator to a bone. Screw purchase in the bone depends on the implant–bone interface. The goal is to achieve as much contact area as possible in a sufficiently stable implant of minimal size. In veterinary practice, the cortex and the cancellous bone screws are generally used. **Cancellous bone screws have a larger outer diameter, a deeper thread, and a larger pitch than cortex screws and are used in metaphyseal or epiphyseal bone. The cortex screw is designed for the diaphysis.** Newly developed screws for use in man, such as self-tapping screws, monocortical screws and those used in locking systems, are likely to find an increasing application in animals, since patient morbidity can be decreased (**Fig 2.1-1**).

3.1 Cortex screw

Since the strength of the bone reduces as the size of the screw increases, it is recommended that the screw diameter should not exceed 40% of the diameter of the bone. Accordingly there are a number of different sizes of cortex screws available to enable fixation of bones of different diameters. The normally available screws are the 5.5, 4.5, 3.5, 2.7, 2.0, and the 1.5 mm cortex screws, all in different lengths (**Fig 2.1-2**). The frequently used 3.5 mm cortex screw has a 6 mm head with a 3.5 mm hexagonal recess, which corresponds to the screwdriver. The outer diameter of the screws shaft is 3.5 mm; the core diameter is 2.4 mm.

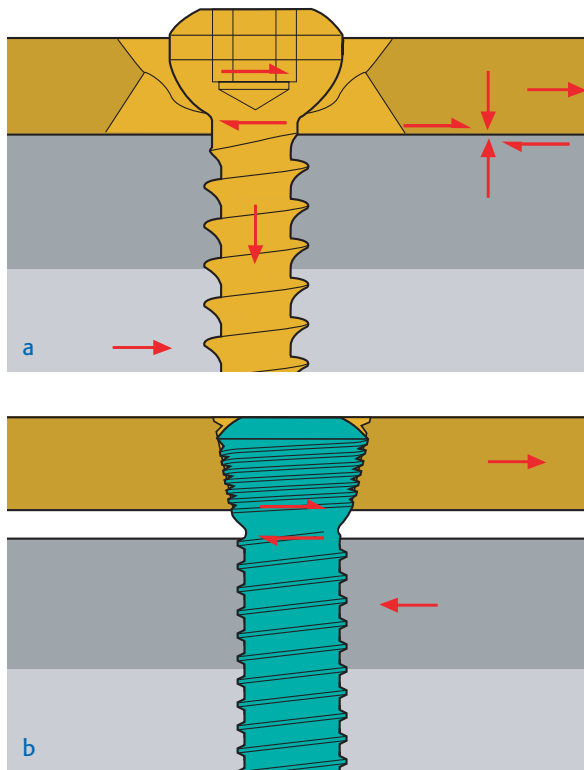Self-tapping screws are designed in such a way that once a pilot hole has been drilled into bone, they

Fig 2.1-1a–b

a   Typical force distribution of a plate osteosynthesis without angular stability: The screw tightening moment leads to surface pressure between the plate and bone. The friction thus created in the plate–bone contact zone stabilizes the bone fragment in relation to the load carrier. This system only becomes statically secure after bicortical screw fixation.

b   Typical distribution of forces for a locking internal fixator (LIF) osteosynthesis with angular stability: This configuration is statically secure with only monocortical fixation since the so-called locking head screw (LHS) is anchored in a mechanically stable manner in the load carrier, perpendicular to the "plate" body. Such systems act more like fixators than plates.

can be inserted by simply screwing them in. The pilot hole is somewhat larger than the core of the screw. Resistance to screw insertion may compromise its accuracy, particularly if the screw is being inserted obliquely to lag two fragments together. Self-tapping screws can be removed and reinserted without weakening their hold in bone. However, if inadvertently misdirected, they will cut a new path and destroy the thread that has already been cut. Self-tapping screws should therefore not be used as lag screws.

The nonself-tapping screw requires a predrilled pilot hole. During drilling, a sharp drill bit and meticulous cooling with sterile physiological saline will reduce thermal necrosis of the bone. The bone is then cut with a tap, which exactly corresponds to the profile of the screw thread. Because the thread is cut with a tap, the pilot hole corresponds in size almost to the core of the screw and the screw thread has a much deeper bite into the adjacent bone. Much less heat is generated when the screw is inserted because there is less resistance. The tap is designed in such a way that not only is it much sharper than the thread of a screw, but it also has a more efficient mechanism to clear the bone debris. Therefore debris does not accumulate to clog the screw threads and obstruct screw insertion. Screws can be removed and reinserted with ease, and without fear of inadvertently cutting a new channel, as the screw alone is incapable of cutting a thread in cortical bone.

3.2 Cancellous bone screw

Cancellous bone screws have a relatively thin core and wide and deep threads. The increase in the ratio of the outer diameter to the core gives this type of screw considerably increased holding power in the fine trabecular bone of the metaphyses and epiphyses.

Cortex screws are designed for use in diaphyseal bone.

Self-tapping screws are best used in applications where applied only once.

Self-tapping screws should not be used as lag screws.

Standard screws are best used when there is an anticipated need to replace or reposition the screw.
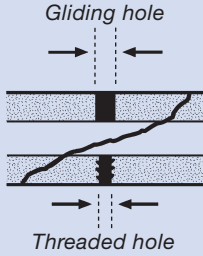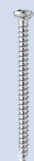
Screws, drill bits, and taps

Screws

Screw diameter (mm)	1.5	2.0	2.7	3.5	4.0		4.5	5.5	6.5		
Screw type		Cortex self-tapping		Cortex	Cancellous nonself-tapping		Cortex		Cancellous nonself-tapping		
	and nonself-tapping	and nonself-tapping	and nonself-tapping	self-tapping and nonself-tapping	partially threaded	fully threaded	self-tapping and non-self-tapping	nonself-tapping	16 mm threaded	32 mm threaded	fully threaded

Drill bits and taps

	1.5	2.0	2.7	3.5	4.0		4.5	5.5	6.5		
Drill (mm) for gliding hole	1.5	2.0	2.7	3.5	–		4.5	5.5	4.5 in hard bone		
Drill bit (mm) for threaded hole	1.1	1.5	2.0	2.5	2.5		3.2	4.0	3.2		
Tap (mm) (in hard bone and for nonself-tapping screws	1.5	2.0	2.7	3.5	4.0		4.5	5.5	6.5		

Gliding hole

Threaded hole

Fig 2.1-2   Summary of available standard screws and their corresponding drill bits and taps.

Cancellous bone screws are either fully or partially threaded. The fully threaded screws are used for fastening devices such as plates to metaphyseal and epiphyseal bone. The partially threaded screws are used as lag screws. In this instance, tapping is only necessary in the near cortex. The screw can easily cut a thread for itself in the cancellous bone, and its holding power is increased if the thread is not cut.

3.3 Shaft screw

The shaft screw is a cortex screw with short threads and a shaft, the diameter of which is equal to that of the thread (**Fig 2.1-3**). **The shaft screw is used as a lag screw in diaphyseal bone.** When an inclined screw is used, so that its head rests on a surface parallel to the long axis of the bone, the shaft screw should be selected. This avoids its head engaging in the gliding hole, thereby losing a degree of compression.

3.4 Cannulated screw

Cannulated bone screws have a central hollow core and are inserted over K-wires that act as guides. Both 3.5, and 6.5 mm cancellous screws are available in the cannulated version. **Cannulated bone screws are employed as lag screws and are particularly suited for the reconstruction of metaphyseal or epiphyseal fractures such as those occuring in the distal humerus or proximal femur.**

Fig 2.1-3a–b   Lag screw effect using fully and partially threaded screws.
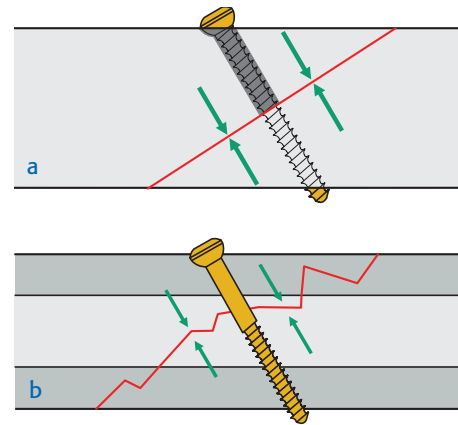
a   By overdrilling the bone thread in the near fragment to the size of the outer diameter of the screw thread, the threaded part of the bone screw may glide in relation to the bone. When this technique is used with an angled screw whose head impacts on one side only, one component of the axial screw force acts along the long axis of the bone which tends to shift the screw head toward the fracture. The screw thread within the gliding hole may then engage and compression is lost for a varying degree.

b   Compression can also be achieved with a shaft screw whose shaft does not produce axial load.

Cannulated bone screws are designed for use in metaphyseal or epiphyseal bone.

3.5 Locking head screw

Locking head screws, as their name implies, have heads that lock in the plate hole (**Fig 2.1-1b**). They are used in internal fixators such as the locking compression plate (LCP) and UniLock system, and they may be self-drilling, self-cutting, and used as monocortical screw. Locking head screws provide better anchorage as their position in relation to the plate is fixed. They can also function as a fixed angle device, which is an advantage in metaphyseal fractures and when minimally invasive techniques are used.

3.6   Application

3.6.1   Lag screw

A fully threaded screw can be used as a lag screw, provided the thread is prevented from engaging within the cortex next to the screw head (cis or near cortex). This is done by drilling a clearance or gliding hole of a diameter equal to, or slightly larger than, the outer diameter of the screw thread in the near cortex. A hole in the trans or far cortex is drilled, corresponding to the core diameter of the screw, the entire drill hole length is measured and the drill hole in the far cortex is tapped. Thus, the fully threaded cortex lag screw is applied with a smaller pilot or threaded hole in the far cortex and a larger clearance or gliding hole within the near cortex (**Fig | Anim 2.1-4, Fig | Video 2.1-5**). A partially threaded screw can be used as a lag screw provided the threaded portion of the screw only engages the far cortex (**DVD | Video 2.1-7**).

In order to achieve maximal interfragmentary compression, the lag screw must be inserted in the middle of the fragment equidistant from the fracture edges and directed at a right angle to the fracture plane.

In order to increase contact between the bone and screw head, the near cortex is reamed with a countersink. The depth of the drill hole is measured after countersinking but before tapping. In areas where cancellous bone is covered by a thin cortical layer, forces may be distributed by using a washer under the screw head.

When an inclined screw thread produces axial force, one component of the force tends to shift the screw head along the bone surface toward the fracture (**Fig | Video 2.1-6**). Under such conditions the use of a lag screw with a shaft corresponding to the outer diameter of the thread (the so-called shaft screw) may be advisable. Otherwise, the screw thread may engage within the gliding hole and some efficiency may be lost (**Fig | Anim 2.1-7**).

3.6.2   Position screw

When the insertion of a lag screw will cause a fragment to collapse into the medullary cavity, it is preferable to use a position screw. The fragments are carefully held in position with pointed reduction forceps and a screw with position function is inserted. In this instance, thread holes are drilled in the cortex of both the far and near fragments. The drill hole is measured and tapped. When the appropriate screw is inserted, the position of the two fragments is maintained (**Fig 2.1-8, Fig | Video 2.1-9**).

3.6.3   Plate screw

Plate screws, as their name implies, are used to attach plates to bones. **The diameter of the screw is dictated by the size of the plate** (see 2.1 Screws and plates; 4 Plates; 4.1 DCP).

The term lag screw refers to the function of the screw. Both fully threaded and partially threaded screws can be used as lag screws.

The fully threaded cortex lag screw is applied with a smaller pilot or threaded hole in the far cortex and a larger clearance or gliding hole within the near cortex.

Lag screws are used mainly to provide interfragmentary compression between two bone fragments.

Video

Fig | Anim 2.1-4a–f   Technique for lag screw fixation after fragment reduction.

a   The gliding hole is drilled the same diameter as the screw thread.

b   The drill sleeve with outer diameter of the gliding hole and inner diameter of the thread hole is inserted. The hole is drilled in the far segment the same diameter as the screw core.

c   The hole is countersunk to enlarge the contact area.

d   The screw length is carefully measured.

e   The thread hole is tapped.

f   The appropriate screw is inserted and tightened. In order to achieve maximal compression, the lag screw must be inserted through the center of both fragments and must be directed at a right angle to the fracture plane.

a

b

c

d

Animation

Video

e

f
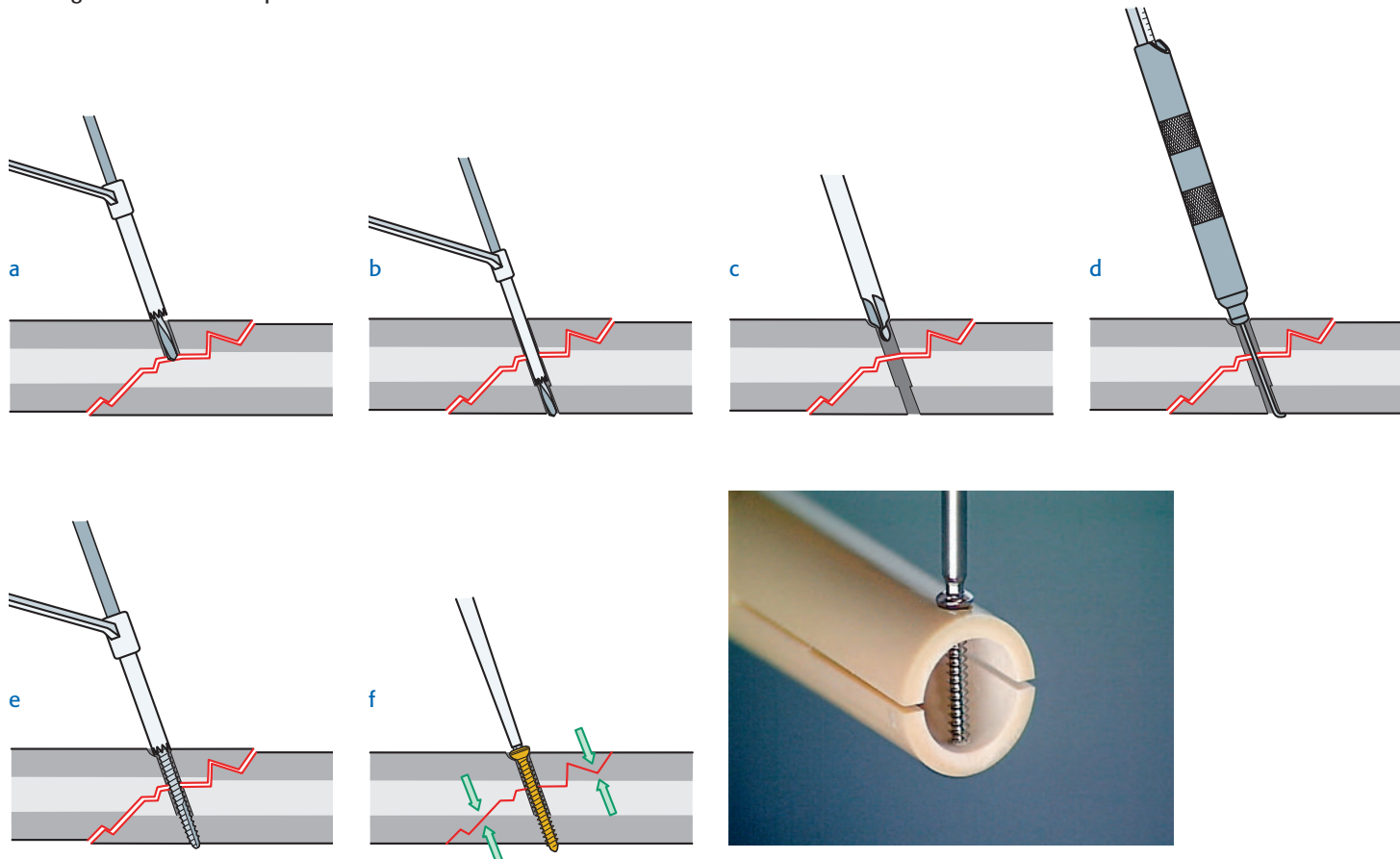
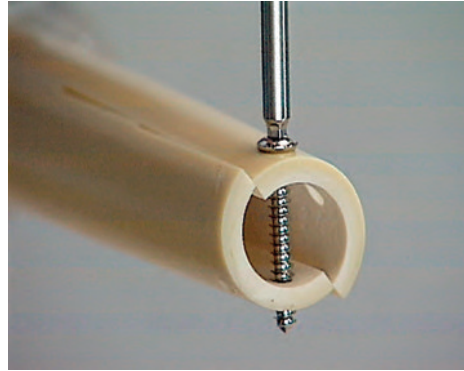Fig | Video 2.1-5   Principle of lag screw insertion.

Fig | Video 2.1-6   Shear forces displace fracture fragments if a lag screw is not placed perpendicular to the fracture line.
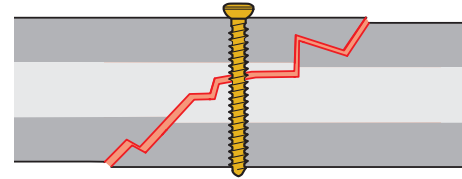

Fig | Anim 2.1-7   Failure to overdrill the near cortex prevents the screw from compressing the fracture. When both cortices are drilled and tapped, the screw functions as a position screw.
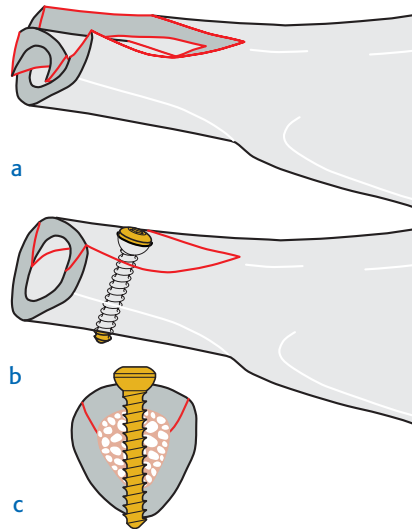

a

b

c

Fig 2.1-8a–c
Steps for inserting a position screw.
a   The fragments are reduced and maintained in position.
b   Both fragments are drilled with thread holes, measured, and tapped.
c   The inserted screw will not collapse the fragment.

Fig | Video 2.1-9
Principle of position screw insertion.

In the case of a 3.5 mm screw used with a dynamic compression plate (DCP) 3.5 or limited contact dynamic compression plate (LC-DCP), the following steps are undertaken. First, the desired function of the plate must be determined (neutralization, compression, bridging, or buttress). The screw hole is drilled with a drill bit through the corresponding drill sleeve. A standard drill sleeve is used for the DCP and the universal sleeve for the LC-DCP (see 2.1 Screws and plates; 4 Plates; 4.2 LC-DCP). In both cases, the screw hole is slightly larger (2.5 mm) than the core of the screw (2.4 mm). The length is measured with the depth gauge. **If the correct screw length is not available, the next longer screw is chosen.** The hole is tapped (3.5 mm) and the screw is inserted with the screwdriver (**Fig 2.1-10**).

As a rule of thumb, the greatest forces that can be applied to the screwdriver when tightening a plate screw are as follows: two fingers for a 2.0 mm screw, three fingers for a 2.7 mm screw and the whole hand for a 3.5 mm screw. For more accurate tightening, torque limiting screw drivers are available. **To ensure axial alignment of the plate to the bone, plate screws are first applied at each end of the plate, then close to the fracture and finally, the remaining plate holes are filled.** Alternatively, if axial alignment is straightforward, the screws may be first applied next to the fracture and the holes filled on alternate sides of the fracture moving toward each end of the plate. In either case, the screws are retightened after they have all been placed until they are seated firmly.
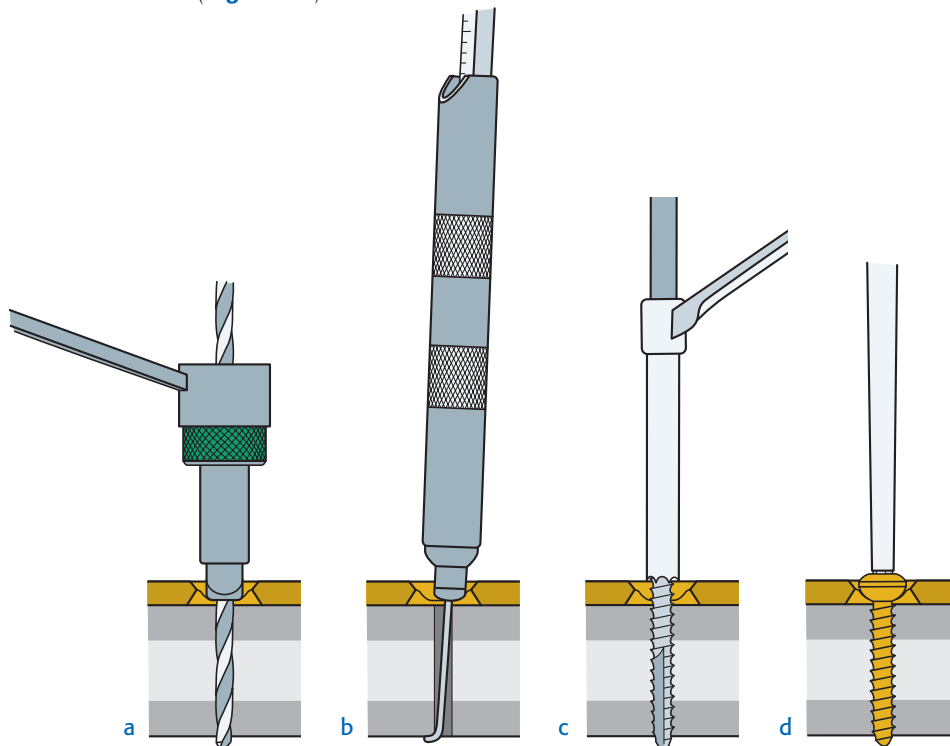

Fig 2.1-10a–d   Application of a plate screw.
a   Drilling of the hole in neutral position.
b   Measuring the hole length.
c   Tapping.
d   Insertion of the screw.

4 Plates

4.1 Dynamic compression plate (DCP)

The dynamic compression plate (DCP) comes in a variety of sizes. The DCP 4.5 is used with 4.5 mm cortex screws, 4.5 mm shaft screws, and 6.5 mm cancellous bone screws. The DCP 3.5 is used with 3.5 mm cortex screws, 3.5 mm shaft screws, and 4.0 mm cancellous bone screws. The DCP 2.7 is used with 2.7 mm cortex screws while the DCP 2.0 is used with 2.0 mm cortex screws.
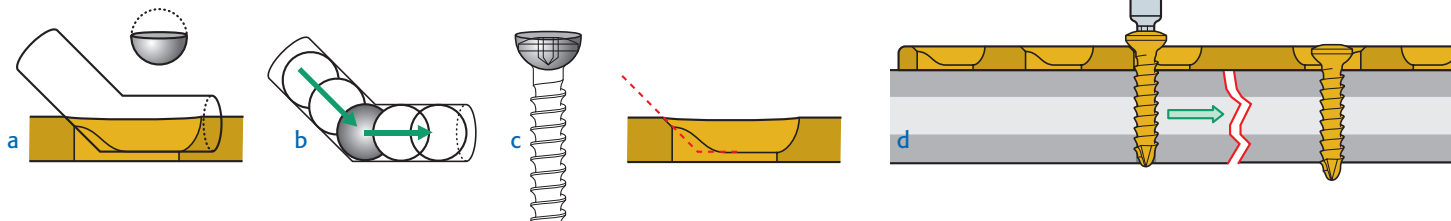
The DCP was introduced in 1969 [3] and featured a revolutionary hole design. This allows for the creation of axial compression by eccentric screw insertion. The screw hole is best described as a portion of an inclined and angled cylinder. Like a ball, the screw head slides down the inclined shoulder of the cylinder. In practice, when the screw is inserted and tightened, the bone fragment moves relative to the plate, and consequently, compression of the fracture occurs (**Fig | Anim 2.1-11**). The design of the screw hole allows for a displacement of up to 1.0 mm per hole in the DCPs 3.5 and 4.5 and up to 0.8 mm in the DCP 2.7. After the insertion of one compression screw, additional compression using a second eccentric screw is possible before the first screw is "locked" (**Fig 2.1-12, Fig | Anim 2.1-13**). Thus it is possible to use either one or two eccentrically placed screws on either side of a fracture. **The oval shape of the holes allows a 25° inclination of the screws in the longitudinal plane and up to 7° inclination in the transverse plane** (**Fig 2.1-14**).

There are two DCP drill guides for each sized plate, one with an eccentric (load) hole and a gold collar, the other with a concentric (neutral) hole and a green collar. Depending upon the intended function of the plate, the eccentric or neutral drill guide is chosen.

> It is possible to use either one or two eccentrically placed screws on either side of a fracture.

> The DCP has a hole design allowing for axial compression by eccentric screw insertion. The same plate may function in different modes: compression, neutralization, bridging, or buttress.

Fig | Anim 2.1-11a–d   Dynamic compression principle.
a   The holes of the plate are shaped like an inclined and transverse cylinder.
b   Like a ball, the screw head slides down the inclined cylinder.
c   Since the screw head is fixed to the bone via the screw shaft, it can only move vertically relative to the bone.
d   The horizontal movement of the head, as it impacts against the angled side of the hole, results in movement of the bone fragment relative to the plate, and leads to compression of the fracture.
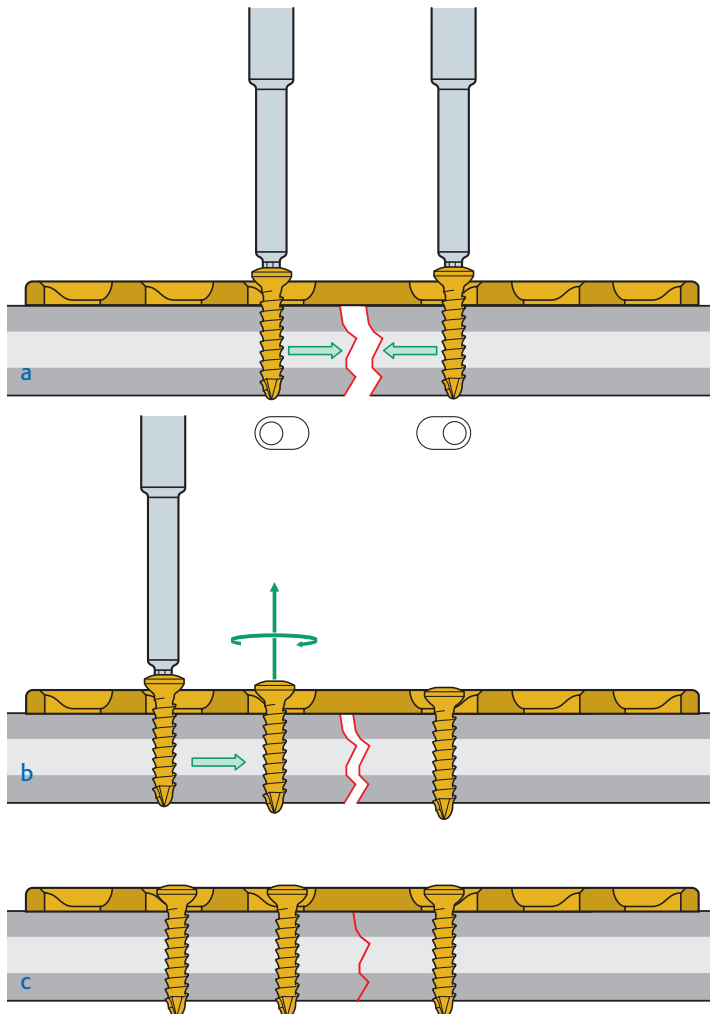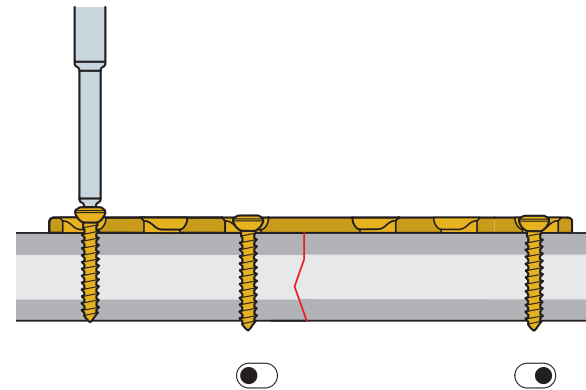

Animation

Fig | Animation 2.1-13   An alternative technique for compression plate application is to first secure the ends of the plate to the bone. The subsequent application of an eccentrically placed screw will compress the fracture, especially if the initially placed screw is temporarily backed out.
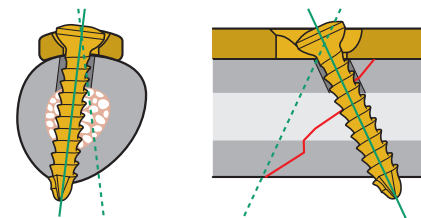

Fig 2.1-12a–c   Additional compression:

a   Inserting one compression screw on either side of the fracture.

b   After insertion of the compression screws, it is possible to insert a third screw with compression function. Before this screw is tightened, the first screw has to be loosened to allow the plate to slide on the bone.

c   After the third screw is tightened the first screw is retightened.

Fig 2.1-14   The shape of the holes of the DCP allows inclination of the screws in a transverse direction of ± 7° and in the longitudinal direction of ± 25°.
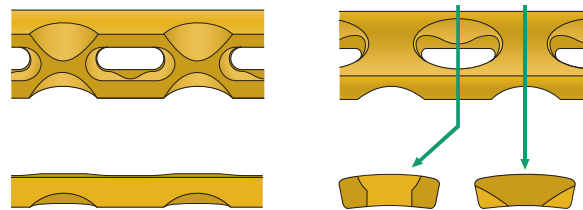
Fig 2.1-15 The LC-DCP with its scalloped undersurface for limited contact between plate and bone and an even distribution of the holes throughout the plate.

If the screw is to be inserted in a neutral (green) position, the hole is, in fact, 0.1 mm off-center, which theoretically adds a small amount of compression even in this neutral position.

The gold drill guide produces a hole 1.0 mm off-center away from the fracture, so that when the screw is tightened, the bone is displaced relative to the plate, causing compression at the fracture site (**DVD | Video 2.1-8**). If the plate is intended to function in buttress/bridging mode, the universal drill guide (or sleeve) should be used, placing the screw at the opposite end of the hole. This prevents any gliding of the plate relative to the bone.

4.2 Limited contact dynamic compression plate (LC-DCP)

The limited contact dynamic compression plate (LC-DCP) represents a further development of the DCP [4]. Several elements of the design have been changed and the plate is available both in stainless steel and in pure titanium. Titanium exhibits outstanding tissue tolerance.

Compared to the DCP, the area of the plate–bone contact (the plate "footprint") of the LC-DCP is greatly reduced (**Fig 2-15**). As a result, the

capillary network of the periosteum under the plate is spared, leading to a relative improvement in cortical perfusion, which in turn reduces the porotic changes under the plate.

The geometry of the plate, with its "scalloped" underside, results in an even distribution of stiffness, making contouring easier, and minimizing the tendency to "kink" at the holes when bent. In buttress or bridging mode, this distribution of stiffness results in a gentle elastic deformation of the entire plate, without stress concentration at any of the screw holes as occurs in the DCP.

The plate holes of the LC-DCP are symmetrical, allowing for eccentric placement of a screw in either direction. This allows for compression at any level along the plate, an obvious advantage when treating a segmental fracture. Moreover, the plate holes are evenly distributed over the entire length of the plate, which adds to the versatility of its application. **Screws can be inclined sideways to a maximum of 7° and in a longitudinal direction up to 40° (as opposed to 25° for DCP as shown in Fig 2.1-14).**

As in the case of the DCP, the screws can be inserted in different modes: compression, neutral, bridging, and buttress (**Fig 2.1-16**). To facilitate insertion, there are two LC-DCP drill guides designed for each of the 3.5 mm and 4.5 mm plates as well as a newer LC-DCP universal drill guide. This universal spring-loaded drill guide permits placement of the drill bit in a neutral or eccentric position relative to the plate hole. If the inner drill sleeve is extended (normal) and placed against the end of the plate hole, an eccentric drill hole will result. In contrast, when the spring-loaded guide is pressed against the bone, the inner tube retracts, and the rounded end of the outer tube glides down the slope of the hole to the neutral position (**Fig 2.1-17, Fig | Video 2.1-18**).

Advantages of LC-DCP design include: decreased plate–bone contact, even distribution of stiffness, ease of contouring, and symmetrical evenly distributed plate holes.

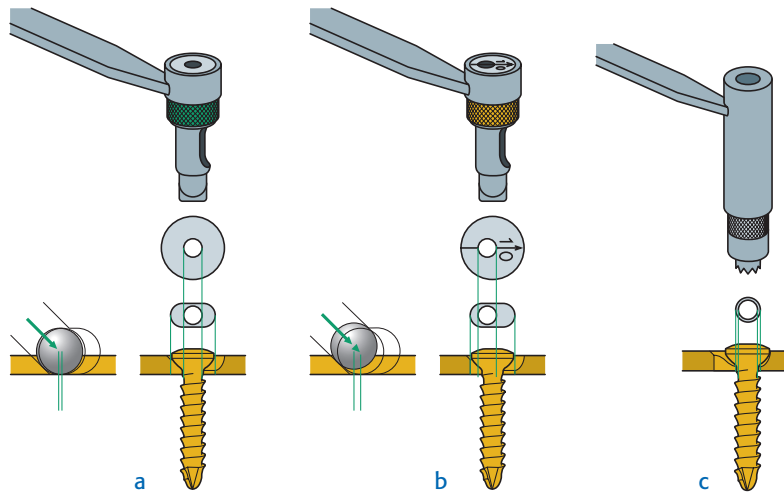Use the LC-DCP guide or universal guide when applying the LC-DCP.

Fig 2.1-16a–c The application of the drill guide depends on the function which the screw should have:
a   Neutral position (green end of the guide),
b   Compression mode (gold end of the guide),
c   Buttress mode (universal drill guide).

A concentric or neutral (green) guide is used to center the drill in the plate hole.

An eccentric or load guide (gold) is used to offset the drill in the plate hole.
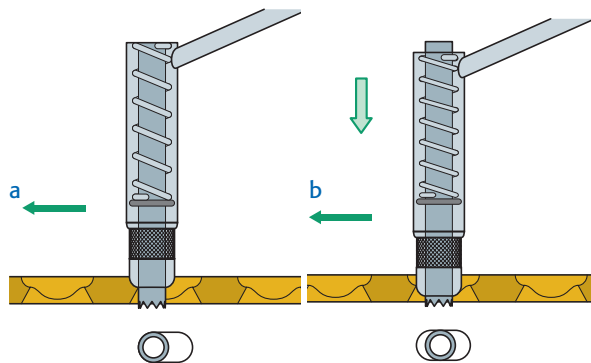
Fig 2.1-17a–b   LC-DCP universal drill guide.
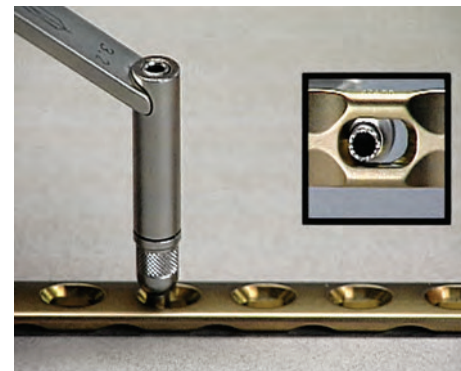a   Application in eccentric position.
b   Application in neutral position.

Fig | Video 2.1-18
Universal drill guide application.

4.3 Veterinary cuttable plate (VCP)

Cuttable plates are versatile plates designed for use in small animals. They may be custom cut to any length to accommodate a variety of fracture situations. Two sizes are available, a smaller plate for 1.5 mm and 2.0 mm screws and a larger plate for 2.0 mm and 2.7 mm screws. Each plate is 300 mm long with 50 round holes (**Fig 2.1-19**). Thus, the cuttable plate is not a compression plate but it does have a high number of screw holes per unit length of plate.

To increase effective plate stiffness, the plates can be stacked one on top of the other. This may be done using plates of the same hole size, or with a plate having the smaller holes being placed on top of the one with the larger holes. In the latter case, in order to distribute stress risers, the more superficial plate is cut shorter than the lower one. **The cuttable plate is a relatively weak plate.**
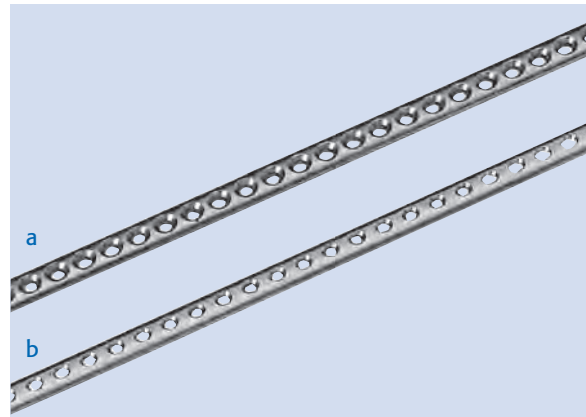
Thus in comminuted fractures, bending forces may need to be counteracted by extra means such as the addition of intramedullary pins as in a plate-rod technique.

4.4 Reconstruction plate

Reconstruction plates are characterized by deep notches between the holes (**Fig 2.1-20**). This permits contouring in an additional plane than is possible with regular plates. They are not as strong as compression plates, and may be further weakened by heavy contouring. Special bending pliers are required for contouring. The holes are oval to allow for dynamic compression. These plates are especially useful to repair fractures of bones with complex 3-D geometry, such as the pelvis, particularly the acetabular region, and the distal humerus. They may also find an application in distal femoral fractures. Reconstruction plates are available in the dimensions of 4.5, 3.5, and 2.7.
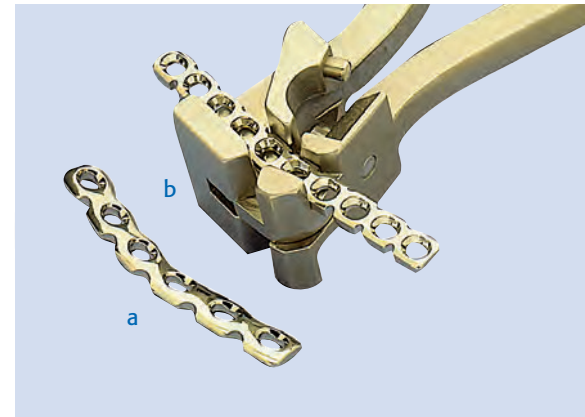

Fig 2.1-19a–b   Cuttable plates exist in two sizes: 2.7/2.0 and 2.0/1.5, and a length of 300 mm.

Fig 2.1-20a–b
a   Reconstruction plate.
b   Special bending pliers for the reconstruction plate: Bending irons are available to twist the plate.

4.5 Special veterinary plates

Due to the fact that animals are not of uniform size, AO has developed a variety of special plates for use in small animals (Fig 2.1-21).

Acetabular plates come in the dimensions of 2.0 and 2.7. Veterinary T- and L-plates are available in different sizes from 2.0 to 3.5. Double hook plates are used in proximal femoral fractures as well as for intertrochanteric osteotomies. Right and left triple pelvic osteotomy plates with different angles of rotation are available in 2.7 and 3.5 versions.

Tubular plates are useful in areas with minimal soft-tissue coverage, such as the olecranon, distal ulna, or the malleoli. In scapular fractures, the tubular plate can be applied with its convex surface laid against the scapular spine.

4.6 Miniplates and maxillofacial plates

Mini-fragment plates are designed for use with the 2.0 mm or 1.5 mm cortex screw. They are available as DCP, round-hole plates, mini L-plates, mini T-plates, or cuttable plates (**Fig 2.1-22**). They are used in long-bone fractures, mandibular fractures, or pelvic fractures of toy breed dogs and cats.

The human compact system was developed for hand and maxillofacial orthopedic surgery. The smaller sizes (1.0, 1.3, and 1.5) and associated plates are now available for veterinary use. The screws are self-tapping and are inserted with the star drive screwdriver. The compact systems are indicated in maxillofacial fractures and for metacarpal and metatarsal fractures in cats and small dogs. Due to their small cross-sectional area, the plates have little resistance to bending.
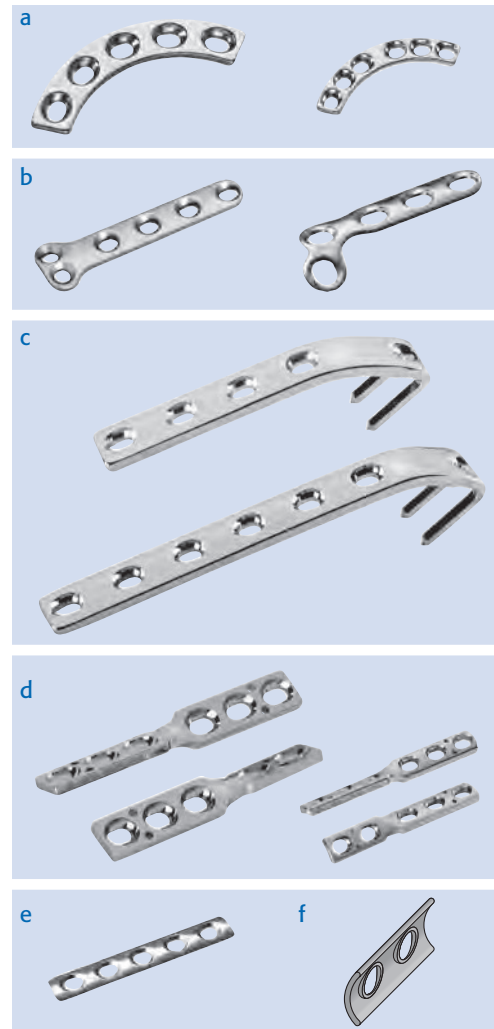
Fig 2.1-21a–f   Special plates:
a   Acetabular plates 2.7 and 2.0.
b   Veterinary T- and L-plates.
c   Double hook plates.
d   Right and left triple pelvic osteotomy plates.
e   Tubular plate.
f   The collar around the hole of the tubular plate prevents the screw head from protruding and secures the plate–bone contact.

The mini instrument set is useful for stabilizing fractures in toy breed dogs and cats.

Fig 2.1-22a–b   Miniplates are used with 1.5 mm and 2.0 mm cortex screws.
a   Miniplate 1.5.
b   Miniplate 2.0.
c   Mini L- and T-plates.

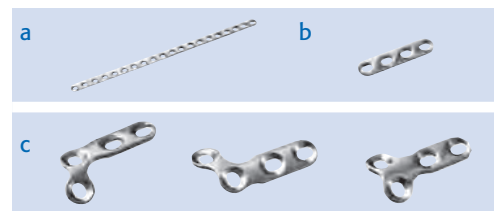**Table 2.1-1** Choice of implant size in relation to animal body size and anatomical region.

Body weight in kg	10	20	30	40

Femur
- DCP 2.0
- DCP 3.5
- DCP 4.5 B
- VCP 2.0/1.5
- DCP 2.7
- DCP 3.5 B or DCP 4.5
- VCP 2.7/2.0

Tibia
- DCP 2.0
- DCP 3.5
- DCP 4.5 B
- VCP 2.0/1.5
- DCP 2.7
- DCP 3.5 B or DCP 4.5
- VCP 2.7/2.0

Humerus
- DCP 2.0
- DCP 3.5
- DCP 4.5 B
- VCP 2.0/1.5
- DCP 2.7
- DCP 3.5 B or DCP 4.5
- VCP 2.7/2.0

Radius/ulna
- MP
- DCP 2.0
- DCP 3.5
- VCP 2.0/1.5
- DCP 2.7
- DCP 3.5 B or DCP 4.5
- VCP 2.7/2.0

Acetabulum
- MP
- DCP 2.7
- RP 2.0
- RP 2.7
- RP 3.5
- AP 2.0
- AP 2.7

Ilium
- MP
- DCP 2.7
- RP 3.5
- RP 2.7
- DCP 3.5
- DCP 2.0 or VCP 2.7/2.0

DCP = dynamic compression plate   RP = reconstruction plate   B = broad
VCP = veterinary cuttable plate   AP = acetabular plate   MP = miniplate

Where avaliable, the LC-DCP of comparable size may be substituted for the DCP.

4.7 Plate function

Selection of plate size will depend upon its function and the size of the bone (**Table 2.1-1**). In general, the following sized plates may be used:
- The DCP or LC-DCP 4.5 for long bone fractures in large and giant breed dogs.
- The broad DCP or LC-DCP 3.5 for fractures in heavy and giant breed dogs.
- The regular DCP or LC-DCP 3.5 for fractures in medium to large dogs.
- The DCP or LC-DCP 2.7 for fractures in cats and small to medium sized dogs.
- The DCP 2.0 for fractures in cats and toy breed dogs (**Table 2.1-1**).

4.7.1 Dynamic compression plate (DCP)

If it is possible to generate axial compression by the use of a tension device or with eccentric loaded screws, the plate functions as a compression plate. In most instances, this mode is only possible in simple transverse fractures (**Fig | Anim 2.1-11, Fig 2.1-12, Fig | Anim 2.1-13**). Prebending the plate to raise it 2 mm above the bone at the fracture line leads to compression of the opposite cortex when the plate is secured to the bone (**Fig | Video 2.1-23**).

4.7.2 Neutralization plate

Whenever internal fixation of a diaphyseal fracture consists of a lag screw or screws in combination with a plate that protects the lag screw fixation, the plate functions in protection or neutralization mode. The plate protects the interfragmentary compression achieved with the lag screw(s) from all rotational, bending, and shearing forces (**Fig 2.1-24, Fig | Video 2.1-25, Fig | Video 2.1-26**).
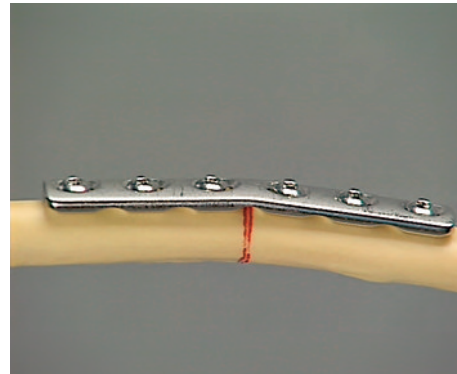
Fig | Video 2.1-23   LC-DCP used as a compression plate.

The function assigned to the plate is independent of plate design.

A DCP or an LC-DCP applied as a compression plate results in axial compression at the fracture line.

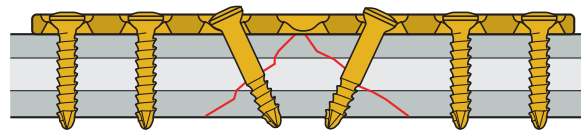Fig 2.1-24   Lag screw osteosynthesis with neutralization plate. Interfragmentary compression is achieved by lag screws, in this case, shaft screws. The function of the plate is to neutralize bending forces. Lag screws applied through the plate do not require additional exposure.

A neutralization plate protects the interfragmentary compression achieved with the lag screw(s) from all rotational, bending, and shearing forces.
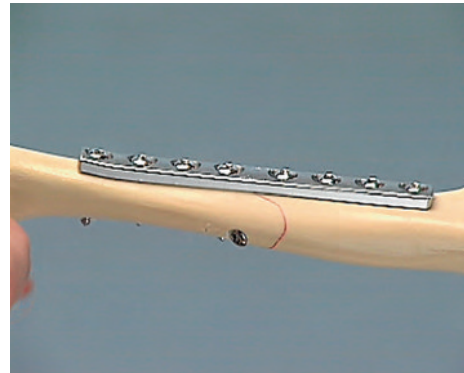
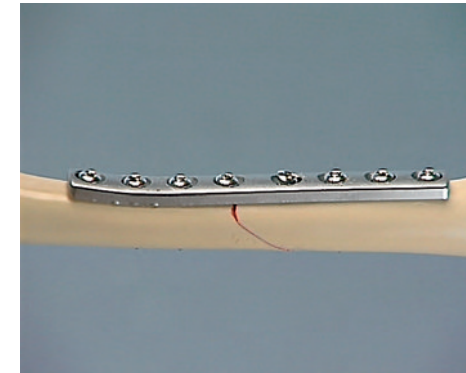Fig | Video 2.1-25   Neutralization plate used to protect a separate lag screw.

Fig | Video 2.1-26   Fixation of an oblique femoral fracture with a lag screw through a neutralization plate.

Fig | Video 2.1-27
LC-DCP used as a bridging plate.

4.7.3   Buttress plate

In metaphyseal fractures, compressive forces tend to collapse the adjacent articular surface. The function of the buttress plate is simply to prevent this collapse. Where the metaphyseal fracture is accompanied by an intraarticular slab fracture, the latter should be repaired with lag screws. Nevertheless, the repair has insufficient strength alone and must be combined with a plate, acting again in buttress mode. In both instances, the plate is subjected to full loading (**Fig | Video 2.1-27, Fig 2.1-28**).

4.7.4   Bridging plate

Biological or bridge plating (also described as buttress plating in earlier terminology) is usually used following some form of indirect reduction. The plate acts as a splint to maintain the correct length of the bone and the normal spatial alignment of the joints proximal and distal to the fracture. The soft-tissue envelope surrounding the fracture site exerts concentric pressure on the fracture fragments as it is placed under tension by the ends of the bones while they are distracted to restore limb length.

The function of the bridging plate is simply to prevent axial deformity as a result of shear or bending forces. The plate is subjected to the full weight-bearing forces. Therefore, every possible effort should be made to maintain the vascular supply to the fragments and all their soft tissue

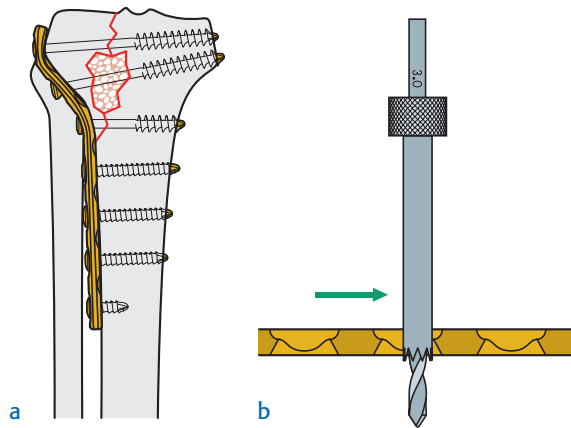> A buttress plate prevents collapse of the fracture.

> Bridging plates are indicated in nonreducible comminuted diaphyseal fractures.

> Use a longer and stronger plate as a bridging plate since it is subjected to the full load of weight bearing.

Fig 2.1-28a–b
a   Application of the DCP in a buttress function.
b   To prevent any sliding of the plate, the screw hole is placed opposite to the slope in the plate hole.

Fig | Video 2.1-29   Plate-rod fixation for treating a nonreducible middiaphyseal humeral fracture.

attachments, since union will depend on the formation of a bridging callus rather than direct bone healing. Both plate ends have to be solidly fixed to their corresponding parts of the bone by at least three screws.

The plate-rod combination is particularly effective for bridging large comminuted fractures because of synergistic mechanical properties. The intramedullary pin is effective in protecting the fracture from bending forces and the plate is effective in protecting the fracture from axial compression and rotational forces. Addition of an intramedullary pin, which is 40–50% of the medullary canal diameter, to the bridging plate reduces the internal plate stress and thereby increases the fatigue life of the plate. Additionally, the intramedullary pin reduces the strain concentration at the screw hole to approximately the strain present at the solid center of a similar plate which is not supported by the intramedullary pin [5] (**Fig | Video 2.1-29, Fig 2.1-30**).
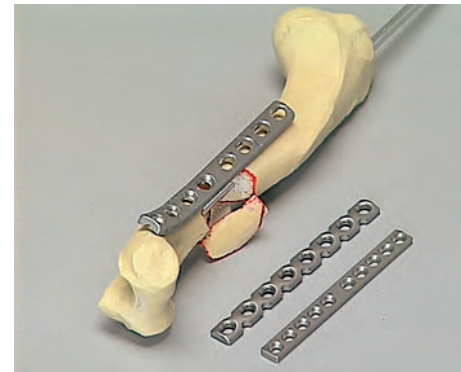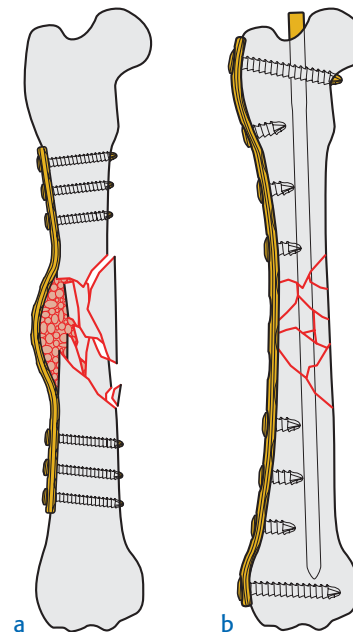

Fig 2.1-30a–b
a   Bridge plating of a comminuted fracture. The wave form allows for grafting of a lateral defect.
b   Plate-rod technique in a comminuted femoral fracture.

5 Internal fixators

Locking plate/screw systems have a number of advantages over other plating methods and are essentially internal fixators. Stability is provided by the locking mechanism between the screw and the plate. The plate does not need to be in intimate contact with the underlying bone, making exact plate contouring less crucial. Reduced contact between the plate and the bone may also preserve the periosteal blood supply, thereby reducing the extent of bone resorption under the plate.

Internal fixators offer greater stability than standard reconstruction plates without locking head screws, especially when only two screws are placed in each bone fragment. The screws must only be inserted in the near cortex. This increases the versatility of internal fixators and makes them useful in the repair of fractures such as acetabular fractures, carpal and tarsal fractures, and in double plating.

5.1 Locking compression plate (LCP)

The innovation in the locking compression plate (LCP) is the "combination" plate hole (**Fig 2.1-31**). This can accommodate either a conventional screw or the new locking head screw (LHS), which has a conical threaded head. The LHS comes in two forms. The self-tapping LHS is designed for use in sites such as the metaphysis, where exact measurement of the screw size is required. The self-drilling and self-tapping LHS is for monocortical use only.

> The "combination" plate hole can accommodate either a conventional screw or the new locking head screw.
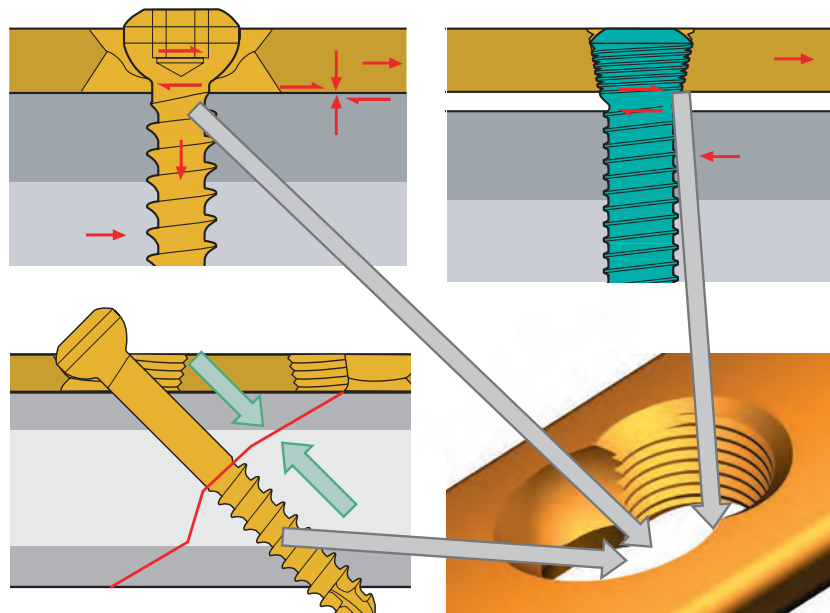

Fig 2.1-31   LCP combination hole combining three proven elements. It mainly consists of two parts:

• One half of the hole has the design of the standard DCP/LC-DCP for conventional screws including lag screws.

• The other half is conical and threaded to accept the matching thread of the new locking head screw providing angular stability.

The new combination hole has two parts: the first part has the design of the standard DCP/LC-DCP compression hole, which accepts a conventional screw allowing axial compression or the placement of an angled lag screw through the plate. The other part is conical and threaded. It accepts the locking head screw, so providing angular stability. Plates 3.5 and 4.5 are available with the new combination hole, but without any change in the overall plate dimensions.

Depending on the desired function, the LCP can be applied in two different ways:

- as a conventional dynamic compression plate for rigid fixation,
- as a pure internal fixator with unicortical locking head screws,

thereby obviating the need for perfect contouring of the plate and anticipating rapid indirect bone healing. Thus, the plate may function as either a compression plate or a bridging plate depending on whether conventional screws or locking head screws are chosen.

5.2 Locking plate (UniLock)

The UniLock is available as a 2.0 and 2.4 system. The locking mechanism consists of threaded screw heads, which are locked in the corresponding threads in the plate. In the 2.0 system, three plates of varying thickness are available. These all accept 2.0 mm screws.

In the 2.4 system, one plate with four different screws (2.4 mm and 3.0 mm locking head screws, 2.4 mm nonlocking cortex screw, 2.7 mm emergency screw) is available (**Fig 2.1-32**). All screws
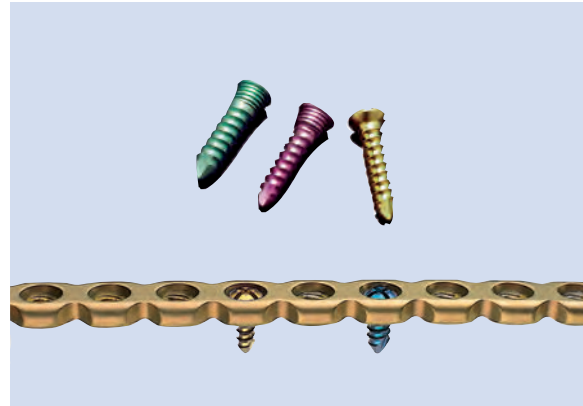
Fig 2.1-32   UniLock 2.4 mm system. The 2.4 mm or 3.0 mm screws are locked in the matching plate holes by conical threads; 2.4 mm nonlocking screws can also be inserted.

are self-tapping. The locking head screws are inserted perpendicular to the plate. A special drill guide, which is screwed into the hole and centers the drill precisely, facilitates locking the screw head to the plate.

In humans, the UniLock system is most frequently used for mandibular fracture repair. In veterinary orthopedics, the potential applications are much wider, given the small bones of cats and dogs.

5.3 Clamp rod internal fixator (CRIF)

The CRIF is a versatile system consisting of a rod, standard screws, and clamps to fix the screws to the rod (**Fig 2.1-33**). It is available for use with 2.0, 2.7, and 3.5 mm screws [6] and can be used for

✏ Video

diaphyseal and metaphyseal fractures in all sizes of dogs and cats. Its properties include excellent versatility, good contouring capability, ease of application, minimal instrumentation, and minimal contact with the bone. It is financially affordable and of sufficient strength to allow immediate weight bearing.

The construction of the CRIF allows optimal blood supply at the fracture site since it touches the bone only at the clamp sites. This favours vascularity and rapid indirect bone healing. The clamps can be arranged along the rod, which is contoured to the outline of the bone. Because the clamps may be placed on either side of the rod, solid fixation even in small fragments is possible. When the screws are tightened, the clamp is firmly fixed to the rod. An AO developed CRIF is in the stage of clinical trial [7].

Fig 2.1-33   Clamp rod internal fixator (CRIF) showing the fixation technique.

6   Contouring of plates

Straight plates often need to be contoured prior to application, to match the anatomy of the bone. If this is not done, the reduction will be lost, especially if there are no lag screws placed across the fracture. Even the anatomically shaped plates may require fine contouring before application. This is best done with the hand-held bending pliers or the bending press as well as bending irons (**Fig 2.1-34**). Plates may be precontoured against an anatomical specimen or against a radiograph of the intact contralateral bone. If complex 3-D contouring is required, special flexible templates are available, which can be modeled to the bone surface. The plate can then be modeled against the template.

Repeated bending back and forth of the plate should be avoided because this weakens the plate. Plates should be bent between the holes, in order to maintain the function of the hole and to avoid stress risers (**DVD | Video 2.1-9**).

Internal fixators, whose principle relies on a firmly locked screw head in the plate, must always be bent with the special bending screws inserted. However, when locking head screws are used, perfect contouring is not necessary.
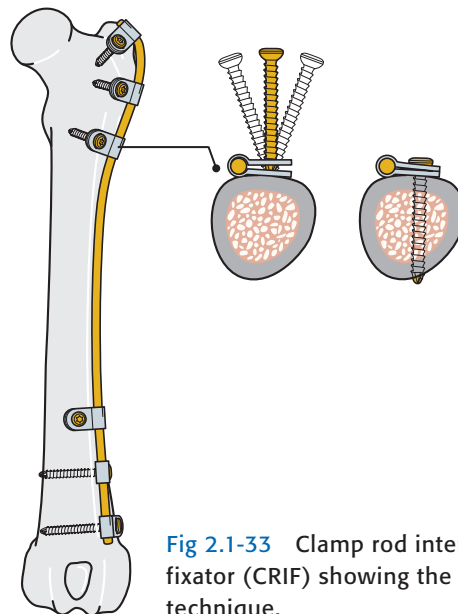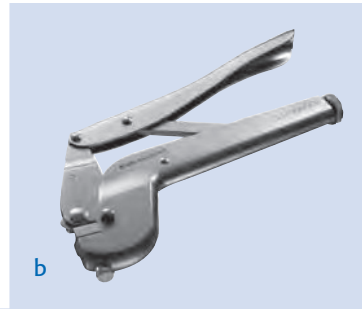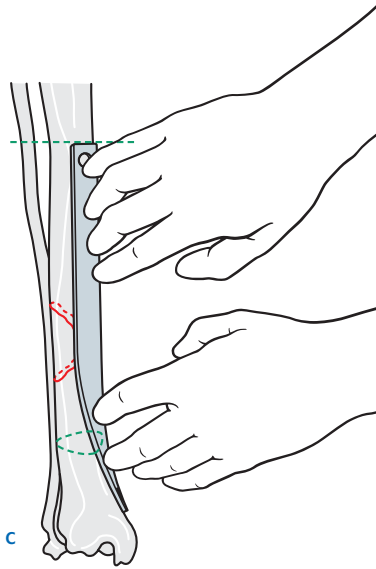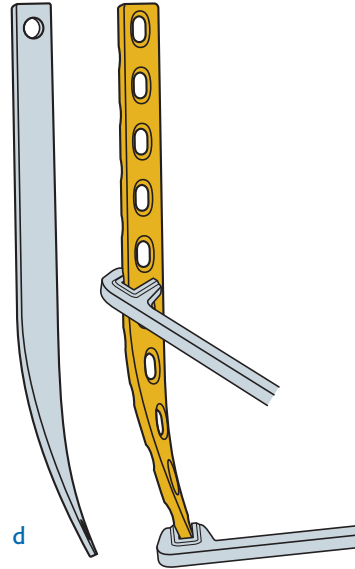
Fig 2.1-34a–c
a   Bending press.
b   Hand-held bending pliers.
c   Flexible templates to facilitate plate contouring.
d   Plate contouring with bending irons.

7 Bibliography

1. **Perren SM** (2002) Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. *J Bone Joint Surg [Br]*; 84(8):1093–1110.

2. **Gauthier E, Perren SM, Ganz R** (1992) Principles of internal fixation. *Curr Orthop*; 6:220–232.

3. **Perren SM, Russenberger M, Steinemann S, et al** (1969) A dynamic compression plate. *Acta Orthop Scand Suppl*; 125:31–41.

4. **Perren SM, Klaue K, Pohler O, et al** (1990) The limited contact dynamic compression plate (LC-DCP). *Arch Orthop Trauma Surg*; 109(6):304–310.

5. **Hulse DA, Hyman W, Nori M, et al** (1997) Reduction in plate strain by addition of an intramedullary pin. *Vet Surg*; 26(6):451–459.

6. **Härdi-Landerer C, Steiner A, Linke B, et al** (2002) Comparison of double dynamic compression plating versus two configurations of an internal veterinary fixation device: results of in vitro mechanical testing using a bone substitute. *Vet Surg*; 31:582–588.

7. **Zahn K, Matis U** (2004) The clamp rod internal fixator-application and results in 120 small animal fracture patients. *Vet Comp Orthop Traumatol*; 3:110–120.

2.2   External fixators, pins, nails, and wires
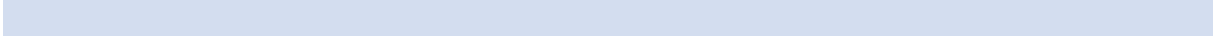
2.2 External fixators, pins, nails, and wires

1 External fixators

1.1 Fixation pins

Pins for external fixation may be either smooth or threaded, and the thread profile may be either negative or positive. Although there are some instances where smooth or negative threaded pins would be acceptable, positive threaded pins are stronger and purchase bone more securely. Thus they have dramatically improved the performance of fixators in veterinary patients. **A positive threaded pin has a shaft diameter that is the same its whole length. This reduces the bending stress, when compared with a negative threaded pin.** The thread diameter is greater than the shaft (**Fig 2.2-1**). Predrilling a hole slightly smaller than shaft diameter improves the quality of the pin–bone interface [1]. Positive threaded pins are available in diameters from 1 to 6 mm from a number of veterinary suppliers. The more common sizes are supplied with threads at one end (for half pins) or in the center (for full pins). Some of the small diameter pins have a portion of their shaft knurled to improve the interface strength with acrylic or epoxy connecting materials.

1.2 Pin gripping clamps

There are a number of different designs for clamps. They have a portion that grips the pin and a portion that grips the connecting bar. The principal design in the past worked well with smooth and negative threaded pins but positive threaded pins of the same size cannot pass through the securing bolt. Also, the older style clamps could only be added to the connecting bar by sliding them onto one end. This made adding clamps during frame construction difficult.

A number of **clamps are now available that accommodate positive threaded pins. They can also be added to the connecting bar wherever needed (Fig | Video 2.2-2, Fig 2.2-3)**. Clamps are available in mini, small, and large sizes, depending on the size of the pin and connecting bar being used. Double clamps, which connect one connecting bar to another, are also available but are used infrequently because they are not as strong as the single clamp.

Pins can also be held to the connecting bar(s) by acrylic or epoxy putty compounds, though, more commonly, these compounds form the connecting bar as well.
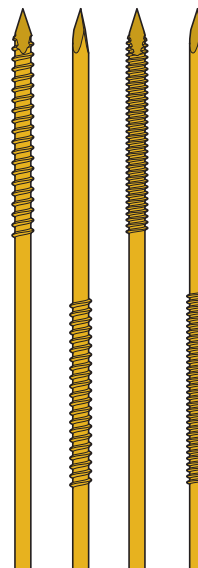
Fig 2.2-1 Examples of end-threaded and centrally threaded pins for external fixators. The finer thread is designed for cortical bone. The coarser thread profile is for cancellous bone.

Positive threaded pins are stronger and purchase bone more securely.

Predrilling a hole slightly smaller than the shaft diameter improves the quality of the pin–bone interface.

Pin gripping clamps are available that accommodate positive threaded pins. They can be added to the connecting bar wherever needed.

Double clamps are used infrequently because they are not as strong as the single clamp.

Fig | Video 2.2-2   Functional design of a pin gripping clamp.
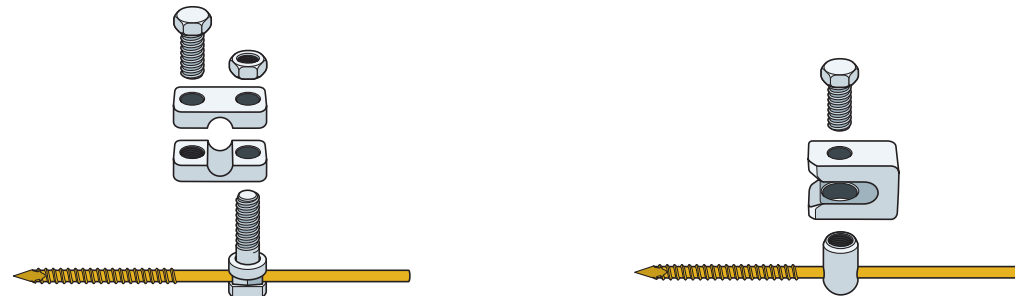
Fig 2.2-3   Examples of two external fixator clamp systems. In contrast to the older Kirschner-Ehmer system, these clamps can be added to a frame at any location and accommodate positive threaded pins.

1.3 Connecting bars

Carbon fiber rods
are radiolucent.

Acrylic can be used as
a connecting bar.

Historically, **connecting bars have been made from hardened stainless steel, though carbon composite and titanium materials are being used very successfully (Fig 2.2-4)**. The diameter is determined by the size of the bone being stabilized and the size of the clamps available.

The number of connecting bars is determined by the frame configuration. As mentioned above, acrylic and epoxy putty compounds can be used to connect the pins and form the supporting bar. **Mechanical studies have shown that a 19 mm diameter acrylic or epoxy bar has similar rigidity to a 3.175 mm stainless steel bar** [2, 3].
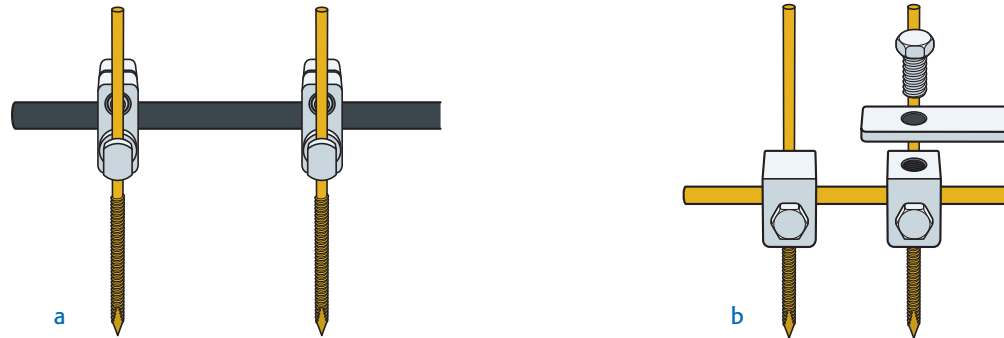
Fig 2.2-4a–b   Connecting bar size and material varies with system.
a   This system uses connecting bars made of a carbon composite. Smaller systems use titanium bars as well.
b   In this system an augmentation plate can be attached to the outer surface of modified clamps to stiffen the portion of the frame that spans the fracture.

1.4 Application

There are many factors to consider when choosing an external fixator to stabilize a fracture. They are most suited to injuries below the elbow and stifle, because there is less soft tissue covering the bones, but they have also been used for more complex femoral and humeral fractures, and for the spine. They are also well suited to more complex fractures of the mandible and maxilla.

One of their primary advantages is that they can often be applied in a closed fashion, thus preserving blood supply and fracture hematoma. Most of the reduction is achieved before pins are placed. A hanging limb system can be very useful for stretching the contracted muscles and swollen soft tissues, and aligning the joints above and below the fracture. Fluoroscopic imaging can be used to improve the accuracy of pin placement and of the final reduction.

The pins are best located so they penetrate as little soft tissue as possible. **Neurovascular structures must be avoided.** This reduces the degree of postoperative problems associated with the pins. It also ensures they are as short as possible, which contributes significantly to frame stability [4]. **Avoiding soft-tissue damage is usually easiest with half pins (penetrate the skin once) and a unilateral frame** (**Fig 2.2-5a**)**, but bilateral frames** (**Fig 2.2-5b**)**, with full pins penetrating the limb completely, have some mechanical advantages.** One approach to improving the mechanical performance of a frame without using full pins is to place two unilateral frames approximately 90° to each other (biplanar configuration) (**Fig 2.2-5c**). Triangular configurations (bilateral with a unilateral frame on the cranial aspect) are very rigid and might be considered for severe fractures with significant soft-tissue injury and a predicted long healing time (**Fig | Video 2.2-6**).

External fixators are most suited to injuries below the elbow and stifle.

External fixators can often be applied with closed reduction for treating comminuted fractures, thus preserving biology.

Pins must be placed to avoid excessive soft-tissue penetration and neurovascular structures.

Bilateral frames are more stable than unilateral frames, but the full pins penetrate more soft tissue.
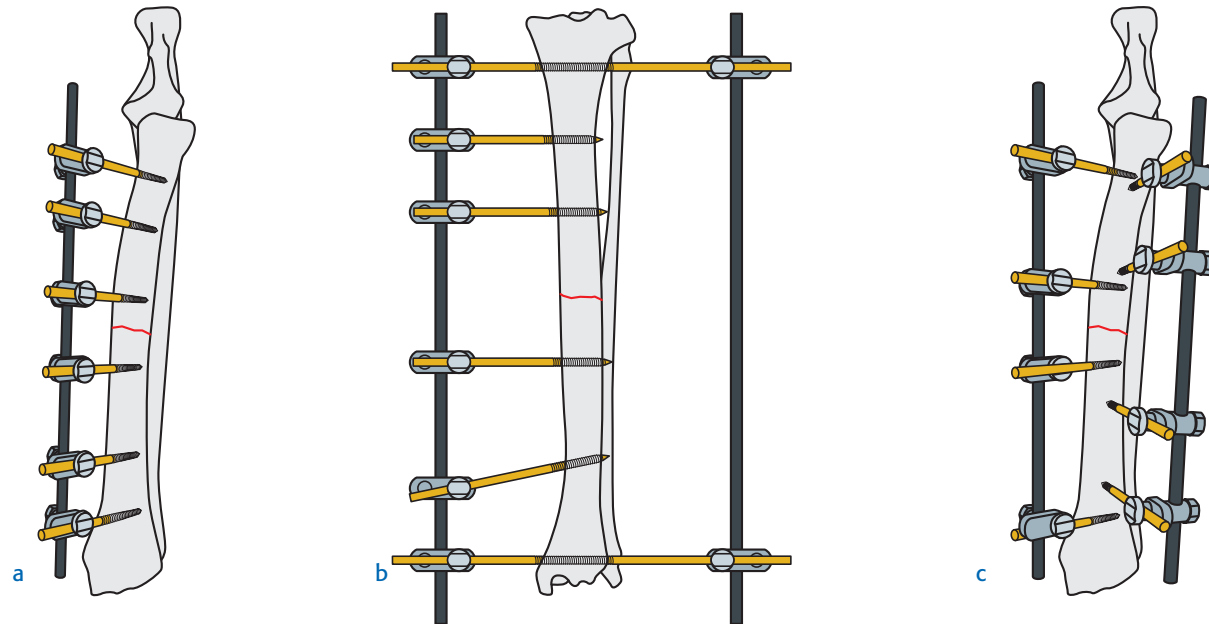
Fig 2.2-5a–c   External fixators can be applied in many ways for fractures of extremities.
a   Unilateral frame on a fracture of the radius and ulna.
b   Bilateral frame on a fracture of the tibia.
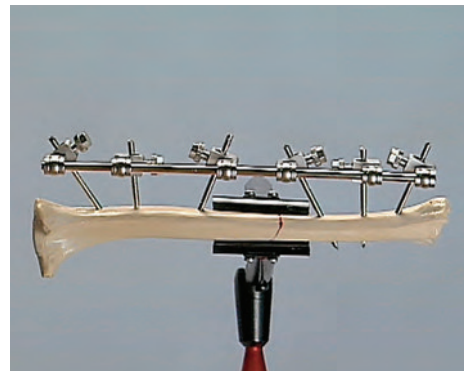c   Biplanar frame on a fracture of the radius and ulna.

Fig | Video 2.2-6   Application of an external fixator using different configurations.

A minimum of two pins must purchase each fragment. The stress at the pin–bone interface is reduced if more pins are used, so three or four pins are often considered. **The diameter of the pins chosen for a particular location should be no more than 25% of the diameter of the bone.** If room is restricted in a fragment, it may be beneficial to use a pin of slightly smaller diameter so that three pins can be placed, rather than using two pins of larger diameter. Although angling pins to one another adds a little to the stability, again, **placing more threaded pins in a parallel alignment will provide a superior purchase to having fewer angled pins**. Pins should not be located too close to the fragment ends, particularly if fissures are likely to be present. **A general rule is to position the pin at least two pin diameters from the fragment edge.**

The pin gripping clamps should be positioned so that the bolt locking the pin is as close to the bone as possible, without making contact with the skin. This shortens the pin length, thus stabilizing the frame [4].

Free form external fixators using acrylic or epoxy putty compounds as connecting materials should be considered when the linear systems might not adapt well to the particular fracture (**Fig 2.2-7**). Their primary advantage is that the pins do not have to be in the same plane, and the putty frames can be formed with curves to match irregular bone shapes (ie, the mandible) or to span joints. The same principles apply to pin application. Once all of the pins are placed, reduction is achieved and maintained. This may be done manually or with a temporary fixation system. The extra pin length can be cut or the pin can be bent over to reinforce the connecting bar. A commercial acrylic system uses tubing that is pushed over the pin ends as a mold for the bar. Alternatively, hand mixed acrylic or epoxy putty can be molded around the pin ends. Once the material has hardened, the temporary connections are removed.

External fixators can be used as adjunct fixation for intramedullary pins and, in rare cases, for locked intramedullary nails or plates.

Three pins placed in each major segment of bone are optimal for stabilization.

Allow at least 1 cm distance between the skin and the pin gripping clamp.

Acrylic external fixators easily accommodate pins of differing sizes placed in different planes.
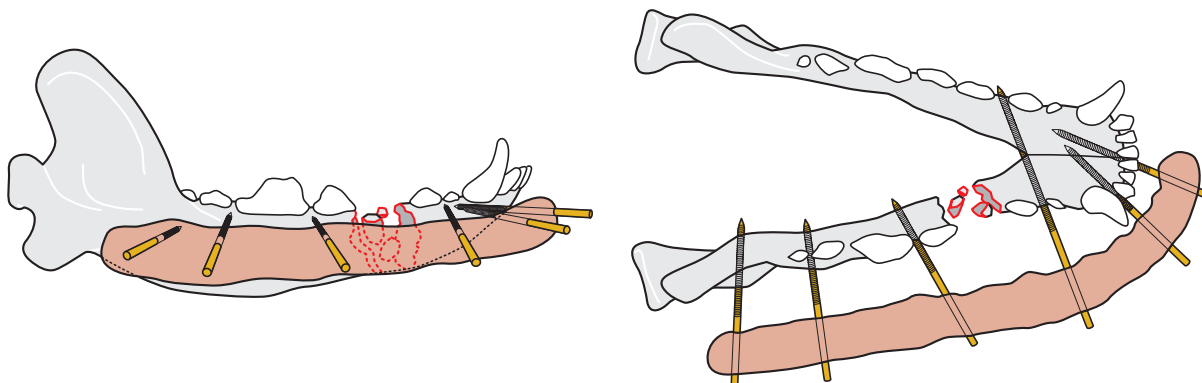

Fig 2.2-7   Free form epoxy putty frame on a comminuted fracture of the mandible.

2 Locked intramedullary nails

2.1 Implants

Locked intramedullary nails resist bending, axial, and rotational forces because they are locked with either bone screws or locking bolts.

A locked intramedullary nail is a stainless steel nail that is placed within the medullary cavity and is locked to the bone by screws or bolts that cross the bone and pass through holes in the nail (Fig 2.2-8). They are available in 8.0, 6.0, 4.7, and 4.0 mm diameters. The 8.0 mm nail can be locked with screws or bolts of 4.5 or 3.5 mm diameter. The 6.0 mm nail can be locked with screws or bolts of 3.5 or 2.7 mm diameter. The 4.7 and 4.0 mm nails can be locked with screws or bolts of 2.0 mm diameter. The standard nail has two holes proximal and two holes distal and they may be either 11 or 22 mm apart in the 8.0 mm and 6.0 mm systems. The holes are 11 mm apart in the 4.7 and 4.0 mm systems. Locked intramedullary nails are also available with one hole proximal and two holes distal, or two holes proximal and one hole distal, for use when fracture fragments are not large enough for two points of purchase.

Locked intramedullary nails attach to a drill jig which passes on the outside of the limb and orients the drill guides such that the screw will be aligned with the holes in the nail.

Intramedullary nails are locked with either bone screws or locking bolts of the appropriate diameter. A locking bolt has a short length of thread immediately below its head that engages the near cortex. The rest of the shaft is unthreaded, thus significantly increasing its bending strength.

The locked intramedullary nail has a trocar point on one end, and two flanges and an internal thread on the other end that enable it to be securely attached to the extension piece that then attaches to the drill jig.

Locked intramedullary nails are most effectively used to stabilize middiaphyseal fractures of the humerus, femur, and tibia.

2.2 Equipment

Reamers that match the size of the selected nail may be used to prepare the medullary canal. An extension piece is attached to the nail so that the nail can be advanced completely into the bone. The insertion tool attaches to the extension piece to assist with driving the nail. Once in position, the insertion tool is removed and the drill jig is attached to the extension piece. The drill jig passes on the outside of the limb and orients the drill guides such that the drills and taps (if used) will be aligned with the holes in the nail (Fig 2.2-8a). A guide sleeve is first placed in the drill jig and a trocar used to score the bone surface to help prevent migration of the drill bit. The appropriate drill guide is placed and a hole drilled across the bone passing through the associated hole in the nail. If a bone screw is used to lock the nail, a tap guide is placed and the hole tapped. Once all screws or bolts are placed, the drill jig and extension are removed (Fig 2.2-8b).

2.3 Application

Locked intramedullary nails are suitable for the stabilization of selected fractures of the humerus, femur, and tibia [5]. **They resist bending forces in all directions because of their large diameter and central location. The locking screws and bolts counter axial and rotational forces.**

They are usually placed in bridging mode, with little disturbance of the fracture site and without addition of adjunct fixation. They can be placed in a closed manner in some fractures.
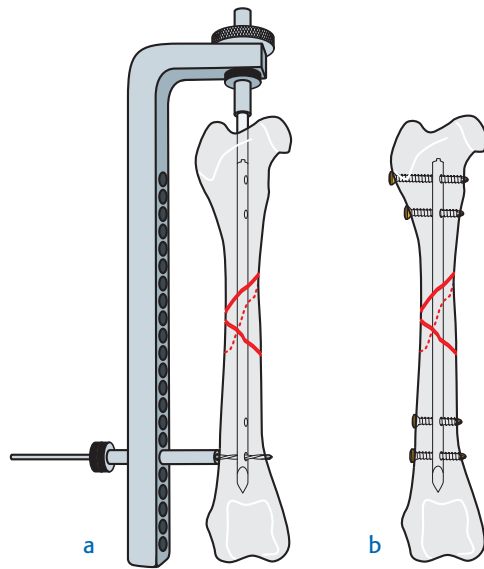
Fig 2.2-8a–b   Specialized equipment is necessary to accurately place the locking screws or bolts.

a   When the nail is in its final position and the fracture reduced, the drilling jig is attached to the extension device. Guide sleeves are placed in the holes of the drilling jig so that the drill bits or taps are accurately aligned with the holes in the nail.

b   The nail resists bending forces in all directions because of its large diameter and central location. The locking screws and bolts counter axial and rotational forces.

Locked intramedullary nails are most stable if the primary fracture fragments are of sufficient size to accommodate two locking screws or bolts. If only one locking screw or bolt is placed, the fragment may rotate around that point. If the nail fits snugly into the fragment, this is less likely. Because the screw or bolt does not lock directly into the nail, it is best if the hole is located as far away from the fracture site as possible. An unfilled hole within the nail greatly weakens the repair.

The largest size of nail that will fit into the bone should be used. This will be influenced by whether or not the narrow isthmus is involved in the fracture.

To insert a nail, the medullary canal can be opened in either a normograde or retrograde manner, though the nail itself must be passed normograde. To attain purchase in the medical epycondyle of the humerus the nail must be inserted quite distally on the greater tubercle. In the femur, normograde placement starting with a smaller diameter pin can ensure that the femoral neck is not injured. Normograde placement in the tibia may decrease the likelihood of damage to the insertion of the cranial cruciate ligament. Normograde placement may also require less dissection and manipulation of the fracture site, thus maintaining the tenuous blood supply.

Placing the nail usually aligns the primary fragments well. Driving the nail distally will often recover much of the shortening due to muscle contracture. Once the nail is assessed to be of the correct size, it is helpful to lock the distal fragment first, and then achieve final lengthening and rotational corrections immediately prior to placing the proximal locking screws or bolts.

The primary fracture fragments should be large enough to accommodate two locking screws in each.

Use the largest nail that can fit into the bone.

The nail must be passed normograde.

Lock the distal fragment first, then correct rotation and lock the proximal fragment.

It is important to be very careful when drilling the holes for the screws in order to ensure that the drill passes through the hole in the nail. The connection between the extension and nail must be very secure. Reduction forceps should be removed from across the fracture and retractors must not contact the drill jig. If the nail is located eccentrically in the medullary canal, the point of contact of the drill bit may be sloped. Scoring the bone surface with the trocar and using sharp drill bits will help prevent drift.

Locked intramedullary nails are only removed if they break and a nonunion develops, or if they become infected. Once the locking screws or bolts are removed, they can be extracted from the top, by reattaching the extension, or through the fracture site.

3 Intramedullary pins and Kirschner wires (K-wires)

3.1 Implants

Intramedullary pins, often termed Steinmann pins, are round stainless steel rods ranging from 2.0 to 5.0 mm. They usually have a point at both ends, but are also available with only a single point. The most common point style is a three-faced trocar, but bayonet and diamond points are also available. They are usually supplied either 230 mm or 300 mm long. They are also available with a negative profile thread cut into one end.

K-wire is the term for small diameter stainless steel pins. They generally range from 0.8 to 2.0 mm in diameter. They are also available with points at both ends or just at one end. Trocar tips are most common. Their length ranges from 150 mm for small fragment work to 300 mm for use with circular fixators.

3.2 Application

As their name implies, **intramedullary pins are frequently placed within the medullary cavity to align and support shaft fractures**. A pin that is approximately 70% of the diameter of the medullary canal is considered optimal. **A pin of this size will generally adequately resist the bending forces experienced by a fracture. Intramedullary pins will not prevent collapse or rotation of a fracture.** If the primary fragments make good contact, and if the ends interdigitate, the aligned bone itself may counter these forces, but this situation is **very** rare. Consequently, **adjunct fixation is necessary in nearly all situations where an intramedullary pin is used**.
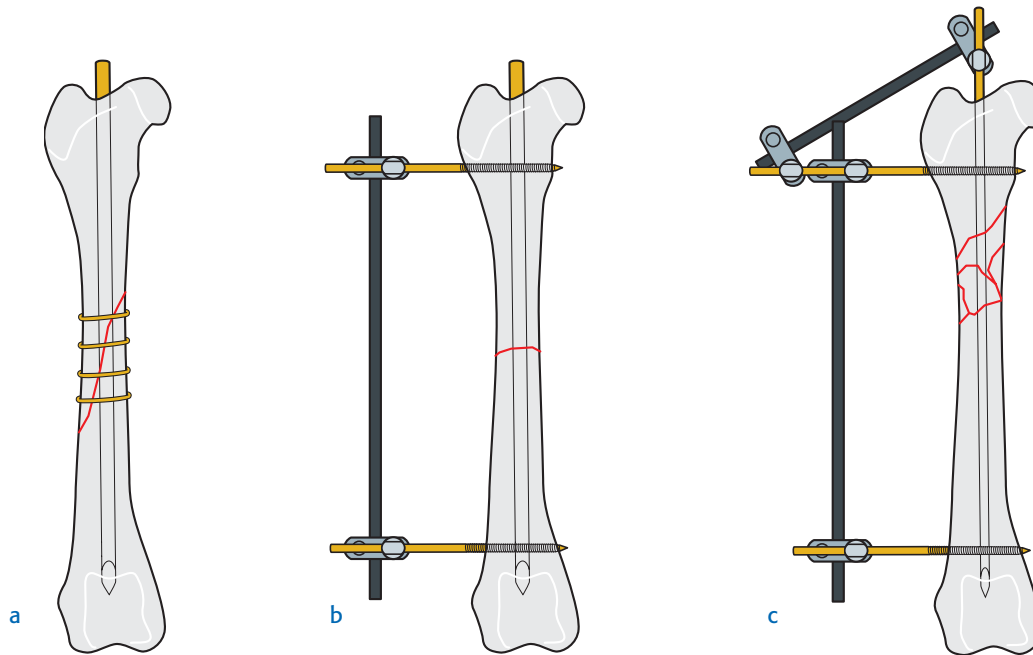
Fig 2.2-9a–c
a   A long oblique fracture can be stabilized with multiple cerclage wires and an intramedullary pin.
b   A transverse fracture can be stabilized with an intramedullary pin and external fixator.
c   A comminuted fracture can be stabilized with an intramedullary pin that is "tied-in" to a unilateral external fixator.

Cerclage or hemicerclage wiring may be sufficient if the fracture configuration lends itself to their use (see 2.2 External fixators, pins, nails, and wires; 4 Orthopedic wire; 4.2 Application) **Fig 2.2-9a**). An external fixator that engages the primary fragments is the most effective method for countering axial and rotational forces around an intramedullary pin (**Fig 2.2-9b**). When the primary fragment is small, the intramedullary pin can be left protruding from the patient and then incorporated into the fixator, as long as it does not interfere with motion of the adjacent joint. This has been termed a "tie-in" configuration (**Fig 2.2-9c**).

Stacking pins, by placing two or three pins beside each other to completely fill the medullary cavity, improves the bending strength but adds little to the axial or rotational stability.

Both intramedullary pins and K-wires can be used as crossed pins to maintain the position of small end fragments (**Fig 2.2-10**). After reduction of the fragment, the pins are driven from either side of the small fragment to cross the fracture and exit on the opposite side of the bone. The primary fragments must have good contact and, ideally, interdigitate to resist rotational forces.

Adjunct fixation, such as cerclage wires or an external fixator, is necessary in nearly all situations where an intramedullary pin is used.

Intramedullary pins and K-wires can be used as crossed pins for the repair of physeal fractures.

Fig 2.2-10　Fracture of the distal femoral physis repaired with crossed K-wires.

Large diameter wire is stronger but more difficult to manipulate through holes or around bones or pins. The surgeon must weigh these two factors when choosing the appropriate sized wire for each particular situation.

Wire should not be kinked as it is passed, as it is difficult to straighten it again and to tighten it down completely.

Soft tissue interposed between wire and bone leads to premature wire loosening.

Wires fail when the structure around which they are wrapped collapses or reduces in diameter, thus causing the wire to loosen.
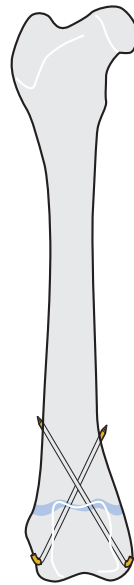
The most common indication for this technique is the repair of physeal fractures. These have the added advantage of healing quickly.

An intramedullary pin can be used in conjunction with a plate placed in buttress mode so that the bending stress is reduced. Because the pin fills a portion of the medullary cavity, it may only be possible to place a cortex screw unicortically through the plate in the diaphysis. The cortex screws should be used bicortically in the metaphysis. A pin that is approximately 50% of the medullary diameter reduced the bending stress in an unsupported plate model to a level below that required for failure [6] (for technique see 2.1 Screws and plates; 4 Plates; 4.1 DCP).

4　Orthopedic wire

4.1 Implants

Orthopedic wire is provided as a malleable form of 316L stainless steel. It comes in a range of diameter, from 0.5 to 1.5 mm (24–16 gauge). The larger the diameter of the wire, the higher is its yield bending and tensile strength. Therefore, a wire may be tied with greater initial tension, and have a knot that will resist greater load before loosening if a larger wire diameter is selected. However, these properties also make it more difficult to manipulate the wire through holes or around bones or pins. The surgeon must weigh these two factors when deciding on the appropriate size for each particular situation.

For most applications, the required length is cut from a spool or coil. Wires that have a preformed eye at one end for a single loop knot are available in 1.0, 1.25, and 1.5 mm diameters. As the wire is being formed for its intended application, it should not be marked by instruments, as this will reduce its ability to resist cycling loads [7]. The wire should not be kinked as it is passed, as it is difficult to straighten it again. Consequently, it is difficult to tighten it down completely.

When placing the wire, it is important that it is in intimate contact with the bone surface. The periosteum must be elevated. If soft tissue is between a wire under tension and the bone, it will necrose and be resorbed. This will result in a reduction of the effective diameter of the bone. It has been shown that, even with very tight wires, very small reductions in diameter or collapse (< 1% of the bone diameter) will cause the wire to loosen and potentially become ineffective [8].

Indeed, it is likely that wires fail more frequently because the structure around which they are wrapped collapses or reduces in diameter, thus causing the wire to loosen, rather than by failure of the knot to resist the loading applied.

4.2   Application

4.2.1 Cerclage wire

Full cerclage wires wrap completely around the bone. In order to compress bone fragments effectively, the cylinder must be fully restored. The more fragments that are present at the level that the wire is being applied, the more difficult this is to achieve. **The ideal configuration is a long oblique fracture, with the general rule that the fracture length should be at least twice the diameter of the bone.** If the fracture is shorter than this, it is possible that the fragments may shear relative to each other as the wire is tightened. **Moreover, to effectively counter bending forces, it is necessary to have at least two cerclages supporting the fragments.** For short fracture lengths, the cerclage wires would be close together and, therefore, will not be effective in countering bending forces. **Cerclage wires should be spaced at distances which are between half and the entire bone diameter apart (Fig 2.2-9a).** This spacing appears sufficient to compress the surfaces effectively while preserving some of the soft-tissue attachments to the fragments.

When cerclage wires are used as an adjunct on shorter oblique fractures, their line of action can be oriented more perpendicular to the fracture line by using a K-wire. This technique has been termed the skewer pin technique. By redirecting the action of the cerclage wire, the fragments are less likely to shear relative to one another. With the fracture reduced, a K-wire is directed from one fragment to the other with the wire just off perpendicular to the fracture plane. With fractures that are more transverse, the K-wire must be oriented on the line bisecting the perpendiculars from the long axis of the bone and the axis of the fracture. Once the K-wire is placed, a full cerclage is placed around it so that, as it is tightened, the cerclage is held in the orientation of the K-wire (**Fig 2.2-11**). This technique can also be used to ensure that cerclage wires placed in the metaphyseal region do not migrate towards the smaller diameter of the diaphysis.
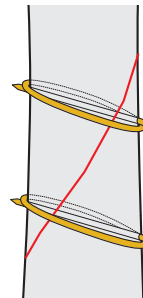

Fig 2.2-11   Skewer pin technique. A K-wire is directed from one fragment to the other. Then a full cerclage is placed around it so that, as the cerclage is tightened, it is held in the orientation of the K-wire.

Even in the ideal situation, **cerclage wires should not be used as the sole means of fracture repair**. They are most commonly used in conjunction with an intramedullary pin. The pin primarily counters bending forces on the bone. The cerclage wires ensure intimate contact between the proximal and distal fragments, thus countering axially aligned compressive forces and rotational forces (**Fig 2.2-9a**). Cerclage wires may be used with locked intramedullary nails, but, because the nail is able to counter compressive and rotational forces as well as bending forces, they are not used frequently. Cerclage wires may be placed preemptively if fissures are present in a fragment that must receive a screw or pin.

Cerclage wires can effectively compress bone fragments only when the bone cylinder is fully restored.

The ideal fracture configuration for cerclage wires is a long oblique or spiral fracture with the fracture length at least twice the diameter of the bone. At least two cerclage wires should be used to effectively counter bending forces.

A skewer pin stops a cerclage wire from migrating toward the smallest diameter of the diaphysis.

Cerclage wires are always used with additional fixation such as an intramedullary pin, external fixator, or plate.
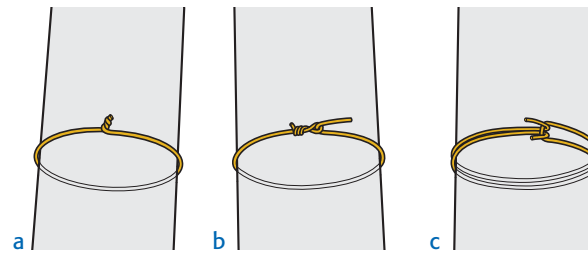
Fig 2.2-12a–c
Orthopedic wire is most commonly tied with:
a   a twist, or
b   a single loop, or
c   a double loop knot.

twist is then grasped with the instrument and further twists formed while pulling very firmly away from the bone. This will ensure that the twist is tightening at its base, and that the wires wrap around each other—not one around the other (**Fig 2.2-13**). Once the wire is tight (ie, no longer moves when pushed) or the surgeon feels that further twists will cause the knot to break, the twist is cut with two to three wraps remaining. It is very important not to wiggle or disturb the cerclage wire while cutting, as this may cause it to lose tension. The twist should not be pushed down flat to the bone, as this will generally reduce the initial tension.

Cerclage wires may be used as temporary devices to maintain reduction during application of a plate. This is particularly helpful if the orientation of the fracture is such that lag screws are best placed through the plate. Once the plate has been contoured and the first screws placed, the wire is removed so that the plate will sit flush with the bone. When fractures occur adjacent to joint prostheses, cerclage may be used to attach the plate to a bone. To hold the wire in position around the plate, cerclage buttons that fit into the screw heads are available for 3.5 and 4.5 mm screws.
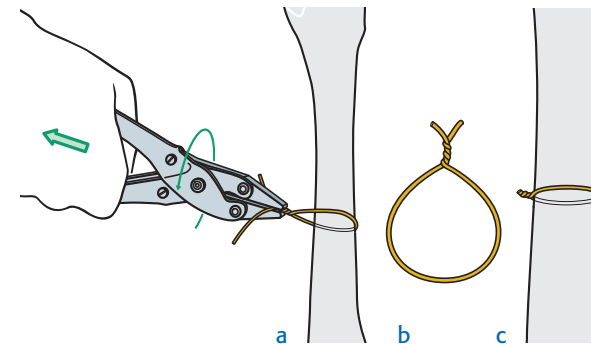
The three most common methods for tightening and securing cerclage are twist, single loop, and double loop knots (**Fig 2.2-12**). There are many instruments for forming a twist knot. Old needle drivers or pliers are the simplest. Instruments that lock the two strands may help ensure that the twist forms with an even wrap. To form a twist with needle drivers or pliers, it is best to ensure that the wire is pulled tight to the bone. The first two to three twists should be formed by hand. The loose

Fig 2.2-13a-c
To form a twist tie with needle drivers or pliers:
a   The wire is pulled tight to the bone and the first two to three twists formed by hand. The twist is tightened with the instrument while pulling very firmly away from the bone.
b   This will ensure that the twist is tightening at its base and that the wires wrap around each other, not one around the other.
c   Once the wire is tight, the twist is cut with two to three wraps remaining.

It is important to pull the wire firmly while twisting.

Cut the twist with two to three wraps remaining and do not push it down flat to the bone, as this will generally reduce the initial tension.

An alternative method for finishing the twist knot is to twist and flatten it simultaneously. The twist is formed as described above and tightening begun. When there is just half to one twist remaining before the wire is considered tight, the knot is cut with five or six twists remaining. The last two twists may be bent over to improve grip. The twist is tightened the final turn while pulling up to start, and then folding flat to finish.

The single loop cerclage knot (**Fig 2.2-12b**) is formed using a length of wire with an eye at one end. The free end is passed around the bone, through the eye, and into the wire tightener. Once the cerclage is roughly tightened by hand, the free end is passed through the crank of the tightener and trimmed to 1.5 cm. The cerclage is tightened by turning the crank. When the surgeon judges the wire to be tight, the wire tightener is bent over so that the free end folds back on itself (**Fig 2.2-14**). Tension must be maintained in the crank while bending over the tightener. The crank is then reversed until 0.5–1.0 cm of wire is exposed, and the folding completed.
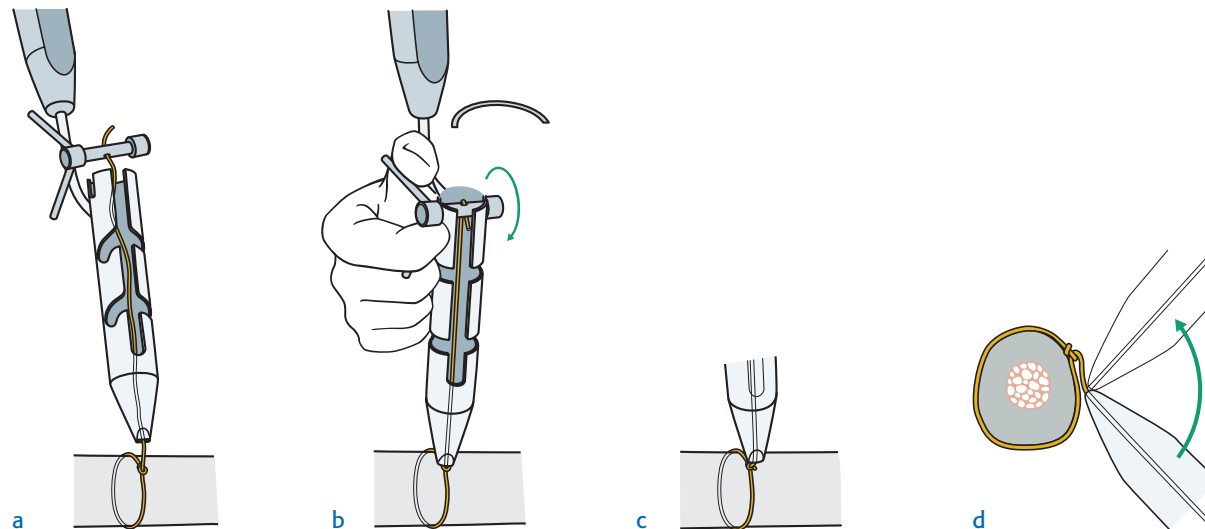
Fig 2.2-14a–d To form a single loop cerclage tie:
a   The free end of the wire is passed around the bone, through the eye, into the wire tightener, and through the crank of the tightener.
b   The cerclage is tightened by turning the crank.
c   The wire tightener is bent over so that the free end of the wire folds back on itself.
d   The crank is reversed until 0.5–1.0 cm of wire is exposed and the folding completed. The wire is cut leaving the 0.5–1.0 cm length, and the arm pushed flat to the bone.

Fig | Video 2.2-15
Cerclage wire application.

Hemicerclage wires add little to the mechanical stability of a fracture.

Further loosening exposes sufficient wire to enable the free arm to be cut, leaving the 0.5–1.0 cm length. The arm is pushed flat to the bone (**Fig | Video 2.2-15**).

The double loop cerclage knot (**Fig 2.2-12c**) is formed using a straight length of wire folded near its middle. For a 2 cm diameter bone, a 36 cm length of wire is a suitable length. The folded end is passed around the bone, and the free ends passed through the loop. After snugging the cerclage wire close to the bone, the free ends are passed into the wire tightener and loaded into the two cranks. The cranks are turned simultaneously until tension is judged appropriate. The wire tightener is bent over so that the free ends are folded back on themselves. It is important to maintain tension in the cranks during this bending maneuver. The cranks are reversed until 0.5–1.0 cm of wire is exposed, and the folding completed. Further loosening exposes

sufficient wire to enable the free arms to be cut, leaving the 0.5–1.0 cm length. The arms are pushed flat to the bone.

The tension that can be generated during tightening and the ability to resist load differs for the three knots (**Table 2.2-1**).

The tension that can be generated is very dependant on technique, but not necessarily on experience [9]. **Double loop knots are twice as tight and twice as strong because they have two strands and two arms to unbend. As they are no more difficult to place and tie, they are the cerclage of choice.**

4.2.2 Hemicerclage and interfragmentary wire

To form a hemicerclage, the wire is passed through holes drilled in the proximal and distal fragments, and then wrapped around the bone. The portion of the wire inside the medullary canal should wrap around the intramedullary pin such that, when

Knot type	Initial tension (N)[9]	Load to loosen (N)[8]
Twist	70–100	260
Single loop	150–200	260
Double loop	300–500	666

Table 2.2-1   The initial tension achieved and the load resisted prior to loosening for twist, single loop, and double loop cerclage formed with 1.0 mm orthopedic wire.

tightened, the pin is pulled to the endosteal surface of the fragments. Although this may improve alignment, it adds little to the mechanical stability of a fracture. The holes in the bone weaken the fragment ends. Because the wire is wrapped on only one side of the bone, it only counters rotational forces in one direction. There are few instances where hemicerclage wires are now considered useful.

Interfragmentary wires are placed like "sutures" holding bone fragments together. Holes are drilled in the apposing fragments so that, when the wire is tightened, the fragments are held in alignment. They are only appropriate for simple fracture configurations that interdigitate well, in the flat, non-weight-bearing bones. As such, they are used mostly for repair of mandibular and maxillary fractures (**Fig 2.2-16**). Interdental wires are a specialized version of interfragmentary wire.

Because interfragmentary wires are often used as the primary fixation device, there is a tendency to select a large diameter wire to optimize knot security. This must be weighed against the difficulty of manipulating the wire. Often, the wire must be passed blindly through one of the holes, and this may be more difficult with less malleable wire. Also with less malleable wire, it can be more difficult to tighten the portion of the wire that does not have the knot. Because the wire makes two right-angled bends as it passes through the hole, the tension generated by tightening may not be sufficient to pull the wire around those bends, and thus, the length on the back side of the bone is not tightened. Moreover, because greater tension can be generated with thicker wire, there is more likelihood of the wire fracturing or cutting through the bone.

The twist knot is used most commonly with interfragmentary wires, probably because the process of tightening and securing occur simultaneously. As with cerclage wires, it is important to pull firmly on the knot while it is being formed so that the wires wrap around one another, and the twist occurs at the base of the knot. To retain tension, the twist must be carefully cut, and not pushed flat.

4.2.3 Tension band wire

Avulsion fragments can be effectively stabilized using the pin and tension band wire technique (**Fig 2.2-17**). The fragment is initially stabilized using either two or more pins or K-wires or a lag screw. To protect these implants from the bending forces exerted by the pull of the attached ligaments or tendons, a wire is placed to oppose the tensile forces. An added advantage of this arrangement is that the pull in the ligament and the counterpull in the wire convert these tensile forces to compressive forces across the fracture line. To take advantage of this resultant force, the pins should be oriented perpendicular to the fracture plane.

Interfragmentary wires are useful for repair of some mandibular and maxillary fractures.

The pull in the ligament and the counterpull in the wire convert tensile forces to compressive forces across the fracture line when a tension band wire is used appropriately.

Fig 2.2-16 A simple fracture of the mandible repaired with interfragmentary wires.
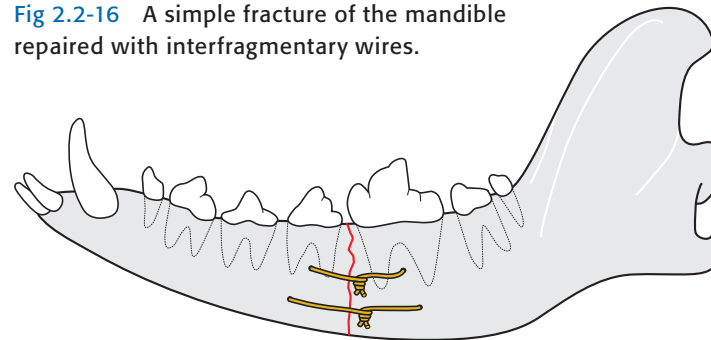
Fig 2.2-17a–c   To place a tension band wire:

a   The fragment is reduced and the pins driven perpendicular to the fracture plane and parallel to each other.

b   A hole is drilled transversely across the main fragment approximately the same distance below the fracture line as the pins are above the fracture line. The wire is passed through the hole in the bone, brought across to the original side of the bone, around the ends of the pins, and back to the other end of the wire on the starting side of the bone to create a figure-of-eight pattern.

c   The wire is tightened with one or two twist ties. The K-wires are cut and bent.
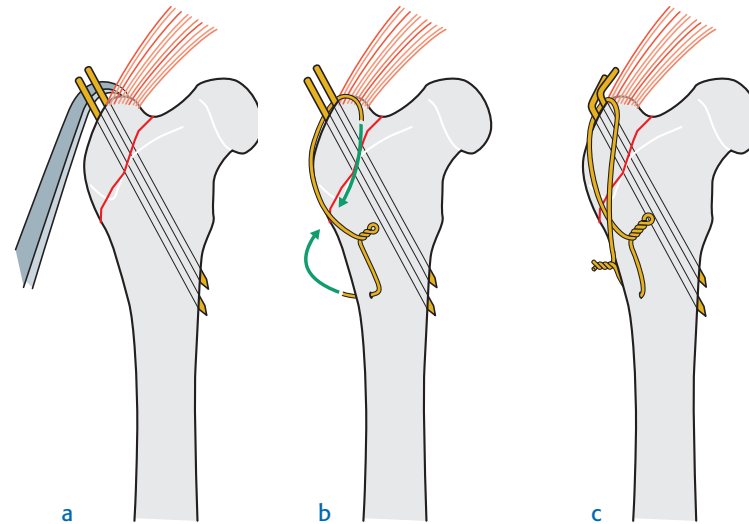
Use two small pins or K-wires placed parallel to each other to counter rotational forces.

The transverse hole for the wire is usually located approximately the same distance below the fracture line as the pins are above the fracture line.

When tightening the wire with a single knot, be sure to tighten the top strand, or second arm, of the figure-of-eight wire.

There are a number of factors that influence the choice of the initial stabilizing device. Two or more small pins or K-wires have the advantage over a single pin or screw of countering rotational forces. To do this effectively, they must be placed parallel to each other. Rotational forces are significant in many avulsion fractures because, although there is a primary direction of pull, as joints move through their normal range of motion, the line of action of the tendon or ligament changes, and this will tend to rotate the fragment. The advantage of the lag screw is that it compresses the fragment to its bed. If there is interdigitation, this will also help counter the rotational forces. A disadvantage of the lag screw is that, if the fragment is small, the size of the gliding hole, the pressure of the head, and the tension from the attached structure may predispose it to fracture.

When pins or K-wires are used, the size selected depends on the size of the fragment and the quantity to be placed. **The fragment is reduced and the pins driven perpendicular to the fracture plane and parallel to each other.** If possible, they should penetrate the cortex opposite the fragment. To anchor the tension band wire, a hole is drilled transversely across the main fragment on the surface away from the ligament or tendon. This hole is usually located approximately the same distance below the fracture line as the pins are above the fracture line, but this may be adjusted depending on the exposure and anatomy of the area. (**Fig 2.2-17**) The hole is generally kept as superficial as possible to reduce the amount of exposure required, but it is important that sufficient bone be purchased to prevent the wire from cutting out. In situations where the pins or lag screw run down

the shaft of the main fragment, they may interfere with placement of the wire, so the hole should be drilled and the wire placed before the pins are driven.

The size of the wire depends on the surgeon's judgment of the tensile forces to be countered. The length required depends on the arrangement of the pins and the hole. **The wire is passed through the hole in the bone, brought across to the original side of the bone, around the ends of the pins or the head of the lag screw, and back to the other end of the wire on the starting side of the bone. This creates a figure-of-eight pattern.** This is necessary to direct the upper portion of the wire opposite to the pull of the ligament or tendon. The tension in the wire will be maintained more effectively if the wire is in direct contact with bone over its whole course. In some situations, it may be necessary to pass the wire under the ligament or tendon so that it is in contact with the bone and the pins (**Fig | Video 2.2-18**).

Twist knots are commonly used for tension band wires, though loop style knots can be used. To effectively tighten a tension band wire with one knot, the slack in the arm opposite the one with the knot must also drawn in by the tightening process. Because the wire makes a number of tight bends, both through the hole in the bone and around the pins, this may not happen with larger diameter wire. To address this deficiency of the single knot technique, a twist knot can be tied in both arms of the figure-of-eight. When placing the wire, a loop is formed in the wire so that it is positioned between the hole and the pins in the first arm of the figure-of-eight.

The tension band wire is tightened by twisting the two knots. Once the slack has been removed, the ends of the pins or K-wires are bent over so that they lie flat to the bone and are directed away from the pull of the wire. This is usually best achieved by bending them away from the bone, cutting them with 2–3 mm of bent arm, and then rotating them to direct the arm away from the wire. The end will usually embed in the soft tissues around the fragment. Once the final position of the pins or K-wires is set, tightening of the figure-of-eight is completed. The amount of static tension that can be generated is determined by the size of wire chosen, but is limited by the bending strength of the pins or K-wires. As the purpose of a tension band wire is primarily to counter the dynamic forces in the ligament or tendon, it may not be important to generate large static forces. Additionally, because a tension band wire is often fairly superficial, the twist and flatten technique may be best for finishing the knots.

To tie a twist knot in both arms of the figure-of-eight, form a loop in the wire so that it is positioned between the hole and the pins in the first arm of the figure-of-eight, then form a twist with the free ends of the wire in the second arm. Tighten the tension band wire by twisting the two knots.

Bend the ends of the pins or K-wires away from the bone, cut them with 2–3 mm of bent arm, and then rotate them to direct the arm away from the wire and embed its end in the soft tissues.

Video

Fig | Video 2.2-18   Tension band wiring of an olecranon fracture.

5 Bibliography

1. **Clary EM, Roe SC** (1996) In vitro biomechanical and histological assessment of pilot hole diameter for positive-profile external skeletal fixation pins in canine tibiae. *Vet Surg*; 25(6):453–462.
2. **Willer RL, Egger EL, Histand MB** (1991) Comparison of stainless steel versus acrylic for the connecting bar of external skeletal fixators. *J Am Anim Hosp Assoc*; 27:541–548.
3. **Roe SC, Keo T** (1997) Epoxy putty for free-form external skeletal fixators. *Vet Surg*; 26(6):472–477.
4. **Bouvy BM, Markel MD, Chelikani S, et al** (1993) Ex vivo biomechanics of Kirschner-Ehmer external skeletal fixation applied to canine tibia. *Vet Surg*; 22(3):194–207.
5. **Dueland RT, Johnson KA, Roe SC, et al** (1999) Interlocking nail treatment of diaphyseal long-bone fractures in dogs. *J Am Vet Med Assoc*; 214(1):59–66.
6. **Hulse D, Ferry K, Fawcett A, et al** (2000) Effect of intramedullary pin size on reducing bone plate strain. *Vet Comp Orthop Traumatol;* 13:185–190.
7. **Oh I, Sander RW, Treharne RW** (1985) The fatigue resistance of orthopaedic wire. *Clin Orthop*; (192):228–236.
8. **Roe SC** (1997) Mechanical characteristics and comparisons of cerclage wires: introduction of the double-wrap and loop/twist tying methods. *Vet Surg*; 26(4):310–316.
9. **Roe SC** (2002) Evaluation of tension obtained by use of three knots for tying cerclage wires by surgeons of various abilities and experience. *J Am Vet Med Assoc*; 220(3):334–336.