How to Use Bone Plates in Practice Mini Series

Session Two: How to Use Non-Locking and Locking Plates

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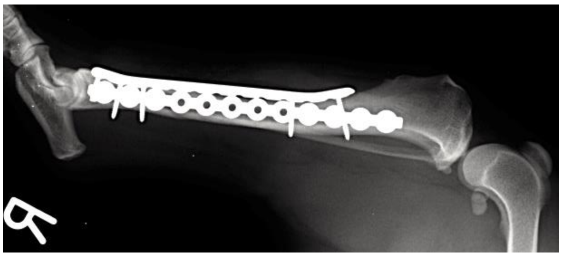


How to Use Bone Plates in Practice
Session 2- How to apply locking and non locking plates

Internal fixation

Advantages

- Rigid fixation whilst allowing normal limb use
- Limb health optimised
  - Muscles function normally
  - Joint motion maintains cartilage nutrition
- Owners often prefer
  - No bandage or ESF to maintain

Disadvantages

- Invasive, tissue damage may delay healing
- Implants remain inside- potentiate infection
- Implants can be expensive

The selection of internal fixation type depends on the fracture type and location and to a lesser extent the surgeon’s preference. The implants can be split into primary implants (bone plates, interlocking nail and intramedullary pins) and secondary implants (kirschner wires, orthopaedic wire and interfragmentary screws).

Interlocking nail

The interlocking nail is an intramedullary pin but with locking screws and bolts that fix the pin to the bone. Therefore they resist bending very well but now also torsion and compression unlike IM pins. They are really only applicable to the humerus, femur and tibia and the newer systems that eliminate slack at the nail/screw interface are expensive. Interlocking nails are the standard of care in some human fractures but their few indications and expense limit their usefulness in general veterinary orthopaedics.

Intramedullary pins

Pins resist bending forces and their stiffness is related to both their diameter and the length over which the pin is subjected to bending (shorter length = stiffer). The stiffness of a pin is determined by its area moment of inertia and the material it is made from. The formula for the AMI of a cylinder uses the radius to the fourth power so for a given material (all stainless steel) pins with a larger diameter are relatively much stiffer. Pins do not resist compression, tension and torsion.
Pins should not be used alone for shaft fractures and IM pin and cerclage wire combinations often result in delayed or non-union. If this technique is chosen the pin should fill 70-80% of the medullary cavity and so Steinmann pins are generally used. Significant protrusion of the pins should be avoided so normograde insertion is best and countersinking is should be utilised.
They are useful as adjunct fixation (plate-rod, tied in ESF construct and in comminuted fracture reconstruction to skewer small fragments).

Bone Plates and screws

The standard internal fixation implants are bone plates and screws, which are generally made from 316L stainless steel but there are also titanium alloys. Originally these are loose screw plates so the screw head lags the plate to the bone. Recently many different locking plate systems have become available and with these the screw locks into the plate.

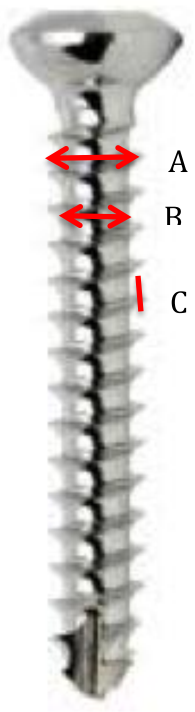
The stability of a plated fracture depends on many different factors

- Bone properties
- Plate material and geometry
- Plate-bone interface
- Screw-bone interface
- No of screws, screw material and torque
- Compression between fragments
- Placement of bone relative to loading

Screws

Screws are normally used to fix bone plates but they can be used as interfragmentary screws and are differentiated by their

- Size
- Shape
- Function
- Technique they are inserted

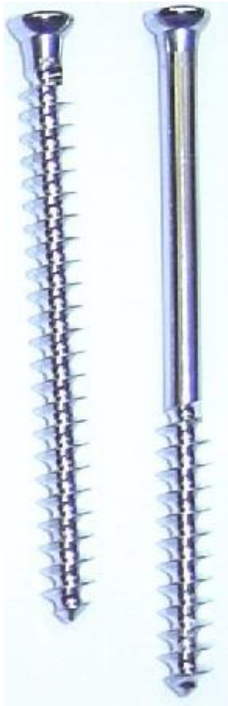


Terminology used to describe screw morphology is the type of head, thread diameter, core diameter, thread height, pitch and screw working length. The thread diameter (A) is the screws widest diameter and defines the screw size (e.g. 3.5mm, 2.7mm). The core diameter (B) is the diameter of the shaft of the screw. The thread height is the difference between the thread diameter and core diameter. Pitch (C) is the distance between adjacent threads. The screw working length is the length of bone traversed by the screw. Each screw size has a corresponding drill bit and tap (see table below). The design of the recess in the screw head varies to accept different screwdrivers (slot, cruciate, hexagonal or star).

When inserting a screw in bone the thread diameter should be up to 25% of the diameter of the bone. It can be up to 33% in exceptional cases but over this can risk weakening the bone possibly leading to fracture and diminishing the screw holding power.

Cortical screws			Cancellous screws		
Thread (mm)	Core (mm)	Drill bit (mm)	Thread (mm)	Core (mm)	Drill bit (mm)
1.0	0.7	0.7	4.0	1.9	2.5
1.5	1.1	1.1	6.5	3.0	3.2
2.0	1.4	1.5			
2.4	1.7	1.8			
2.7	1.9	2.0			
3.5	2.4	2.5			
4.5	3.2	3.2			
5.5	3.9	4.0			

Locking screw	Drill bit (pilot hole)
2.0mm	1.5mm
2.4mm	1.8mm
2.7mm	2.0mm
3.5mm	2.8mm
4.0mm	3.2mm
5.0mm	4.3mm



The two basic types of screw are the cortical screw, which has a smaller pitch (less distance between threads) and less depth to the thread and the cancellous screw, which has a larger pitch and a larger depth to the thread therefore a smaller core diameter. Cancellous screws can be fully or partially threaded. Locking screws have recently become available for different locking plate systems. These generally have a larger core diameter than standard bone screws.

Screws can be self-tapping or non self tapping, the difference being that non self tapped screws require the drill hole to have the threads cut by a tap prior to screw placement. Non-self tapping screws can be removed and re-inserted easily. Self tapping screws have a cutting flute at the tip that cuts a thread in the bone as the screw is advanced. Care needs to be taken in soft bone and when removing a re-inserting self tapping screws as it is possible to cut a new thread in the bone.

Two biomechanical features of screws must be appreciated.

The ***pull out strength*** of a screw is related to the outer diameter of the screw, the thread depth and the material it is placed into.

The ***bending strength*** of a screw is related to its core diameter with a larger core diameter better able to resist bending (remember AMI of cylinder = πr^4 so a small increase in radius results in a large increase in AMI).

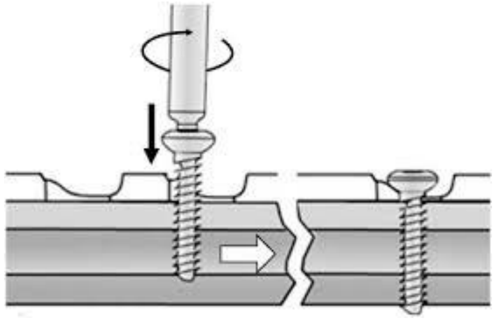
Screws can be placed in one of two ways, either in a lag fashion or as a position screw. Any screw can be placed in a lag fashion where the screw threads engage only the far (trans) cortex and this compresses the fracture fragments together. The near (cis) cortex is over drilled, the so-called glide hole. To achieve good compression the screw should be perpendicular to fracture line. Lag screws are preferred for fracture reconstruction because apposition of fracture fragments without compression leads to small gaps and high interfragmentary strain (remember bone does not tolerate a high strain environment).
The cis (near) cortex is drilled with a drill bit the same size as the screw you will place (i.e. 3.5mm drill bit for 3.5mm screw)- this is the glide hole. An appropriately sized insert sleeve is placed into the hole. The trans (far) cortex is drilled with a drill bit corresponding to the core diameter of the screw (2.5mm drill bit for 3.5mm screw). This is the thread hole. Ideally the dill hole should be perpendicular to the fracture line. The screw head should be countersunk to spread the stress created when compressing the fragments over a greater area. The drill hole is measured with a depth gauge and the trans cortex tapped if required. The screw is placed and as the threads only engage the far cortex as the screw is tightened the fragments are compressed together.

A position screw is placed so that the threads engage both the near (cis) and far (trans) cortex. The same drill is used to drill the cis and trans cortex. This results in less stable fixation and is used in complex articular fractures.

Bone Plates

Bone plates are differentiated by the

- System of coupling between plate and screws
  - Non- locking
  - Locking
  - Many different types of each
- Function
  - Compression
  - Neutralisation
  - Bridging
  - Buttress



With compression plate fixation the design of the screw hole infers axial compression across the fracture as the screw is inserted. The screw hole has a specific oval hole geometry that means when a drill hole is drilled eccentrically away from the fracture, as the screw is tightened onto the plate it moves downwards and horizontally.

In neutralization mode the fracture is reconstructed with screws, pins or wires and the plate is applied to help protect the reconstruction by resisting bending forces.
In bridging mode a plate is applied across a non-reconstructed fracture and as such is required to resist all the forces- load bearing (plate bears all of the forces until bone healing is well under way). The plate is subject to high bending forces so additional fixation is often used i.e. an intramedullary pin, orthogonal plate.
In buttress mode a plate is used to hold collapsed juxta-articular fragments in position after they have been reduced which is a rare application.

There are a range of shapes and sizes of non locking bone plates and they re named by the size of screw they will accept. The screw lags the plate to the bone and these plates need to be accurately contoured to the bone.

- Dynamic Compression Plate (DCP)
- Limited contact DCP
- Cuttable plates
- Reconstruction plates
- Acetabular plates
- L and T plates
- Lengthening plates
- Osteotomy plates
- Arthrodesis plate

The stability of non locking plates and in particular the DCP and LC-DCP rely on all the factors mentioned before and listed again below

- Bone properties
- Plate material and geometry
- Plate-bone interface
- Screw-bone interface
- No of screws, screw material and torque
- Compression between fragments

- Placement of bone relative to loading

Ideally plates should be applied to the tension side of the bone. Bone is weaker under tension than compression whereas metal plates have good tensile strength. For example the tension side of the femur is the lateral surface and the radius the cranial surface.
In reality plates can be applied to different aspects of the bone dependent on fracture location.

- Humerus
    - Medial, lateral, cranial
- Radius
    - Cranial, medial
    - Plate ulna
- Femur
    - Lateral
- Tibia
    - Medial, cranial

The dynamic compression plate (DCP) is the most widely used plate and is designed to compress fracture fragments together. It has an oval hole design and must be contoured to the bone. Only transverse or short oblique fractures can be compressed together and this results in load sharing (bone and plate share the axial forces). Despite the name static compression is achieved. Screws can be placed in ***neutral*** or ***load*** position depending on how the drill guide is used. With the drill guide in load position the screw is placed eccentrically and the screw head interacts with screw hole geometry, which permits simultaneous downward and horizontal movement of the screw as it is tightened to the plate.

The principles of DCP use are accurate bone hugging contouring, which is often difficult and damages the periosteal vasculature (hence LC-DCP design), all the screw holes should be filled, as empty screw holes are a weak point but this is often impossible in comminuted fractures, ideally six cortices should be engaged by screw threads either side of the fracture (three bicortical screws), there should be a minimum of 4-5mm from the fracture line to the first screw on either side and the plate should be applied to the tension side of the bone as it will resist bending forces better. With a DCP the screws can be angled 25° longitudinally and 7° transversely. When pre contouring a DCP to apply compression to a fracture the plate should be pre-stressed. This means slightly over contouring the plate so there is a small gap between the plate and the bone over the fracture. This produces compression at the trans cortex and the plate is compressed against the bone.

The application of a DCP should follow the following steps

- Appropriate sized hole drilled in neutral position
- Hole measured and tapped (if necessary)
- Screw inserted and tightened
- Ensure plate is aligned on bone
    - Especially proximal and distal ends
- Drill screw hole on opposite side of fracture
- Drill Guide in Load Position
- Hole measured and tapped
- Screw inserted and tightened
- Compresses the fracture
    - A 3.5mm DCP achieves 1mm of compression

- Can insert a second screw in compression
- Do as previously
- However before you tighten the second screw
- The first screw on the same side must be loosened
- Tighten both screws
- Avoid over compressing
    - Fissure formation
- Further screws are inserted in Neutral
- Progressively move away from fracture
- Alternating screw insertion on either side
- Ensure all screws are checked for tightness
    - Bone relaxes within minutes so screws will loosen

Application of a neutralisation plate

- Reconstruct fragments
    - Forceps, K wires, screws, assistant
- Interfragmentary compression
    - Lag screws- care not to interfere with plate
    - Can be placed through plate if appropriate
- Plate contoured to bone
- Drill guide used in neutral position
- Plate screws applied
- Order of screw insertion not as important
    - Ensure plate is aligned to bone

Application of a bridging plate

- No attempt to reconstruct fracture
- Bone length and alignment must be restored
- Plate applied to major fragments
    - Pre-contouring to opposite limb can be helpful
- Maintain bone length and alignment
- Drill guide used in neutral position
- Absolute minimum 3 screws (6 cortices) in each fragment
- Plates resists all forces
    - Load bearing
- Robust fixation is required
    - Long, stiff and strong plate
    - IM Pin
    - Orthogonal plating

The Limited Contact DCP has a number of advantages compared to a standard DCP. It has grooves on the undersurface, which confers a more even stiffness profile than a DCP (where the stress is concentrated at each screw hole) and results in a smaller footprint so there is less periosteal vascular compromise. However the scalloped undersurface also results in the plate being slightly less stiff and less strong than an equivalent DCP. The plate holes allow increased screw angulation and screws can be angled 40° longitudinally.
The plate has uniform screw hole placing and the screw hole has been re-designed so that compression can be produced in both directions.

In contrast the DCP has a slightly extended middle section and the holes on either side of this only allow compression to be applied towards the centre of the plate.

Locking Plates

Locking plates were originally designed for osteoporotic bone, with biological osteosynthesis in mind and to overcome the failings of the DCP. They act as an internal external fixator as the screws lock into the plate. The weak point is now the plate-screw interface. Locking plates do not rely on bone –plate contact for construct stiffness so accurate contouring is not required. This minimises fragment displacement and limits damage to periosteum and in addition locking plates are conducive to minimally invasive surgery, which limits the damage to the extraosseous blood supply. However not all locking systems are the same and each has its own biomechanics, which need to be understood. Fundamentally the principles and rules of the 'DCP' cannot just be extrapolated to locking plates. Locking plates have very different biomechanics.

Locking plate advantages

- Elimination of screw toggling
    - Entire plate and screw construct acts as single unit
- Improved periosteal vascularity
    - No need to compress plate onto bone
- Simpler plate contouring
    - Internal fixator- no accurate 'bone-hugging' contouring
- Monocortical screw fixation

Locking plate Disadvantages

- Fixed screw angles
    - Some locking systems have polyaxial screws
- Increased cost
    - Locking screws very expensive
- Pre-contoured plates cannot be used to reduce fracture

Locking screw biomechanics

Conventional, non-locking, plates rely on friction between plate and bone for stability. The frictional force generated must exceed the disruptive forces (shear force at screws). The coefficient of friction between bone and metal is low (0.37+/- 0.05) so much of the effort of the screw is wasted on the lagging the plate to the bone. To decrease the disruptive forces with a DCP for example, you can anatomically reconstruct the fracture, increase the bending stiffness of the plate (i.e. use a bigger plate but the size of the bone limits this), place the plate on the tension side of the bone (this may be difficult depending on the fracture configuration) and use in cortical bone (again may not be possible depending on the fracture configuration).

In bridging plate fixation axial load (the largest force) is transferred from bone – plate – bone by means of screws. With non-locking plates e.g. DCP, the screw is loose in the screw hole i.e. it can pivot/toggle. The friction of the plate-bone interface alone is responsible for stability. The screw produces the plate-bone compression by the torque of tightening down on the plate and screw holding power in bone. Bone is viscoelastic so after screw insertion the bone relaxes within minutes and so friction and therefore stability decreases over time.
Additionally screw bending is counteracted by the trans (far) cortex and the holding power of the bone –screw thread interface.

As the screw is not locked in the plate it can toggle within the screw hole, which is prevented by the trans cortex and the active thread holding power. Without the trans cortex screw holding power alone prevents failure. This is why with non-locking plates monocortical screws often fail. If the screws loosen then the plate-bone friction is reduced and the construct stability decreases. If the axial load exceeds frictional force of the plate-bone interface then the plate loosens and the screws are subject to axial pull out force. The screw- bone interface is the weak link and the screws sequentially loosen.

Locking screws are locked at the head/plate and so cannot toggle. They are subject to basic cantilever bending mechanics. The axial forces are transmitted to the transverse member (screw) and the opposing forces are linearly related to cantilever distance, i.e. greatest force closed to locked head. Therefore monocortical screws are effective as the greatest force is opposed at the cis cortex. However bicortical screws are better in torsion, in thin cortices and infer a greater stiffness to the construct. If possible bicortical screws should be placed. As the weak link of locking plate constructs is now the screw-plate interface the number of screws used in the construct is important.

Locking Plate construct failure

- Screw breakage
- Concurrent axial pull out of all screws
- Compressive failure of bone around screws
- Stiffness of construct
    - Material properties of implants
    - Number of screws

The stability of locking plate constructs relies on

- Plate material and geometry
- No of screws, screw material and torque
- Placement of bone relative to loading

And to a much lesser degree

- Bone properties
- Plate-bone interface
- Screw-bone interface
- Compression between fragments

Many different locking systems are available and each has their own specific biomechanics and guidelines, which are outwith the scope of this webinar.
Locking Compression Plate (LCP), String of Pearls (SOP) Plate, ALPs Plate, Fixin Plates, PAX System, others.
The following guidelines are used in human orthopaedics to decrease plate strain and plate failure and they have been used in veterinary orthopaedics however the guidelines result in relatively flexible constructs. This is acceptable in humans where minimal load bearing can be advised but the role of the guidelines is unclear in our patients and have not been validated.

- Span long segment of bone (plate span ratio)
    - Greater than 3 x length of fractured segment
- Screw-to-hole ratio less than 0.5
    - Less than half the screw holes filled with screws
- Leave at least 2-3 holes empty over fracture

Locking plates present a number of different challenges for application compared to DCPs. Most systems have fixed angle screws so it is not possible to re-direct them so it is essential to ensure that the plate is well aligned to the bone. The order of screw insertion unimportant but tightening of a locked screw does not pull bone to plate. The exception to this is in systems such as the LCP or ALPs where both locking and non-locking screws can be used. If screws are to be mixed then normally the non-locking screw is placed first. It is important with locking screws to ensure the screw engages the bone, as it is possible to push the bone away from plate.

Additional Fixation

Orthogonal plating

Orthogonal plating involves applying plates at 90° to each other. This significantly increases the stiffness and strength of the repair and is particularly useful when there is limited bone stock close to a joint.

Pins

Kirschner wires
    Trochar point at one end
Arthrodesis wires
    Trochar point at both ends
Intramedullary pins, Steinmann pins
    Larger diameter

Pins are useful as adjunct fixation in a Plate-rod or Tied in ESF construct. They can also be used in comminuted fracture reconstruction to skewer small fragments. A Plate-Rod construct involves using a bone plate with an intramedullary pin. The IM pin is placed first and this aids in fracture reduction, limb length and alignment and also resists bending which helps protect the plate from fatigue failure. With a DCP an IM pin of 35-40% of the medullary cavity is required. It can be difficult to place bicortical screws and guidelines were produced that a minimum of 5 cortices above and below the fracture were engaged with at least one bicortical screw above and below. Locking plates will have different guidelines

Orthopaedic wire

Orthopaedic wire is made from 316L stainless steel. It is malleable which allows us to use it but has little bending strength. Its tensile strength is better and just as with pins a small increase in diameter significantly increases tensile strength. The guide is to use the biggest size that seems appropriate to size of bone. The weak point is usually the knot, which can be a twist knot, a single loop knot or a double loop knot. Twist knots and single loop knots mechanically behave similarly but the double loop knot has a higher resting tension and can resist greater loads before loosening.

Wire use is of four types

- Tension band
    - Oppose pull of muscle or ligament
    - Two pins and figure of eight wire
    - Principle is to convert tension into compression at the fracture site
- Cerclage
- Hemicerclage

- Interfragmentary