Fracture Masterclass
Mini Series

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Introduction

Welcome to CDP solutions fracture masterclass webinars and these accompanying notes. The format of the series will be:

1. Fracture principles, October 10th

2. Thoracic limb fractures, October 24th

3. Pelvic limb fractures, November 7th

These notes summarize the material presented in webinar 1, fracture principles. The subsequent two webinars will feature case discussions using the principles. As this is a masterclass and not a basic class, we will cover the principles quite quickly in the first webinar; as a reminder, rather than explaining the theory behind all the principles.

There will not be any direct notes for these latter two parts as the material covered is applying the principles into practical fractures scenarios.

Patient assessment and stabilization

Ensure that the patient is stable

Fracture surgery itself is rarely, if ever, a life threatening emergency and most orthopaedic procedures can wait at least 24 to 48 hours without significantly adversely affecting the outcome for the patient. Most emergency orthopaedic patients have been involved in some sort of trauma and usually this is a collision with a vehicle. There is significant potential for a wide variety of other injuries to be present. These could be catastrophic or fatal if missed. The majority of trauma patients have other injuries in addition to the fracture. Common concurrent injuries, and this list is not exhaustive, are:

- Haemorrhage leading to anaemia
- Thoracic injuries including pulmonary contusions, fractured ribs, pneumothorax, haemothorax or diaphragmatic rupture
- Abdominal trauma including haemorrhage and visceral rupture such as ureteric, ureteral, or bladder rupture
- Head trauma and associated neurological signs
- It is therefore critical that a patient is stable prior to considering general anaesthesia for orthopaedic surgery. A recommended minimum screen for a patient involved in an RTA would be:
- Full physical examination including thoracic auscultation and abdominal palpation
- Blood work including PCV, total protein, urea, creatinine & electrolytes
- Thoracic radiographs
- Abdominal ultrasound to check for free fluid and viscus rupture

Perform a thorough orthopaedic examination

The orthopaedic examination is critical as it allows the source of lameness / orthopaedic abnormality to be correctly identified, and ensures that other abnormalities which could be significant are not missed. Performing a comprehensive orthopaedic examination takes time and requires experience to master but if the orthopaedic examination is not correct, then subsequent differential diagnoses, diagnostic tests and treatment recommendations may be either inappropriate or flawed. Specifically in the fracture / trauma patient, there may be more than one fracture / injury and it is all too easy to focus on the obvious fracture but the less obvious one may not be discovered until too late i.e. post-operatively. As most fracture patients are painful, a thorough orthopaedic examination may not be possible with the patient conscious therefore this may have to be repeated once the patient is sedated or anaesthetised for diagnostic imaging or surgery.

Always take orthogonal radiographs before surgery

This is to confirm or make the diagnosis and to rule out potential differential diagnoses including concurrent pathology such as bone tumor. Radiographs are taken to plan for surgery including assessing and sizing implants and to formulate a surgical plan. If orthogonal radiographs are not taken, it can be all too easy to miss a critical lesion or make a misdiagnosis. For example:

- A lateral humeral condylar fracture is easily missed on a mediolateral view alone but is readily seen on the cranio-caudal view.
- Serious pelvic fractures can be difficult to appreciate on a lateral view alone.
- Central tarsal bone or calcaneal fractures may not be fully appreciated

Take radiographs of the contralateral limb for comparison

Sometimes it can be difficult to know whether a lesion seen on radiographs is significant i.e. is the suspected abnormality a lesion, normal anatomic variation, or completely insignificant? If in doubt, radiograph the same anatomic area of the contralateral limb. If the “lesion” is not present on the contralateral limb, it may be significant. However if the “lesion” is present on the contralateral limb then either the finding is normal, or the pathology may be bilateral. If doubt still persists, consult and compare with radiology textbook or refer the radiographs for a second opinion. Examples include differentiating:

- whether a tibial tuberosity physeal avulsion fracture is present or not, and whether significant displacement has occurred?
- whether an ununited anconeal process is present or not
- if a non displaced fracture is present, or is it the nutrient foramen of the bone?
- is a fracture present, or is it a normal physis?

Understanding Bone healing

An understanding of bone healing is essential to successful fracture management because the mechanical environment created at the fracture site is dictated by the fixation method chosen. The mechanical environment in turn dictates the type of bone healing that is likely to occur.

Gap strain

Gap strain describes the amount of deformation of the healing tissues at the fracture site. The degree of tissue deformation dictates the types of healing tissue that can and cannot form, and therefore whether a fracture will heal by direct bone union, by callus, or not at all and instead develop into a non-union. The smaller the deformation of the fracture gap and / or the greater the original length of the fracture gap, the lower the gap strain will be.

The mechanical environment at the fracture created by the surgeon depends on the fixation method used and is manipulated to exploit bone healing characteristics, either by controlling the absolute movement at the fracture gap or the size of the fracture gap and thus gap strain.

Direct (primary) bone union.

During primary bone union, bone heals by being immediately and directly laid down across the fracture gap. In other words, there is no callus that is later gradually transformed into bone. Direct bone union occurs only if the fracture gap measures less than 1mm, and if inter-fragmentary deformation (strain) is less than 2%. Direct bone healing can occur in two slightly different ways; contact healing and gap healing.

1. **Contact healing** occurs when the fracture gap is less than 0.01mm and there is absolutely rigid fracture fixation i.e. gap strain = 0%. New bone is deposited over the fracture gap by the process of normal bone turnover and remodeling i.e. Haversian remodeling of leading cutting cones of osteoclasts and trailing osteoblasts etc. This remodeling process is part of natural bone turnover and is very slow i.e. contact healing is very slow.

2. **Gap healing** occurs when the fracture gap is between 0.01mm to 1mm and gap strain is < 2% i.e. the fracture gap is not absolutely rigid. New bone is first deposited across the fracture gap by intramembranous ossification. This lamellar bone is initially oriented perpendicular to the long axis of the bone but subsequently this undergoes osteonal reconstruction and remodels such that the bone becomes oriented normally i.e. parallel with the long axis of the bone.

Indirect (secondary) bone union

Secondary bone union is characterized by callus formation and occurs if there is a fracture gap of more than 1mm, or instability of the fracture i.e. gap strain more than 2%. Secondary bone union occurs through a complex series of events that see the transformation of the fracture haematoma through stages of organising granulation tissue, fibrous tissue, cartilaginous tissue and finally into bone. At each of these stages, the tissue becomes stiffer and stronger thus reducing inter-fragmentary movement and gap strain, and gradually stabilising the fracture to the point that the next (more rigid) tissue phase can form. Once gap strain is less than 2%, mineralised bone formation (hard callus) can occur. Callus healing occurs through three phases:

1. **Inflammatory phase.** This start immediately after and continues until the formation of bone and cartilage starts; it lasts for 3 to 4 days or longer. As it ends, pain and swelling also reduce. The inflammatory phase starts with the fracture haematoma which releases growth factors that initially stimulate angiogenesis and ultimately bone formation**.** The net result of the ifnalmmatory mediators is that within a few hours of fracture , re-vascularisation of the hypoxic fracture site has started.

2. **Proliferation / Repair phase.** Towards the end of the inflammatory phase but overlapping with it, in-growth of capillaries, mononuclear cells and fibroblasts start the process of transforming the haematoma into granulation tissue which can withstand deformation of about 100%. Collagen fibres appear and transform the granulation tissue into connective tissues which can tolerate 17% deformation. Initially collagen 1,2, & 3 is present but this matures to predominantly collagen 1. The periosteum thickens and undergoes chondrogenic transformation which produces external callus that is vascularised by extra-osseous vessels. The endosteal cell layers produce the intramedullary or endosteal callus. This combination of the external and internal callus is called bridging callus; early soft callus is typically formed within the first 3 weeks. Fibrous tissue within the fracture gap undergoes intramembranous ossification, as long as there is sufficient vascularity and deformation is not excessive i.e. below 2%. At the end of the repair phase bone union is complete, and the healed bone can withstand low impact exercise, but the structure and strength of the bone is different to normal bone.

3. **Remodeling phase –** this is the slowest part of the fracture healing process; during this time, the bone adapts and remodels to regain strength and function. Remodeling happens according to Wolff's law and is governed by piezoelectric currents within the long bone that occur in response to micro stretching and compression. This in turn drives osteoclast and osteoblast activity that results in the slow remodeling of the bone.

Consider the forces acting on bones

There are five different forces that act on bone, including fractured bone. These mus be considered when dealing with a fracture, as the reconstructed bone must be able to withstand all forces, but it may only be inherently stable to some forces. Understanding the forces that the bone may be unstable to enables the surgeon to utilise fixation devices that will neutralize the remaining forces.

Diaphyseal bones are typically subject to the four forces of compression, bending, shear and rotation, but not avulsion. Avulsion forces occur at the point of insertion of tendons and ligaments e.g. insertion of the quadriceps mechanism patellar ligament on the tibial tuberosity, insertion of the common calcaneal mechanism tendon on the calcaneous, or insertion of the triceps tendon on the tip of the olecranon. Avulsion fractures are a specific sub-set of fractures that are usually treated with a pin-and-tension band wire, which converts the avulsion force into a compressive force across the fracture thereby stabilizing it and allowing bone union.

Fracture Healing Score

***Consider the patient*. A young healthy patient with a simple closed long bone fracture is likely to have a quicker, more predictable, less complicated recovery than an elderly patient with multiple traumas. Factors to consider include:**

- **Patient age.** Younger patients <12 months old will heal quicker, and older patients >12 years of age for dogs and >14 years of age for cats will heal slower.

- **Patient health status.** Patients with systemic disease e.g. neoplasia, renal failure, hepatic failure, significant enteropathy i.e. in a catabolic state are likely to heal slower than normal.

- **Patient trauma.** Patients with multiple limb injuries or with other diseases, such as neurological dysfunction, may have an increased risk of post-operative complications. This is because limb loading cannot be re-distributed away from the injured limb. Therefore mechanical protection of the fractured limb and implants does not occur.

- **Patient weight.** An obese patient will load the injured limb(s) greater than a patient of normal weight; this may lead to a higher complication rate such as premature implant failure.

- **Patient temperament.** A patient that is quite-mannered, cooperative, obedient and will tolerate relatively low levels of exercise should be easy to manage post-operatively, and be at low risk of suffering complications. Conversely, a patient that is very energetic, cannot be controlled, or is aggressive and cannot be handled without sedation or anaesthesia may be more difficult to assess and monitor, or more likely to suffer complications due to higher activity levels. A patient that is difficult / aggressive to handle is usually easier to manage post-operative with internal rather than external fixation as fixators required more post-operative maintenance.

Consider fracture biology. A fracture with more favorable biology should heal quicker and with less chance of complications than one with compromised biology.

- A low energy e.g. spiral or greenstick fracture should heal more quickly and reliably than a high energy fracture e.g. comminuted or segmental fracture

- A fracture involving cancellous bone or a cartilaginous physis will heal more quickly than a fracture of cortical bone

- An open fracture is likely to suffer more complications than a closed fracture because of contamination and disturbance to vascularity and local host defence mechanisms.

- The higher the grade of open fracture, the more likely complications are to occur, and the more severe they are likely to be if they occur.

- A limited surgical approach should facilitate more rapid and uncomplicated fracture healing compared to an extensive surgical approach.

These patient and fracture considerations can be combined into a single fracture patient score with a numerical grading scale from 1 to 10. A score of 10 indicates a patient / fracture scenario with high healing potential i.e. very likely to heal quickly with minimal chance of problems. A score of 1 indicates a patient / fracture scenario with low healing potential i.e. unlikely to heal quickly, and a high chance of complications.

Is the fracture reconstructable or not?

Reconstructable means being able to completely reconstruct the fractured bone back into its original state i.e. putting the 'jigsaw' of fractured pieces of bone back together into a single column of bone. This can be achieved using a combination of a plate and screws including lag or positional screws, K-wires, orthopaedic wire, interlocking nail, an intramedullary pin or an ESF.

Simple transverse, oblique and spiral fractures are usually relatively straightforward to reconstruct. Segmental and mildly comminuted fractures can also be reconstructed but are more challenging. Moderately to highly comminuted fractures are very unlikely to be reconstructable without extensive dissection or extended surgical time. Just because the fracture can be reconstructed, does not necessarily mean that the fracture should be reconstructed. As a general guide:

- If a fracture can be reconstructed relatively quickly and straightforwardly, this is often the best option as reconstruction ensures that correct bone alignment and length are achieved, direct bone contact maximises bone healing potential and bone-implant load sharing. However, often reconstruction is achieved at the cost of losing the fracture haematoma and damaging adjacent soft tissues i.e. biological fixation is not achieved .

- If reconstructing the bone is likely to be very time consuming, involves extensive dissection, the placement of large numbers of implants, or if placing implants risks fracturing the bone further, it is probably best not to attempt reconstruction but to instead aim to use fixation devices to achieve correct alignment and length of the fractured bone. In other words, instead of reconstruction, use implants to bridge the fracture, preserve the fracture biology, and allow healing by secondary bone union / callus formation.

- If the bone is fractured into more than 3 or 4 pieces, it is probably not worth attempting reconstruction.

- External Skeletal Fixators are well suited to fractures that are not reconstructable and allow a biological approach because they can be applied to the bone with a very limited (or zero) surgical approach and dissection. The converse is true of bone plates i.e. they need a more open approach for placement which involves soft tissue dissection and disruption of the fracture haematoma, but bone plates are excellent for achieving and maintaining complete bone reconstruction and/or fracture compression with high inherent rigidity. The exception to this would be look-but-do-not-touch surgery, and Minimally Invasive Plate Osteosynthesis.

Screws

Screws are machines that convert axial torque into longitudinal force. In other words, as the screw is rotated and tightened into a material such as bone by turning it with a screwdriver (axial torque), as the head of the screw engages the surface of either the bone or a plate, this creates a longitudinal compressive force between the head of the screw and the bone or plate with which the screw head engages. Screws have a number of design features that enable their function and performance to be maximised. The three main functional parts of a screw are:

Screw head

Inner surface; this is designed to engage the tip of the screwdriver to allow the screw to be turned and tightened in an efficient and reliable manner and avoiding slippage. The three common types of screwdriver and head design are cruciform, hexagonal and stardrive.

Outer surface; this engages the hole in the plate or the cortical bone itself which the screw has been inserted. The outer surface is designed to allow the head to fit in a plate hole in a tight and secure fashion that distributes stress and maintains axial and longitudinal tension. There are two common designs of screw head: bone (non-locking) and locking.

Screw shaft

The thicker the shaft of the screw, the disproportionately stronger the screw is; this is because there is a non linear relationship between shaft diameter and strength. Strength is expressed as the Area Moment Inertia (AMI) which is a measure that is independent of specific material qualities and is proportional to the radius to the 4^{th} power.

Screw thread

A non self tapping screw has a blunt thread and has a rounded tip i.e. it cannot cut into the bone. Prior to placement of the screw, the profile of the thread has to be cut (tapped) into the bone using a tap. A self-tapping screw has a sharp cutting tip with a triangular thread at the tip of the thread. It cuts its own thread in the bone and does not need pre-tapping; it can be screwed into the bone immediately after drilling.

The design of the screw thread is engineered to allow the screw to perform at its best in different mechanical environments e.g. hard cortical bone vs. relatively soft cancellous bone. The thread features that are important are:

Thread depth = distance between outer thread diameter and inner shaft diameter

Thread pitch = distance between the threads i.e. number of threads per unit length

Cortical screws have a low thread depth and thread pitch i.e. the thread is fine; this is designed to maximise bone purchase in dense cortical bone. Locking screws have finer more shallow thread than non-locking screws.

Cancellous screws have the opposite design to maximise bone purchase in relatively soft cancellous bone; they have a coarse thread with larger outer diameter and a narrower core diameter i.e. a deeper thread, and a larger pitch (thread spacing). The thread is relatively over-sized compared to the shaft diameter; a big coarse thread achieves better bone purchase in soft cancellous bone.

Positional screw. A positional screw securely holds two pieces of bone in position relative to each other. Each section of bone has the hole drilled and the thread tapped into it; the screw is tightened and holds the two pieces of bone in the same *position as when the screw was applied.* A positional screw does not create compression.

Lag screw. A lag screw compresses two pieces of bone against each other, creating a mechanical environment designed to encourage contact healing between the two pieces of bone; for example when a long oblique or spiral fracture is reconstructed, reduced and compressed.

Plate screw. The screw is secured in the bone through a hole in the plate i.e. the head of the screw engages the plate. A screw can be placed in a plate in four ways that result in different biomechanical function:

- ***Compression screw*** - the screw is placed eccentrically in an oval DCP screw hole; as the screw is tightened, as well as tightening the plate down onto the bone surface, it also travels in the direction of the fracture causing compression at the fracture site.
- ***Neutral screw*** – the screw is placed centrally in an oval DCP plate hole, or a round-hole non-DCP plate. As the screw is tightened, it tightens the plate down onto the bone surface
- ***Lag screw*** – as per the lag screw above but in this instance the screw is placed through the plate. This screw should be placed prior to the other screws in the plate.
- ***Locking screw*** – the screw head locks into the hole in the plate. The locking screw / plate interface is a rigid coupling that behaves very differently to non-locking screws. The locking screw/plate construct is essentially an “internal” external skeletal fixator and the locking screw/plate mechanism is the equivalent of the ESF clamp.

Non-locking plates

Non locking plates function to stabilise fractured bone, because as the screw is placed through the plate hole and the diaphyseal bone beneath, as the screw is turned and tightened into the bone, the screw head moves closer to the plate hole and bone surface until the screw head engages the plate hole. At this point, friction and a compressive forces are simultaneously generated between the screw head and plate, and between the plate and bone. As the screw is tightened, the plate is tightened down onto the bone and friction stabilizes it and prevents it from moving. The dynamic compression plate is the most commonly used plate in small animal orthopedics. In addition to the commonly used and versatile Dynamic Compression Plate, there are a large number of other plate designs that have specific purposes. These include the reconstruction plate, the Veterinary Cuttable Plate, and anatomic and procedure specific such as TPLO, TPO, distal femoral and acetabular plate. Non-locking plates can be applied in 3 different mechanical configurations:

1. ***Dynamic Compression Plate (DCP) as a compression plate.*** The fracture is reduced, and the plate is applied to the bone using at least 1 screw in the loaded (compression) position; this applies compression to the fracture. In order to function as a compression plate, the plate must have DCP style oval screw holes. Only transverse fractures are appropriate for compression plating because compression applied to oblique or spiral fractures will cause shear and loss of fracture reduction.

2. ***Neutralisation plate.*** The fracture is reduced using adjunctive fixation devices such as lag screws, positional screws, cerclage wires or K wires. This stabilizes the reconstructed bone to some but not all forces. The neutralisation plate neutralizes the remaining forces to which the reconstructed bone is weak or relatively unstable. The plate and bone share the load of weight bearing. Any plate can be used as a neutralisation plate. If a DCP is used as neutralisation plate, the screws must be placed in the neutral position i.e. using the non-loaded (neutral) drill guide.

3. ***Bridging plate.*** The plate takes all the force of weight bearing. In this situation, the fracture is not reconstructed, and the bone is unable to withstand any forces or load itself. The bridging plate spans the fracture gap and is responsible for all load bearing during the healing period. Any plate can be used as a bridging plate but this requires careful attention and caution. As the bridging plate takes all the load, it is subjected to much greater load than a plate in compression or neutralisation mode. Because it is loaded more, early weakening and potential failure are significant risks. When a plate is placed in bridging fashion, a plate is chosen that is larger than would otherwise have been used had the fracture been reconstructed, or it is protected mechanically by concurrent use of an intramedullary pin i.e. a plate-rod construct.

Non-locking plates - Principles and Rules

1. Number of screws: engage a minimum of 6 cortices either side of the fracture i.e. 3 bicortical screws

2. Application of plate to tension side of the bone, and not the compression side

3. Pre-stress the plate to ensure no gapping of the trans-cortex

4. Use as long as plate as possible to reduce the lever arm effect.

5. Accurately contour the plate to the bone to ensure absolute screw-plate and plate-bone contact.

6. Fill as many screw holes as possible. If screw holes have to be left empty over the fracture site, it is better to level several holes empty rather than just one.

7. All screws must be tight; a stripped screw that will not tighten is mechanically useless and should be removed.

8. All screws should engage both cortices because non-locking screws are not angle stable therefore they may toggle in the screw hole if placed as unicortical screws.

9. Only lag screws should cross the fracture.

10. If the fracture is being reconstructed, avoid cortical defects

11. Plan carefully; have a plan A, plan B and plan C

Adjunctive fixation

Intramedullary pin is a metal rod of more than 2mm in diameter with a sharp tip that is inserted into the medullary cavity of a long bone to stabilize the bone. Intramedullary pins provide good resistance to bending and reasonable resistance to shear, but poor resistance to compression or rotation.

An intramedullary pin is usually used in combination with another fixation device e.g. a bone plate (plate-rod construct) or an external skeletal fixator either tied in or not. A pin diameter of 20 to 50% the size of the medullary canal is chosen in order to provide adequate stabilization yet still allow passage of or ESF pins past the intramedullary pin.

K-wire is a smooth metallic pin with a sharp point at both one or both ends, and of between 0.9mm and 2mm in diameter. K-wires are best placed using a power drill rather than a chuck. After placement, the end of the K-wire is bent to prevent migration along the long axis of the wire. K-wires are commonly used for:

- **Avulsion fractures** at the insertion point of tendons: K-wires are used in combination with figure of 8 orthopaedic wire to produce a Pin-and-Tension-Band configuration.
- **Physeal fractures** e.g. distal femoral, tibial or radial physeal fractures; K-wires can be used in pairs as crossed K-wires, parallel K-wires or as dynamic K-wires (Rush pin style) configurations.

Orthopaedic wire is stainless steel monofilament wire that is flexible, comes on a reel and is cut to required length. Wire diameter is between 0.6mm and 1.2mm. The wire is placed around the bone to be stabilised then the free ends are twisted around each other to tighten the wire. The wire can be used as cerclage wire or a tension band:

Cerclage wire; the wire is looped around the reconstructed long bone diaphysis and tightened to maintain tension and prevent slipping. The rules of cerclage wire application are:

- Only use when complete anatomic fracture reduction can be achieved. Do not use on a comminuted fractures as the fracture will collapse
- Only use when the fracture length is ≥ 2 times bone diameter i.e. oblique fractures
- Minimum of 2 cerclage wires should be placed and ideally more
- The distance between the wires should be at least 0.5 times bone diameter

Pin and Tension Band

This is the combination of one or two K-wires and orthopaedic wire in figure-of-8 configuration. The construct converts avulsion / tension force into a compression force by exploiting Newton’s second law “for every force there is an equal and opposite force”. The technique is used for the stabilisation of osteotomies apophyseal avulsion fractures that occur in skeletally immature animals e.g. insertion of the gluteals on the greater trochanter of the femur, the quadriceps on the tibial tuberosity, or the triceps on the olecranon. The principles of pin-and-tension band application are:

- Use of 2 rather than 1 K-wire gives better rotational stability of the bone fragment
- The K-wires should be placed parallel to each other and perpendicular to the fracture
- The distance between the drilled hole and the fracture should be at least as long as the distance between the fracture and the K-wire.

External Skeletal Fixation

External Skeletal Fixation (ESF) is an invaluable technique for fracture and osteotomy repair and stabilisation. Many systems exist and potential applications are varied and diverse. The main types of ESF are linear, circular, free-form and hybrid.

Principles of ESF application

1. Use strict aseptic technique.
2. Use safe corridors for pin placement.
3. Frame type: select and use the ESF frame type that is most appropriate to the fracture type.
4. Number of Pins. Aim for 4 pins per bone segment to minimise failure of the Pin Bone Interface. Minimum is 2 pins per bone segment.
5. Apply the Far-Near-Near-Far principle.
6. The Minimum distance between ESF pin and end of the bone or fracture = half bone diameter
7. Pin Spacing. Space out the pins out far as possible.
8. Pin Design – Use positive threaded pins because of superior pull-out resistance.
9. If using smooth pins, place at 70 degrees to each other to maximise pull-out resistance.
10. Pin size. Larger pins are stiffer than small pins but larger pins require larger holes in the bone, and larger holes in the bone weaken the bone which could fracture. Aim for pin size 20-25% bone diameter. Maximum = 30% bone diameter. This then sets ESF clamp and connecting bar size.
11. Pin Length should be as short as possible whilst leaving space for soft tissue swelling. Orienting the clamp to be close to the bone reduces pin length.
12. Pre-drill the pin to minimise heat production and bone necrosis during pin insertion. Use a drill bit about 10% smaller than pin shank diameter.
13. Pin placement**:** Do not place pins through the surgical incision or traumatic wound. Make separate stab incisions using a #11 blade through fresh healthy skin.
14. When placing the pin, use a power drill at <150rpm to minimise heat production and bone necrosis. Do not use a hand chuck as this creates wobble
15. Ensure that pins penetrate both cortices of the bone (cis and trans).

Adjunctive fixation. Consider using adjunctive fixation in addition to the ESF. Using an intra-medullary pin enables axial and spatial alignment of the fracture to be achieved quickly, simply and relatively atraumatically, by minimising the amount of fracture manipulation that is necessary. When tied-in to the ESF construct, an intra-medullary pin increases the fixator construct strength and stiffness.

Surgical method. Using a hanging limb preparation before surgery helps to overcome fracture over-riding and loss of longitudinal length caused by post-fracture muscle contraction. During surgery, the hanging limb preparation will help to achieve correct spatial alignment of the fractured bone.

Locking Plates

A locking plating system is one in which the screw head locks into the plate hole thus creating an angle stable device between the plate and screw. Angle stable means that the screw cannot toggle in the plate screw hole. This is different from non-locking plates that rely on friction between the screw head, the plate and the bone to achieve stability. The screw head locking mechanism varies between locking systems. The stability of the construct depends on the stability of the locking mechanism. The locking plate is comparable to an internal External Skeletal Fixator.

For a locking plate system, the screw head locks directly into the plate via a strong and reliable locking mechanism. The stability of the implant is not as reliant on the quality of screw-bone purchase, nor is it at all dependent on the magnitude of compression of the plate onto the bone by the screw head. The locking plate construct has a number of important theoretical advantages over non-locking constructs:

- Implant stability is not reliant on ensuring the screw is as tight as possible therefore:
- Stripping of screws in the bone is much less likely
- Locking plates are ideal for placing in poor quality bone stock e.g. thin bone, osteopaenic bone, immature bone or diseased bone
- Screw loosening is much less likely; in fact the opposite problem can apply i.e. the screw can become so tightly embedded in the plate that removal if required might be problematic
- As the plate is not compressed onto the bone, periosteal blood supply is not disturbed
- Approximate contouring of the plate is necessary but accurate contouring to superficial shape of the bone is not: this can save considerable surgical time and may reduce implant weakening that can result from repeated efforts to contour.
- As the screw head locking plate coupling is angle stable, the screw cannot toggle in the plate hole therefore mono-cortical screws are adequate, at least in theory. Bicortical screws are not essential but can be used. This has particular advantages if penetration of the trans-cortex is to be avoided e.g. spinal or articular fractures.
- Locking implants lend themselves well to minimally invasive surgical techniques, particularly with the assistance of intra-operative fluoroscopy.

However, the locking construct is not without its drawbacks and potential disadvantages. For exmaple, cold welding of the screw into the plate is at least a theoretical possibility, as the screw is acting as a fixator pin, there is a higher risk of fracture because of increased loading, and compression cannot be applied with locking screws. A number of locking plate systems are available; the locking systems currently available in the UK including:

1. Synthes Locking Compression plate (LCP) – fixed angle
2. Orthomed String of Pearls plate (SOP) – fixed angle
3. Veterinary Instrumentation vertically stacked locking system – fixed angle
4. Traumavet FiXiN system – fixed angle
5. Securos PAX - polyaxial locking system
6. Freelance vetLOX - polyaxial locking system

Locking systems engage a different set of fixation rules compared to non-locking systems. Some of the rules are listed here, but they do vary between systems:

- Approximate plate contouring is required, exact contouring is not
- Absolute minimum = 2 screws either side of the fracture
- The plate should be as long as possible
- Screw stocking density should be 0 over the fracture, 0.75 elsewhere = average 0.4-0.5
- Application of a locking plate will maintain bone alignment and malalignment.

The surgical approach – open, or closed?

Four types of surgical approaches can be considered for fracture repair and each has different implications in terms of preserving local biology, fracture haematoma related growth fractures at the fracture site, and ease of visualization and manipulation of the fracture. Before starting, the surgeon must understand whether the fracture is reconstructable, and be clear whether he/she intends to reconstruct the fracture, whether the benefits of reconstruction outweigh the disadvantage of disturbing the fracture haematoma, what type of fracture healing is likely to occur and therefore how stiff the fixation device needs to achieve either direct or indirect bone union.

Open approach. A full surgical incision is made to the fracture and the fragments of bone are explored and reconstructed using implants as appropriate. Stabilisation is usually achieved using a bone plate although other implants such as lag screws may be used. The fracture haematoma with all its biological factors are disturbed and may be destroyed. In order to achieve gap strain of <2% and primary bone healing, rigid fixation must be achieved; usually this is with screws and a bone plate.

Open and look-but-do-not touch approach. As per the open approach above, the fracture is opened surgically for implant placement, but the fracture site is not touched and the fracture haematoma and soft tissue attachments are undisturbed. The proximal and distal aspects of the bone are aligned and an implant is placed whilst preserving the biology of the fracture site.

Minimally Invasive Plate Osteosynthesis / surgery. Very small incisions are made over the proximal and distal metaphyses of the bone, the fractured bone is distracted to the correct length and aligned. The fracture its stabilised, typically by placement of a locking plate that is introduced adjacent to the fractured bone in an epiperiosteal tunnel that has been made by blunt dissecting between the bone and the overlying deep muscles.

Closed approach. No incisions are made other than stab incisions necessary for fixator pin placement. Fixator pins are placed proximally and distally, used to distract and correctly align the fracture, and then the fracture is stabilised by application of connecting bars.

The latter two approaches are minimal surgical approaches; these are greatly facilitated by advanced imaging such as fluoroscopy or intra-operative radiography. The fracture site is disturbed minimally therefore the fracture haematoma and all its growth factors remain in situ to maximize bone healing potential.

Bone Grafts

Bone grafting is the application of a substance to a fracture, osteotomy, arthrodesis or other bone defect site with the purpose of inducing and/or facilitating bone healing. The qualities that a bone graft or graft substitute may confer onto a bone healing site are:

- **Osteoconduction** is the provision of a scaffold or matrix that allows the growth and development of bone across the scaffold
- **Osteoinduction** is the ability of the graft material to induce adjacent native bone or local stem cells to differentiate and be biologically active.
- **Osteogenesis** is the ability of the graft material to generate new bone itself. To do this, the graft needs to be alive and contain viable osteoprogenitor stem cells.
- **Osteopromotion** is the creation of an environment favorable to bone formation. This is a more abstract concept of bone grafting and is harder to quantify but is still important.

Bone graft material can be obtained from a number of different sources:

Autograft – the graft is sourced from the patient's own body, almost always at the same time as the definitive fracture / osteotomy / arthrodesis surgery. Autograft is osteoconductive, osteoinductive and osteogenic. Autogenous cancellous bone is considered to be the gold standard for osteogenesis and osteoinduction.

Allograft: the graft is sourced from a different individual of the same species. Allograft may be osteoconductive, osteoinductive and osteopromotive. It is usually not alive and therefore cannot be osteogenic. In small animal orthopaedics, this is bone graft that is sourced from a pet dog or cat that has been euthanased, and the animal's body has been donated for allograft purposes. The patient may be screened for disease prior to processing. The bone is harvested and processed in a number of different ways to produce different graft types. The graft is supplied as an "off-the-shelf" product, for example Demineralised Bone Matrix (DBM), cortical or cancellous bone chips, bone struts, or whole bones.

Xenograft: the graft is sourced from a donor of a different species to the recipient. Xenografts may be osteoconductive, osteoinductive and osteopromotive but cannot be osteogenic. Such grafts are rarely used in small animal orthopaedics but recent developments have lead to the production of a human recombinant Bone Morphogenic Protein (hrBMPs) licensed for use in dogs. This preparation contains rhBMP2 on a bovine collagen sponge carrier matrix and is licensed for diaphyseal fracture repair in dogs (Truscient™, Zoetis UK Ltd).

Fracture complications

Numerous complications can develop following fracture surgery. Some complications such as mild serous ooze or superficial surgical site infection may not affect the outcome. Other complications are much more serious and may not resolve without revision surgery or other treatment e.g. implant failure, or fracture non-union

Surgical Site Infection (SSI)

Surgical site infection might be superficial and mild and easily resolved, or deep, serious and hard to resolve. Most surgical site infections (SSIs) are caused by resident skin flora e.g. staphylococcus aureus or staphylococcus pseudointermedius or by oro-faecal floral contamination e.g. Enterococucs faecalis. Risk factors for SSI include length of anaesthetic and surgical time, whether implants are placed, whether the surgical site is clean, contaminated or grossly contaminated, and surgical technique factors such as gentle tissue handling and accurate haemostasis.

Definition: of surgical site infection is one that occurs up to 30 days after surgery if no implants are placed, or up to 1 year after surgery if implants are placed. Hence reporting of SSI is likely prone to under-reporting as long term follow up is unreliable and - many late infections may not be counted as surgical site infections.

Management: If a SSI infection is present or suspected, samples should be submitted for Culture and Sensitivity (C&S). The wound should be cleaned and flushed regularly up to several times daily under sedation, dressed and the patient should be barrier nursed as a minimum. A course high dose antibiotics; initially broad spectrum e.g. Co-Amoxyclav or Cefalexin until the C&S results are returned at which time the antibiotics are changed if necessary to a drug that the bacteria are sensitive to. Most SSIs respond quickly to systemic antibiotics and local flushing. Superficial infections (skin and immediate subcutaneous tissues) should be treated for 10-14 days. Deeper infections such as an infected joint or osteomyelitis should be treated at high doses for at least 6 weeks, and ideally until repeat sampling at the end of that period demonstrates the absence of infection e.g. by repeat joint tap.

Prevention: For clean surgery, a post-operative SSI rate of 2.5 – 5 % of cases is accepted; some sources suggest that orthopaedic surgery has a higher rate of infection compared to soft tissue procedures. This is probably because implants compromise the local host defences, and reduce the minimum number of bacteria that are necessary to initiate infection.

Implant infection: is a specific case of SSI but implant infections are more difficult to treat permanently. Sometimes resolution of treatment requires implant removal, which may not be possible until bone healing. Bacteria such as Staphylococci secrete a glycocalyx which is an extracellular glycoprotein matrix – this forms a biofilm that enables the bacteria to hide from the antibiotics. The use of antibiotics will control but not eradicate such infection; the clinical signs are controlled whilst the antibiotics are given but once the antibiotics are discontinued, the bacteria multiply and the clinical signs of infection return. In this circumstance, the only way to control the infection is to remove the implants and the glycocalyx but this can only happen once the mechanical function of the implant is no longer required e.g. the bone has healed.

Implant failure

Implant failure is an infrequent but potentially catastrophic complication of orthopaedic surgery. Implants may fail in a variety of different ways e.g. snapping of material such as lateral fabella suture, implant pull out e.g. bone screw, ESF pin or suture anchor i.e. failure of pin-bone interface, implant failure by fracturing or bending e.g. bone plate, bone screw or ESF pin. Implant failure can occur through a number of different mechanical scenarios:

Repetitive strain and cyclic loading. This occurs when an implant is bent back and forth multiple times, and after thousands or tens of thousands of cycles of bending. With each small bend, the implant material suffers a minor deformation and a tiny microscopic crack will propagate and enlarge slightly. These minor deformations are cumulative until finally the crack is so big that the implant snaps or fractures. This is the most common cause of plate failure after fracture repair and typically happens 3 to 5 weeks after fracture surgery because it is at this time that sufficient cumulative cyclic loading has occurred for the cracks to propagate enough to implant failure.

Acute overload of the implant. This is when an implant is exposed to a far greater force than it was designed to withstand and it suffers acute and catastrophic failure i.e. plastic deformation. For example, a plate that is applied that is too small for the patient and as a result, immediately bends and fails with the first few steps that the patient takes. This is a relatively uncommon cause of failure in small animal orthopaedics but does happen in equine orthopaedics where the loads are orders of magnitude higher and the implants used are relatively weaker.

Implant pull out occurs due to breakdown of the bone-implant interface, usually because the bone shatters, disintegrates or fractures because of overloading of the bone in the region that the thread is cut into the bone. Once the bone-implant interface fails, implant pull-out occurs. For example, when a screw strips the bone thread during screwdriver tightening , this is bone-implant interface failure; this example this is in a controlled environment of the surgery where the failure is identified and can be remedied.

Avoiding implant failure depends on the reliable selection of implants that can withstand the forces to which they are being subjected, and controlling the patient’s activity to prevent the implants being subjected to excessive load. When implant failure occurs, it is easy to blame the failure on poor owner/patient compliance but in the majority of cases, there is a failure on the part of the surgeon to adequately assess the implants required to maintain bone alignment for a sufficient time for uncomplicated bone healing to occur.

Problems of bone healing

Delayed union

Delayed union is the failure of the bone to heal in the time frame normally expected of a given fracture scenario i.e. bone healing is delayed compared to expectations. Serial radiographs of the fracture / osteotomy site are needed to monitor progress of bone union and to pick up complications such as delayed union at an early stage. Some cases of delayed union may not require intervention because with more time, the bone will heal. Other cases of delayed union may require intervention to ensure a successful outcome and avoid a serious complication from happening.

Non union

Failure of the bone to heal is called non union. This occurs when the bone has stopped healing and there is no possibility that it will progress to union without intervention. In reality, differentiating non union from delayed union can be very difficult. Delayed bone union is when the bone takes longer than anticipated to heal; this becomes non-union when there is no progress at all in bone union over at least 2 serial radiographs or 2 to 3 months. Non unions can have two different biological types:

Viable / Reactive / Vascular / Biologically active non unions occur when callus forms with cartilage / fibrous tissue at the fracture site but the bone has not healed. There are three types i.e. hypertrophic, moderately hypertrophic and oligotrophic non-union. Viable non unions usually develop because of excessive movement at the fracture site, therefore the most important aspect of treatment is reestablishing fracture stabilisation. If possible, the bridging callus is not disturbed as this will contribute to healing and stability. However, if fracture reduction or alignment is poor, this must be corrected i.e. - the callus must be incised and it may be advisable to resect the bone ends, apply bone graft and compress the fracture.

Non-viable / Non reactive / Avascular / Biologically inactive non unions are characterized by failure of bone healing with lack of callus formation. Fortunately non unions are not common as this complication can be very difficult to manage successfully. The four types of non-viable non unions include avascular, defect, necrotic and the common end stage, atrophic. Characteristic radiographic features of non-viable non unions include no callus bridging the fracture gap, the sealing of at least one medullary, the ends of the fractured bones become, sclerotic and rounded, the adjacent bones may be osteopaenic and sequestra may be present

Non-viable non-unions will not heal unattended and require need revision surgery to correct. Treatment typically involves resecting the fibrous tissue that spans the fracture gap, freshening and opening the medullary canal either by drilling / reaming or osteotomy, and applying bone graft to maximize healing. Stabilisation is usually either by compression across the fracture gap using a Dynamic Compression Plate, or circular ESF.