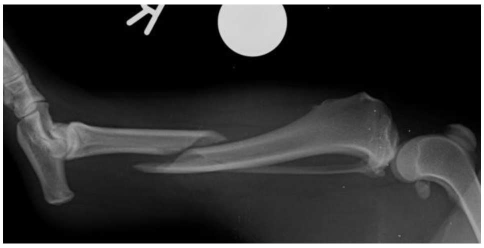
How to Use Bone Plates in Practice Mini Series

Session One: Bone Plating Principles

Scott RutherfordBVMS Cert SAS DipECVS MRCVS
RCVS Specialist in Small Animal Surgery (Orthopaedics)
European Specialist in Small Animal Surgery



How to Use Bone Plates in Practice

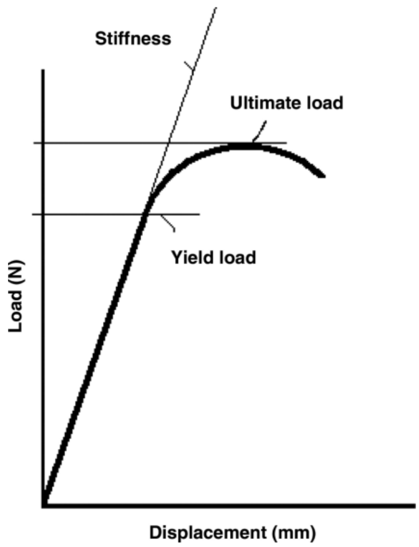
Session 1- Fracture and Bone Plating Principles

Fracture biology and biomechanics

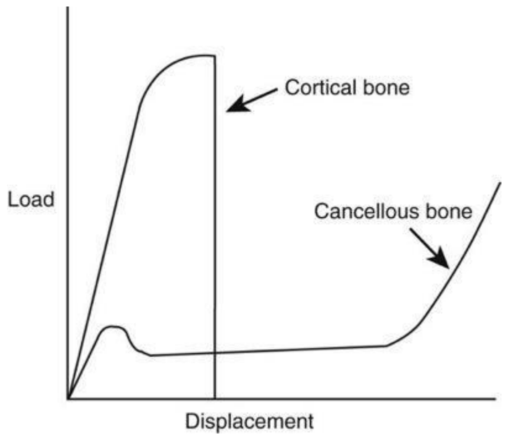
Bone is a complex tissue and to treat fractures successfully we must understand its biology and biomechanics. According to Wolff's law bone adapts to the loads under which it is placed and is constantly being turned over.
Bone is viscoelastic, which means among other things that its strength and stiffness depend on the rate at which it is loaded. The more rapidly it is loaded the stronger and stiffer it becomes.
Bone is also anisotropic so its strength and stiffness depend on the direction of loading. Bone is stronger and stiffer when loaded longitudinally than when loaded transversely.

Furthermore some basic biomechanical terms need to be understood during fracture discussions.

- Stress
  - Local force expressed in units of force per unit area (N/m^2)
- Strain
  - Local deformation. Change in length divided by original length normally expressed as a percentage
- Strength
  - Ultimate load a material can withstand before failure
- Stiffness
  - The rate at which a material deforms when a load is applied.



The load displacement curve, left, is derived from mechanical testing of materials and allows the stiffness and strength of a material to be calculated. The linear portion represents the elastic modulus or stiffness. In this potion of the curve the strain (displacement) is elastic meaning that the material can return to its original shape. This is known as ***elastic deformation***. The steeper the linear portion the stiffer the material is. The yield load is load at which the deformation becomes permanent. This is known as ***plastic deformation***. The uultimate load is the load at which the material ultimately fails. The area under curve equals the energy absorbed.



Cortical bone is brittle and plastic deformation does happen but this phase is short before ultimate failure, which is why we see fractures not bent bones. As bone is viscoelastic the more rapidly the bone is loaded the stronger and stiffer it becomes. It therefore stores more energy (area under the curve). Therefore rapidly loaded bone releases more energy at ultimate failure, which results in complex fractures and greater soft tissue damage. Slower loading results in less energy release and simpler fractures. In comparison to cortical bone, cancellous bone is porous (75-95% compared to 5-10% for cortical bone) which means it is weaker and less stiff.

Bone is subjected to many and combined forces during normal function and if the magnitude of these exceeds the ultimate strength of the bone a fracture occurs. The main force applied to long bones are axial - compression or tension. Bone is weaker in tension than compression. Bone is also subjected to varying degrees of torsion, shear and bending. Bending includes pure bending where equal force is applied at either end of the bone, cantilever bending where one end of the bone is fixed and the force is applied at the other end and three point bending where two equal forces are applied at each end and a third force in the middle. Four-point bending has two forces in between the end forces.

The fracture pattern is largely determined by first the orientation of the forces applied and second the relative strength of the bone in each loading orientation.
Torsion generally cause spiral fractures whereas compression causes oblique fractures. Transverse fractures can be the result of tension or bending. Bending and compression leads to a comminuted fracture with a butterfly fragment. The bone starts to fracture on the tension side (convex) but the fracture propagates through shear stress lines to the compressive side creating a butterfly fragment. Comminuted fractures are a complex combination of forces.

Physeal fractures have their own classification system, Salter Harris Classification (I-V).
Type I - Fracture across the physis
Type II - Fracture across the physis and into metaphysis
Type III- Fracture across the physis and into epiphysis
Type IV - Fracture through epiphysis, physis and metaphysis
Type V - Compressive injury to physis without obvious fracture, premature closure

Two other fracture types are important to recognise, pathological and fatigue fractures. Pathological fractures are fractures that occur in bones that are in a disease state. The bone is typically affected by neoplasia but osteopenia due to immobilization, osteomyelitis or iatrogenic bone damage (surgery or implant removal) can also result in fracture. Pathological fractures do not follow the typical behaviour regarding loading and pattern. Fatigue fracture is a fracture that occurs through repetitive loading of the bone where the bone is damaged at a rate faster than it can be repaired. This most commonly occurs with athletic training and competition so Greyhounds with central tarsal bone fracture being the most widely studied.

<u>Bone Healing</u>

It is important to remember that most fractures will heal without surgical intervention or even external coaptation. However the bone is unlikely to function adequately due to limb malalignment (malunion), limb shortening, soft tissue contraction or secondary osteoarthritis in the case of articular fractures. The goal of fracture repair is to attain function equivalent to pre-fracture function and an understanding of bone healing is essential to make decision on appropriate treatment.

Bones heal either by Primary bone healing (gap or contact primary bone healing) or Secondary bone healing (often considered the 'normal' course of bone healing). Central to bone healing is strain theory. Strain is local deformation and equals change is length divided by the original length. So for a given amount of instability a smaller fracture gap will have a higher strain than larger fracture gap.

1mm fracture gap with 0.5mm instability = 50% strain
10mm fracture gap with 0.5mm instability = 5% strain

Bone tolerates 2% strain, cartilage 15% and granulation tissue 100%

Secondary bone healing

Bone healing is divided into the classic tissue healing phases of inflammation, repair and remodeling. There is a progression of healing through a callus of progressively stiffer tissue types.
Haematoma first followed by granulation tissue and then progressively stiffer connective tissue forms the fracture callus. This callus extends radially away from the fracture and so bending is resisted. This decreases the local strain so fibrous tissue forms then fibrocartilage then cartilage then woven bone. The woven bone is replaced by lamellar bone and the medullary cavity is reestablished and finally lamellar bone. Unneeded bone is resorbed and the medullary as Haversian remodeling progresses. The unneeded bone is resorbed and the bone approximates to original shape according to Wolff's Law.

Primary Bone healing

Primary bone healing skips the initial secondary bone healing phases with lamellar bone formation and haversian remodelling progressing from the beginning. For this to occur there has to be less than 2% interfragmentary strain environment and less than 1mm interfragmentary gap.
With gap primary bone healing granulation tissue appears first however within days lamellar bone is deposited on the fragment ends without a cartilage intermediary until the fracture gap is filled with bone. Initially lamellar bone is transversely orientated but Haversian remodelling starts around the third week of healing and the new transverse lamellar bone is resorbed and replaced with longitudinally orientated bone.
Contact primary bone healing occurs when fracture surfaces are in direct contact and there is no interfragmentary motion. Haversian remodelling occurs directly forming longitudinal lamellar bone with no transverse lamellar bone formation. This is a slow process and difficult to judge when complete but is likely to take several months.
In the clinical setting primary bone healing is a combination of both gap and contact healing.

Biological osteosynthesis

Bone healing requires adequate blood supply and associated oxygen tension. The intrinsic blood supply of a fractured bone has a limited ability to maintain healing. It is the extraosseous vasculature that supplies the callus initially. Successful fracture surgery requires both the preservation of remaining intrinsic blood supply (limited intramedullary disruption and periosteal stripping) and the encouragement of the development of an extraosseous blood supply (minimally invasive surgical techniques).

Original AO/ASIF principles for fracture surgery were

- Anatomical reduction of fracture fragments
- Rigid internal fixation
- Preservation of blood supply
- Early active pain-free mobilization

The interpretation of these AO/ASIF guidelines has changed over the years with a shift away from precise reconstruction and absolute rigid fixation to creating an environment more conducive to healing. With biological osteosynthesis the primary consideration is protection of the soft tissues and blood supply.

Anatomical reconstruction is now deemed necessary only for articular fractures or where interfragmentary compression and load sharing of the bone can be achieved. The aim for reconstruction is to restore axial alignment, eliminate torsional deformity and maintain bone length.

Absolute rigid internal fixation to allow primary bone healing is difficult to achieve and if interfragmentary motion is not eliminated then small amounts of motion can leave high strain environment leading to delayed healing. The aim of biological osteosynthesis is to have a repair that is only stiff and strong enough to allow callus formation. In this situation a small amount of interfragmentary motion is desirable for callus formation.

Atraumatic technique is essential with the aim of preservation of the blood supply to the fracture fragments and the soft tissue envelope.

- ‘Open but do not touch’
- Minimally invasive osteosynthesis (MIO)

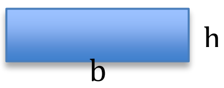
Implant Biomechanics

Implant biomechanics depend on the material properties (type of metal) and the structural properties (area moment of inertia, AMI and polar moment of inertia, PMI). Orthopaedic implants are typically made from stainless steel (316LVM), Titanium or titanium alloys. Stainless steel has increased stiffness and strength compared to titanium. Titanium alloys (eg Ti-6Al-4V) have superior fatigue and corrosion resistance compared to stainless steel. The titanium alloys have increased strength and stiffness compared to pure titanium. Pure titanium is reported to have improved biocompatibility. Titanium and its alloys are expensive compared to stainless steel.

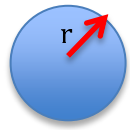
The **area moment of inertia (AMI)** is a measure of a structure’s resistance to bending. The **polar moment of inertia (PMI)** is a measure of a cylindrical object’s resistance to torsion. They both ignore the material properties so can only be used to compare structures of the same material. The measurements can be used with the material properties to predict stiffness.

Area Moment of Inertia

- AMI of a beam
  - b h^3/12
  - think plate in cross-section



- AMI of a rod
  - π r^4 /4
  - think IM Pin in cross-section
  -



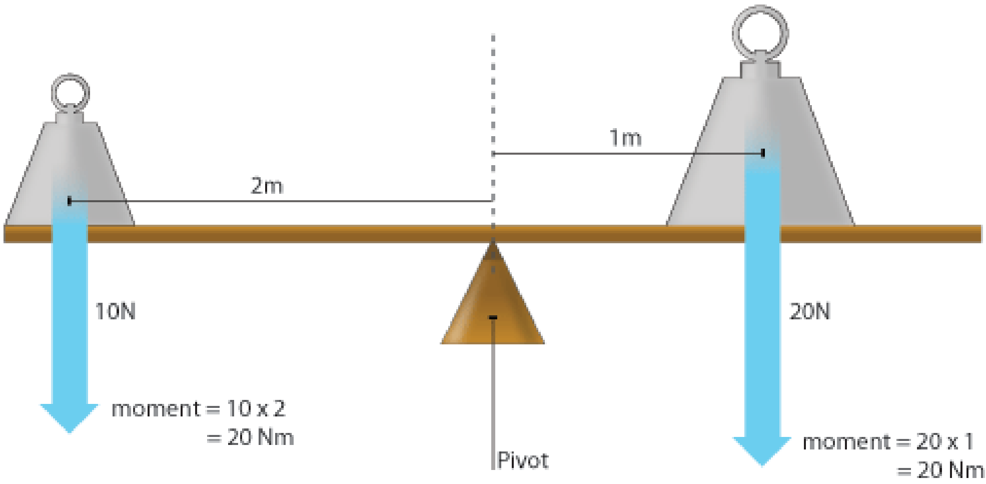
Small changes in h or r result in large changes in AMI

Area moment of inertia

- 3.5mm cortical screw
  - Outer diameter- 3.5mm
  - Core diameter – 2.4mm
  - AMI- 26.1mm^4
- 4.0mm cancellous screw
  - Outer diameter- 4.0mm
  - Core diameter- 1.9mm
  - AMI- 10.2mm^4

A force acting on an object will have internal effects, eg it results in stress and possible deformation of a bone. There will also be external effects, eg causing the bone or limb to move. A **moment** is the action of a force that moves an object about its axis.

Moment = force x distance between force and axis of rotation



On a seesaw a 20kg weight 1m from the centre (fulcrum, pivot) will balance a 10kg weight 2m away from the fulcrum. The moments are equal and opposite. This explains why the benefit of lever arms where less force is required the further away from an object the force is applied.

Implant comparison

Implant	Disruptive Force			
	Bending	Rotation	Axial (Shear)	Tension
IM Pin	++	-	-	-
IM Pin and cerclage wire	++	+	+	-
Interlocking nail	++	+	+	-
Bone plate and screws	+	++	++	++
ESF	++	++	++	-
Pin and tension band wire	-	-	-	++

Basic Principles of Fracture Surgery

Fracture surgery follows the same basic principles that Dr William Halstead devised over 100 years ago.

- Halsted's Principles
    - Atraumatic tissue handling
    - Adequate haemostasis
    - Strict aseptic technique
    - Preservation of blood supply
    - Elimination of dead space
    - Accurate apposition of tissues
    - Minimal tension on tissues

The primary aims of fracture surgery are to alleviate pain, achieve fracture healing and restore normal function. Most fractures will heal without surgery but the functional use of the limb may be significantly impaired. The AO principles of fracture fixation, below, should be followed remembering the biological osteosynthesis interpretation of preserving the soft tissue envelope and protection of the vascular supply

- Accurate anatomical reduction
- Rigid stabilisation appropriate to the requirements of the fracture
- Preservation of the blood supply to soft tissues and bone
- Early and safe mobilization of the limb and patient

If a fracture can be reconstructed and load sharing achieved then this counteracts the need for wider dissection and iatrogenic damage to the vasculature however if load sharing cannot be achieved then disruption to the fracture haematoma, soft tissue envelope extra-osseous blood supply should be minimised.

Asepsis

The act of implanting foreign material increases the risk of infection so strict attention must be paid to aseptic techniques.

- Predisposing factors to infections
    - Avasular tissues
    - Presence of foreign material
    - Increased surgical times
    - Increased anaesthetic times
    - Loose implants
    - Poor theatre practice
    - Contamination from hair/skin

The operating theatre should not have general thoroughfare to minimise airborne bacterial contamination. Dedicated surgical clothing ie scrubs and hats, should be worn by all staff in theatre. The scrubs should not be worn outside and they should be changed if dirty. The operating staff should wear sterile attire eg gowns and gloves.
The initial preparation of the patient, ie clipping and first prep should be performed outside of the theatre. The bladder should be emptied and a purse string suture placed in the anus if surgery will be performed close to it.
Good organisation of the theatre is essential to minimise contamination and reducing the risk of breaking asepsis.

All Instruments should be sterilized which is normally achieved by an autoclave however not all instruments can be autoclaved. Ideally ethylene oxide gas sterilisation should be used. Some devices such as drills can be covered with an instrument drape however this is not advisable as it can lead to contamination of the surgical site. Instruments should be double wrapped and have any sharp points covered. Soaking instruments in sterilising solutions is not advisable as it is not always effective.

Antibiotics

Antibiotics should not be used to justify poor aseptic technique, poor tissue handling or inadequate haemostasis. The use of peri-operative antibiotics in clean surgeries is controversial however fracture surgeries justify their use because they tend to be prolonged surgeries with traumatised tissues and involve the placement of implants. Peri-operative antibiotics must be present at surgical site before first incision.

Antibiotic selection consider
- Spectrum of activity
- Pharmacokinetics
- Availability
- Route- IV preferred
- Toxicity
- Cascade

Usually cephalosporins or amoxicillin/clavulanate are used. They should be given IV 30-60 minutes before first incision and repeated every 90-120 minutes.
- Cefuroxime (Zinacef) 10-15mg/kg
- Potentiated Amoxicillin (Augmentin) 20mg/kg

There is a risk of hypersensitivity reaction (swollen eyelids, muzzles, lips) with Augmentin.

The use of post-operative antibiotics is also controversial. The current recommendation is that they should not be required however there is some recent evidence that 7-14 day courses decrease infection rates.

Analgesia

Fractures are inherently painful although stabilisation significantly reduces the pain. Analgesia is required before, during and after surgery and a balanced multi-modal approach is best. Opioids, full mu agonists such as methadone and NSAIDs are the mainstay of analgesics. Others such as ketamine, medetomidine, morphine-lidocaine-ketamine CRIs and local anaesthetics such as epidurals and nerve blocks all have their place on a case to case basis. Potent analgesia must be continued for approximately 24hrs although this is case dependent and should be based on pain scoring. NSAIDS are generally continued for at least two weeks following surgery.

Limb Preparation for surgery

Before inducing anaesthesia and then again before surgery a WHO surgical safety checklist should be completed. This ensures you have the correct patient and prepare the correct limb. Good verbal communication between colleagues prevents avoidable mistakes and ensures compliance with the plan.

The surgical site should be clipped liberally; small clips may be desired by the owner but are the source of significant contamination. Shaving and the use of razors can cause micro-lacerations, which may promote infection and cause irritation. Loose hair should be vacuumed and a lint roller should be used to remove stubborn hair and dead skin cells. The skin and coat are the two greatest sources of wound contamination. It is not possible to remove all skin bacteria i.e. sterilise the skin but the aim is to significantly reduce the number. The most commonly used scrub solutions are chlorhexidine, iodophors and alcohols. They have antiseptic and detergent properties. Don’t be overzealous with scrubbing as this can cause skin irritation, damaging the skin and allowing bacteria in the deeper layers to come to the surface. It is necessary to avoid excessive water; use enough to produce a lather but not strike through and hypothermia.

The initial skin preparation should take place before the patient is transported into theatre. Hands should be washed prior to skin preparation and gloves (non sterile) should be worn. Scrub the clipped area with a general scrub antiseptic solution to reduce the bacterial population and remove debris, dirt and oils. The bladder should be emptied before the patient is transported into theatre. The final preparation should be done in theatre. The incision site should be confirmed with the surgeon and using gentle pressure in a circular motion the limb should be prepared starting at the proposed incision site. The swab should be replaced with a clean swab once the periphery of clipped area is reached. This should be repeated until dirt is absent from the discarded swabs. It is important to monitor contact time and the scrub should continue for a minimum of five minutes. Finally spray the clipped region with antiseptic solution (70% ethyl alcohol).

The patient should be draped ideally with quarter draping followed by sterile draping of the foot and a final large second drape layer. The instruments must be passed aseptically from the nurse to surgeon. This must be done carefully as it is a potential source of contamination. The instruments should be placed on a fully draped table; partially draped tables are not acceptable. There should be no gap between the operating table and instrument table. Theatre personnel who are not aseptically prepared should not pass between sterile instruments or tables. The operating theatre should regularly undergo deep cleaning.

Following surgery a sterile wound cover (eg primapore) should be applied for at least 24 hours until a serum seal has formed. The wound should be kept dry, ideally do <u>not</u> use water to clean blood from around the wound as this may transport bacteria into the wound.

Techniques of fracture surgery

ORIF

Open reduction internal fixation

OBDNT

Open but do not touch

MIPO

Minimally invasive plate osteosynthesis

Open reduction internal fixation can be used for simple fractures eg transverse and oblique patterns and for fractures that can be reconstructed eg one large intermediate fragment where load sharing between bone and implants can be achieved. Articular fractures require accurate anatomical reconstruction to minimise the progression of degenerative changes.

With comminuted fractures accurate reconstruction is normally impossible and so load sharing cannot be achieved. Therefore the aim is to preserve blood supply to the fracture fragments and provide an adequate mechanical repair.
'Open but do not touch' involves an open approach but avoids manipulation of the fracture haematoma and fragments.
With 'Minimally invasive osteosynthesis' the fracture is reduced indirectly and the implants are applied through small incisions away from fracture site. This is technically demanding surgery. In humans it has been shown to reduce healing time and minimise complications. The benefits in small animals have yet to be completely elucidated.

Fracture reduction techniques

The reduction of fractures can be challenging especially in bigger patients due to the tension and contraction of the soft tissues. This is compounded by the fact of needing to preserve neurovascular structures and the soft tissue envelope. Instruments such as gelpis, periosteal elevators, hohmann retractors, pointed reduction forceps and bone-holding forceps are required to aid the surgeon in reduction techniques.

Reduction techniques include countertraction, toggling, levering, pointed reduction forceps, pusher pins and orthopaedic distractors.

Countertraction involves applying traction (pulling) distal to the fracture while applying countertraction proximal to the fracture. Slow application of the force is more effective and holding the fracture in traction for a few minutes fatigues the muscles and can overcome soft tissue contracture. A hanging limb prep can apply significant countertraction. Countertraction can be applied open or closed and bone holding forceps significantly help in an open approach. It often requires an assistant or the patient to be appropriately secured to the table.

It can be difficult to reduce fractures with traction alone. Toggling involves traction to allow one side of the fracture fragments to be brought into contact. A V shape is formed and the fracture is forcefully reduced as the fragment ends are kept in contact. Care must be taken not to propagate any fissures present.

Levering involves using an instrument such as a hohmann retractor or periosteal elevator to lever the bone fragments apart. The instrument is slipped between the fracture segments to pull the fragments apart before allowing reduction.

Pointed reduction forceps can be used to achieve the last small amount of distraction of oblique fractures to achieve good reduction. The forceps are applied finger tight across partially reduced oblique fracture and then rotated to force the fragments into good reduction.

A large steinmann pin, 'pusher pin', can be used to distract the fracture. The pin is placed in the medullary cavity and driven across the fracture into the metaphysis of the distal fragment. Continued pressure distracts the limb and aids in alignment of other fragments. It can be left in situ as part of a plate-rod construct.

The use of an orthopaedic distractor can be used in difficult to reduce fractures. Transfixation pins are placed through both cortices above and below the fracture and then attached to the distractor using wing nuts. The wings nuts sit on a threaded rod, which means as the wing nuts are wound round and round the fracture is distracted. Modified external skeletal fixators can be used in a similar way.

Fracture reduction can be maintained by an assistant, pointed reduction forceps, bone plate holding forceps, an intramedullary pin, lag screws, temporary K wires or a temporary ESF until the plate and screws are applied.