Introduction to Orthopaedics Mini Series

Session Two: Introduction to Fracture Surgery - What Should I Do in First Opinion Practice?

Scott Rutherford BVMS CertSAS DipECVS MRCVS
RCVS Recognised and European Specialist in Small Animal Surgery

Orthopaedic Examination
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.

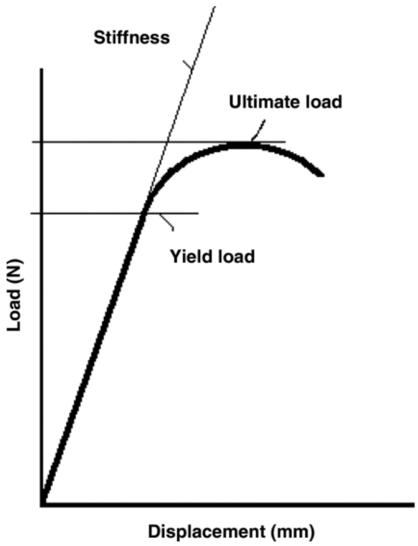
Bone is viscoelastic, which means among other things that its strength and stiffness depend on the rate at which it is loaded. The more rapidly it is loaded the stronger and stiffer it becomes.

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, below, 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.

Bone Healing

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 AO/ASIF guidelines has changed over the years. 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)

Fracture Treatment

When presented with a trauma patient it is vitally important to assess systemic health of the animal. This may sound obvious but some trauma patients can look remarkably well despite significant hidden pathology. Assess the animal for other traumatic injuries, pneumo-, haemothorax, hernias, splenic/hepatic haemorrhage, and head trauma. Initial stabilisation with analgesics, intravenous fluids, oxygen supplementation and blood products should commence as soon as possible. Once stable your attention can turn to assessing the fracture. Treatment of fractures can be achieved by conservative means, external coaptation, internal fixation or external skeletal fixation.

Conservative

There are a number of situations where conservative treatment with strict rest (often a cage) can be considered.

In very young animals the periosteum may remain complete resulting in minimal displacement in which case conservative treatment is entirely appropriate. Healing of the fracture should be assessed radiographically regularly, 5-7 days after the diagnosis. Fracture disease eg quadriceps contracture is a possibility so early limb use is necessary. If there is any fragment displacement then reduction and stabilisation is best.

Pelvic fractures can be treated by cage rest however surgery is best if there is disruption of the weight bearing axis and or a decrease in pelvic canal width. Pain is also better controlled with stabilization of the fragments.

Minimally displaced/incomplete fractures can also be treated with strict rest but again regular radiographic evaluation of healing is required.

External Coaptation

External coaptation is a popular means to treat fractures as it is considered easy. It is actually not easy and can be difficult to achieve the best outcome possible. Patient comfort and tolerance is vital to success.

External coaptation is appropriate in several situations

- Young patient with fast healing
    - Very young patients should not be placed in bandages or casts
- Stable minimally displaced or Incomplete fractures
- Ulnar fractures with intact radius

However good internal or external skeletal fixation will almost always results in a better outcome.
The advantages of external coaptation compared to surgery are

- Disruption to fracture site is minimal
- Blood supply is not further compromised
- No implants or surgery so risk of infection is decreased
- No implants that may need removal
- Can be cheaper (but not always)

However the disadvantages are

- Need to immobilise joint above and below fracture
    - Impossible in proximal limb
- Prolonged immobilisation can result in disuse atrophy and fracture disease
- Inadequate reduction
- Inadequate alignment

Assessment of the patient and fracture are the key to success.
Patient assessment

- Young patients heal quickly thereby limiting time in coaptation
    - Very young animals should not be put in coaptation
- Breed is important
    - Antebrachial fractures in toy and small breeds
    - Never use external coaptation (83% risk of malunion/nonunion)
- Patient conformation
    - Difficult in obese animals or chondrodystrophoid breeds
- Soft tissue injury
    - External coaptation less than ideal
- Multiple limb injury
- Patient temperament

Fracture assessment

- Fracture environment – open v closed
- Type and location of fracture
- Degree of displacement
- Multiple fractures
- Fracture forces present
    - Can counteract bending and rotation
        - Provided joints above and below fracture are immobilized
    - Cannot counteract compression, tension and shear
        - Most fractures are under axial compression

Basic guidelines for external coaptation

Fracture reduction

- Healing is greatly influenced by fracture reduction
- 50% rule
    - 50% contact for healing to be possible
    - Aim for 100%
- Closed reduction very seldom achieves perfect reduction
- Weight bearing after application likely to disrupt reduction

Fracture alignment

- Rotational alignment between proximal and distal joints
- Imperative to limb function
- Rotational or angular limb deformities
    - Functional gait abnormality
    - Lameness due to secondary osteoarthritis

Standing position

- Joint stiffness common after external coaptation
- Prolonged immobilization
    - Adhesions between muscle, tendons and bone
- Neutral standing position
- Limb should be used after application
- Joint mobilisation as early as possible

Joints proximal and distal

- To counteract bending and rotation the joint proximal and distal must be immobilized
- Distal to elbow and stifle

Temporary immobilization

- Prior to definitive surgery
- Useful for open fracture management
- Travelling
- Most dogs don't need if cage rested with sedatives and analgesia
    - Poorly applied immobilisation causes more problems

There are many types of external coaptation - bandages, casts, splints, slings etc. and the precise nature and application of each can be found in an orthopaedic textbook. The Robert Jones dressing and synthetic casts are the most applicable. All bandages etc. must be kept clean and dry with close monitoring for the bandage slipping, smelling and development of sores. Dogs generally do not chew at bandages/casts that are well placed causing no irritation.

External coaptation has a role in veterinary orthopaedics where there are financial constraints, minimally displaced or incomplete fractures, adjacent bones intact, metacarpal, metatarsal, digit fractures (one or two affected especially non weight bearing digits) and as adjunct stabilization (malleolar fractures, tarsal/carpal fractures arthrodesis).

<u>Surgical fracture stabilisation</u>

Internal fixation

- Pins
- Wires
- Screws
- Plates
- Interlocking nail

External fixation

- Linear
- Circular
- Hybrid

Combination of internal and external

Internal fixation

Advantages

- Rigid fixation whilst allowing normal limb use
- Limb health optimized
  - 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).

Plates

The standard internal fixation implants are bone plates, 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. There are a range of shapes and sizes

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

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 fractures can be compressed together and this results in load sharing (bone and plate share the axial forces).

Plates including the DCP can also be applied as neutralisation or bridging plates. With a neutralisation plate the fracture is reconstructed with screws, pins or wires and the plate is applied to help protect the reconstruction by resisting bending forces. A bridging 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 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 and the screws can be angled), 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.

Locking plates were designed 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.

Bone plates can be combined with an intramedullary pin where the IM pin resists bending and so protects the plate from fatigue failure. A DCP requires an IM pin of approximately 40% of the medullary cavity. The use of an IM pin makes it difficult to place bicortical screws and the clinical guideline is a minimum of 5 cortices above and below the fracture with at least one bicortical screw either side. Locking plates will have different guidelines for each plate.

Screws

Screws are normally used to fix bone plates but they can be used as interfragmentary screws. The two basic types of screw are the cortical screw, which has a smaller pitch (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 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.

Two biomechanical features of screws must be appreciated- the pull out strength of a screw is related to the outer diameter of the screw and the material it is placed into and the bending strength of a screw is relayed to its core diameter (larger core diameter better able to resist bending).

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

Pins

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

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 their area moment of inertia and the material they are 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 results in delayed or non-union. They are useful as adjunct fixation (plate-rod, tied in ESF construct and in comminuted fracture reconstruction to skewer small fragments). An exception when pins are used alone is in cross pinning of physeal fractures.

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

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.

External skeletal fixation

The basic components of external skeletal fixators are a connecting bar, which can be made out of many different materials (Steel, Titanium, Carbon, Acrylic), connecting clamps and fixation pins. The fixation pins can be smooth or threaded (end or mid threaded, positive or negative thread) and the fixation pins can be attached to one connecting bar, half pin or be attached to two connecting bars opposite each other, full pin. ESFs can be linear, circular or a hybrid of both.

Linear ESFs

- Type 1a
  - Unilateral, uniplanar
- Type 1b
  - Unilateral, biplanar

- Type II
    - Bilateral, uniplanar
    - IIa- Full pins, IIb Full/Half pins

- Type III
    - Bilateral, biplanar

- Modified tied in
    - IM pin tied in

The stiffness of liner ESF frames is due to many different factors. Frame configuration can alter stiffness.

Stiffness in compression and rotation

- Type III > Type II > Type Ib > Type Ia

Stiffness in bending

- Type III > Type Ib > Type II > Type Ia

The frame becomes stiffer with an increased number of fixation pins and as the pins' diameter increases. Minimum number of pins is two but more than four has minimal further increase in stiffness. Pin placement alters stiffness as stiffer frames have pins placed close to the fracture and bone ends. Increasing the connecting bar diameter and decreasing the distance of the connecting bar from the bone will also increase the frame's stiffness. With smooth fixation pins angling them at 70° to long axis will increase the frame's stiffness but this has no effect for positive threaded pins.

Circular or hybrid ESFs are extremely useful in certain situations but are complex to use appropriately

- Juxtaarticular fractures
- Angular limb deformities
- Distraction osteogenesis

Circular ESFs use full or half rings and tensioned K wires whereas the hybrid is part circular, part linear.

Advantages of ESF

- Applied open or closed
- Ease of application (linear)
- Can be altered after application
- All metalwork removed in end (if ESF alone)
- Open wound management
- Reasonable cost

Disadvantages of ESF

- Needs aftercare by owner
- Many owners cannot cope
- Pin tract discharge/infection
- Iatrogenic fracture

Open fractures

An open fracture is one in which fractured bone is exposed to environmental contamination due to disruption of the soft tissue integrity. They present a unique combination of soft tissue and orthopaedic injury. Referral is always advised as better results occur with experience.

Open fractures vary in severity and classified based on the degree of soft tissue damage

- Type I
    - Wound smaller than 1 cm
- Type II
    - Wound larger than 1 cm
    - Without extensive soft tissue damage, flaps or avulsions
- Type III
    - Extensive soft tissue damage
    - IIIA - Adequate soft tissue coverage of bone despite extensive soft tissue laceration or flaps
    - IIIB – Extensive soft tissue loss, periosteal stripping and bone exposure with massive contamination
    - IIIc – Associated with arterial injury requiring repair

The aim of treatment is to restore soft tissue coverage to healing bone, tendons, ligaments and neurovascular structures.

Key initial principles

- Assess for vascular and neurological deficits
- Prompt and aggressive debridement of contaminated material and non viable tissue
    - Cover with sterile dressing until this can happen
- Vigorous irrigation
- Administration of antibiotics
    - Intravenous initially and ASAP
- Bacterial swab of wound before start
- Early fracture fixation and soft tissue reconstruction

Definitive treatment

Soft tissue closure can be achieved by

- Primary closure
- Second intention healing
- Axial pattern flaps or free skin grafts

Fracture treatment

- External Coaptation not recommended
- Internal or External fixation can be used
- Principle of 'no metal in contaminated fracture' challenged
    - Internal fixation regularly used in humans
- However internal implants may require removal
- Severe tissue loss may preclude internal fixation.

Complications of open fracture surgery include superficial infection, deep infection (implant associated or osteomyelitis), delayed union or nonunion, necrosis of soft tissue, wound reconstruction dehiscence and neurological damage.

Delayed, non- and malunion

Bone healing is naturally vigorous and we as surgeons have mechanical and biological strategies to enhance this healing.

- Mechanical
    - Realign fracture fragments
    - Attenuate motion at fracture site
- Biologic
    - Growth factors and cells (bone graft)
    - Preserve soft tissue viability and vasculature

Inadequate mechanical or biological environment leads to retarded healing (delayed union), unsuccessful healing (nonunion) or improper healing (malunion).

Delayed union

- Prolonged time to heal
- Assumes eventual healing
- How do we know it will heal and not become a non-union

Nonunion

- Viable nonunion
    - Hypertrophic, oligotrophic
- Nonviable nonunion
    - Dystrophic, necrotic, defect and atrophic

Malunion

- Healing has occurred
- Failed to reestablish form and function of bone

Treatment is aimed at finding the cause and correcting. With inadequate stabilisation (mechanics) treatment is either the removal of loose and or infected implants, complete revision of fixation or the use additional fixation. With inadequate growth factors/cells (biology) treatment is aimed at preserving the soft tissue and vasculature and bone grafts.
With malunion an osteotomy and revision surgery is required and with most nonunions new bone has to be regenerated – bone graft or distraction osteogenesis.

The best treatment for any of these complications is to try your best to avoid in the first place.