Surgery Guide

The Essentials of Fracture Management

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Fracture management is a complex topic and it is of paramount importance that surgeons have a good understanding of the principles before attempting surgical fixation of any fracture. This surgery guide offers insight into the essential considerations around the subject of fracture management.

Contents

Stabilising the Trauma Patient

Assessing and stabilising the patient is the first critical step in fracture management. Failure to do this can result in a patient that is suffering, is painful, or may even die.

Ensure the fracture patient is stable. Checklist would include:

- Airway.
- Breathing.
- Circulation.
- Biochemistry, Haematology & Electrolytes.
- Thoracic X-rays and/or thoracic ultrasound (T-FAST).
- Abdominal X-rays and/or ultrasound (A-FAST).

Stabilise the patient if not stable, to include:

- Oxygen therapy.
- Manage shock; fluid resuscitation.
- Give analgesia: usually Opioid, Paracetamol, or NSAID (if perfusion is adequate).
- Flush and dress wounds as necessary.
- For fractures distal to the elbow or stifle, apply a dressing to control swelling & stabilise the fracture.

Radiography

1.

Once the patient is stable, under heavy sedation or general anaesthesia; obtain orthogonal radiographs of the fractured limb. The radiographs should:

- Be good quality.
- Be well exposed.
- Be well collimated.
- Include the whole of the fractured bone including the joints above and below.
- Be orthogonal radiographs, i.e., at 90 degrees to each other i.e. mediolateral and craniocaudal, dorso-palmar or dorso-plantar.
- Include a scale marker.

2.

Obtain orthogonal radiographs of the contralateral un-fractured limb, for comparison.

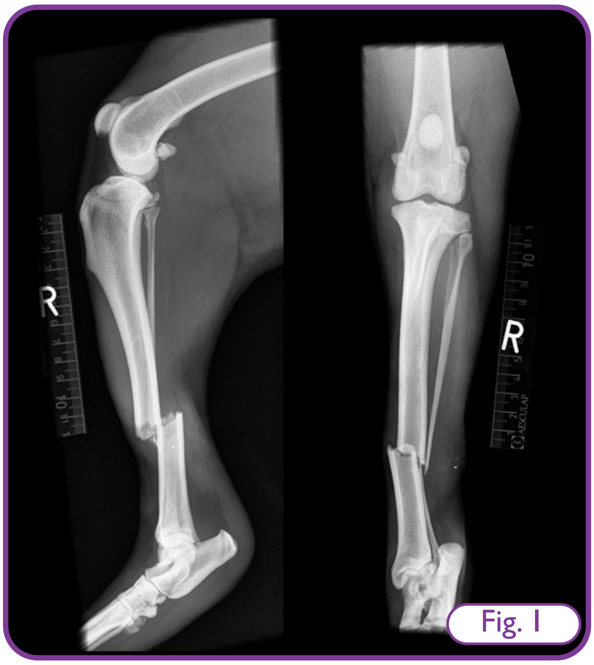


Fig. 1

Fig. 1 shows a good example of orthogonal radiographs: orthogonal views; well positioned, exposed and collimated; scale and L/R markers are included.

3.

Standard radiographs are perfectly adequate in the majority of cases. In the minority of cases, CT is advantageous as a full interpretation/diagnosis may not be possible from radiographs alone. For example, fractures that would benefit from CT include:

- Pelvis, including acetabulum.
- Hock.
- Elbow condylar fractures.
- Carpus.
- Skull.
- Fractures with fissures where it is unclear where the fissure ends, and whether the fissure is communicating directly with a joint.
- Articular fractures.

4.

Take your time to look at the radiographs properly, interpret them carefully, classify the fracture, and formulate your fracture fixation treatment plan.

Classifying the Fracture and Decision Making

There are a number of different ways of classifying a fracture. These are outlined below. Correct clasification of a fracture is the first and critical step to appropriate decision making for successful fracture management.

Classifying the Fracture - Which Part of the Bone is Fractured?

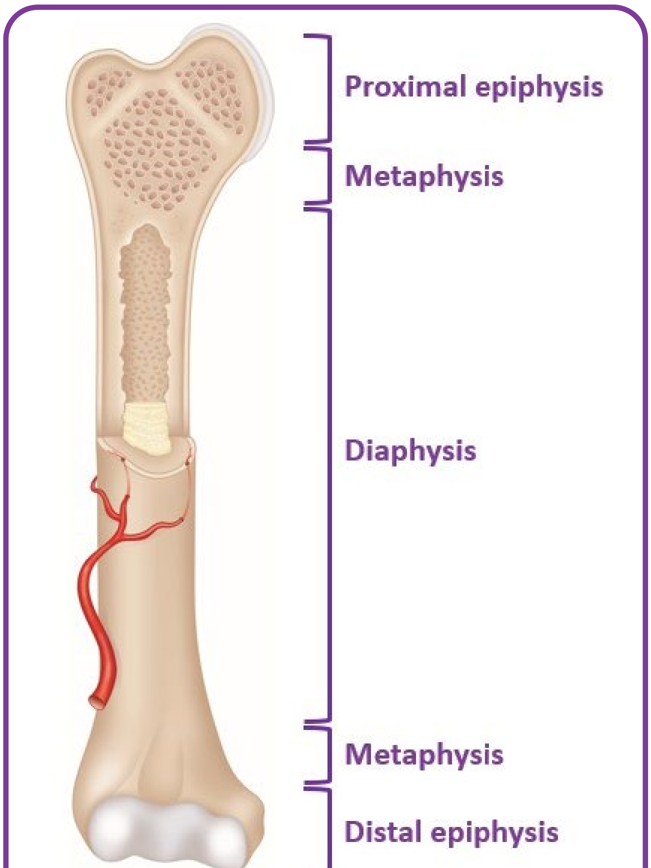


Fig. 2

Fig.2 shows the anatomy of the bone with the 4 main regions highlighted.

Physeal fractures: these are classified by the "Salter-Harris" system. This is a physeal fracture classification system that is helpful in determining prognosis in humans (children). In small animal orthopaedics, the system is more helpful to guide fracture repair decision making:

Salter-Harris type 1 & 2 fractures are simple physeal fractures; these are typically repaired using crossed K-wires, or rush pins.

Salter-Harris type 3 & 4 fractures have an articular /epiphyseal component. These require perfect apposition and alignment and compression across the epiphysis.

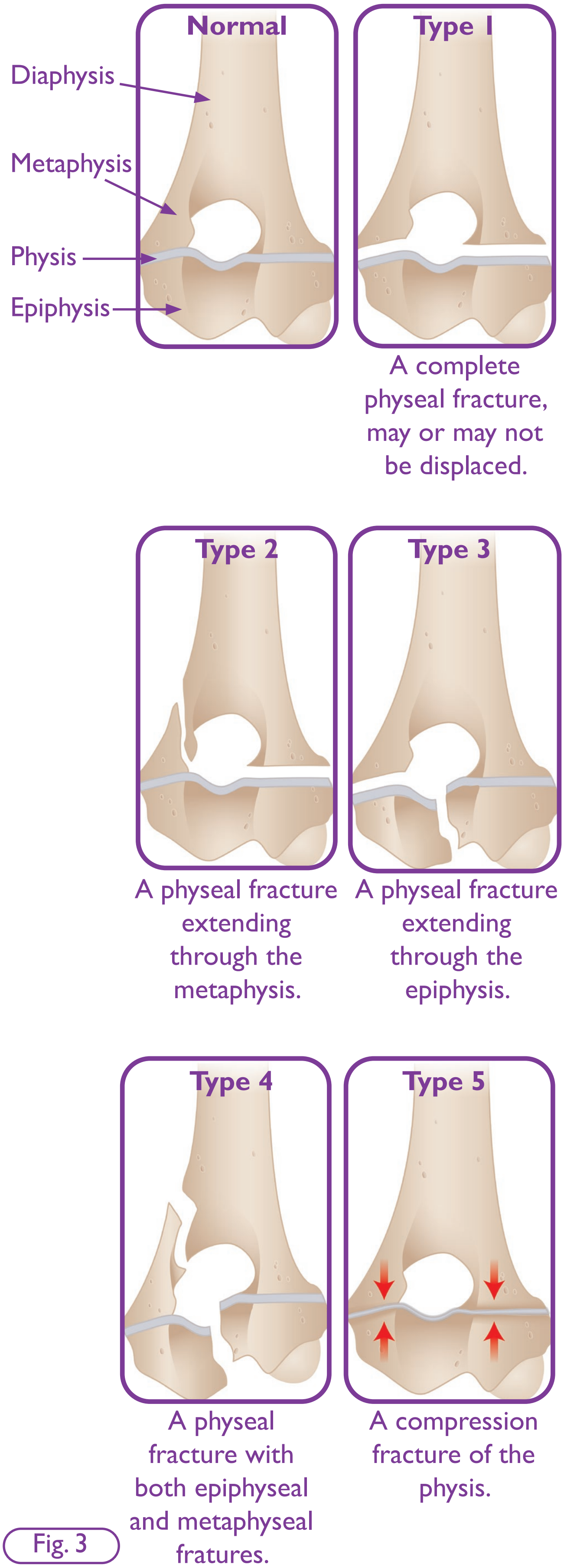


Fig. 3

Fig. 3 illustrates the Salter-Harris classification of physeal fractures.

Apophyseal fractures: these are typically avulsion fractures of apophyseal bone at the insertion point of a tendon or ligament, and usually occur in skeletally immature patients through the weaker physeal cartilage (compared to bone). The most common example is the tibial tuberosity avulsion fracture of Staffordshire Bull Terrier puppies; other examples of apophyseal fractures include avulsion fractures of the olecranon, or greater trochanter fractures.

Fig. 4

Fig.4 shows a tibial tuberosity avulsion fracture in a SBT puppy.

Articular fractures: these can be very challenging to repair. For optimal outcome, they require a number of criteria to be satisfied perfectly:

- Articular fracture repair should be completed as soon as possible, and ideally within 5 days.
- Perfect reduction and alignment is essential: a step of even 1mm in the articular surface can lead to degenerative joint disease and sub-optimal joint function.
- Compression of the articular fracture is essential; this is to ensure the bone heals by primary bone union rather than callus. Callus would be disastrous to the congruity and smooth movement and functioning of the joint.

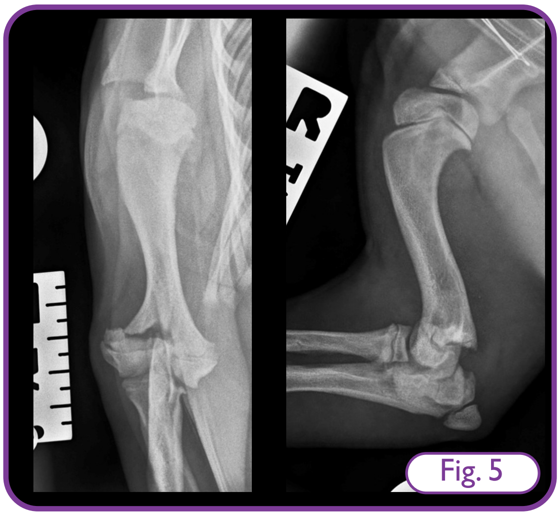


Fig. 5

Fig.5 shows a condylar fracture which is the most common presentation of articular fracture.

Diaphyseal fractures: These are the most common and are either simple or comminuted:

Simple fractures: there is one fracture line and two pieces of bone. In general, these fractures can and should be reconstructed, and compressed to achieve primary bone union. This means there is "load-sharing" between the bone and the implant, which means the implant is less likely to fail prematurely.

There are three types of simple fractures:

(Simple) Transverse fractures: the fracture line is 90 degrees (perpendicular) to the long axis of the bone, or more precisely: the fracture line is orientated 30 degrees or less from the perpendicular. Transverse fractures should be axially compressed e.g. with a Dynamic Compression Plate.

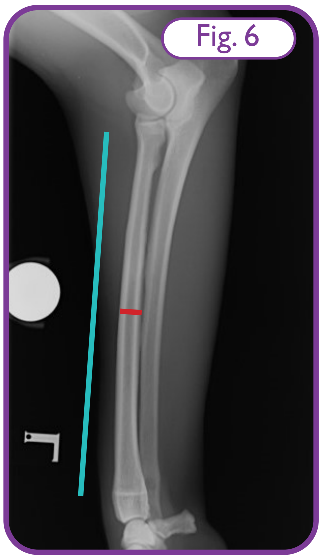


Fig. 6

Fig. 6 shows the axes of the bone; the long axis (light blue) and the perpendicular (red). A transverse fracture is aligned 30 degrees or less from the perpendicular.

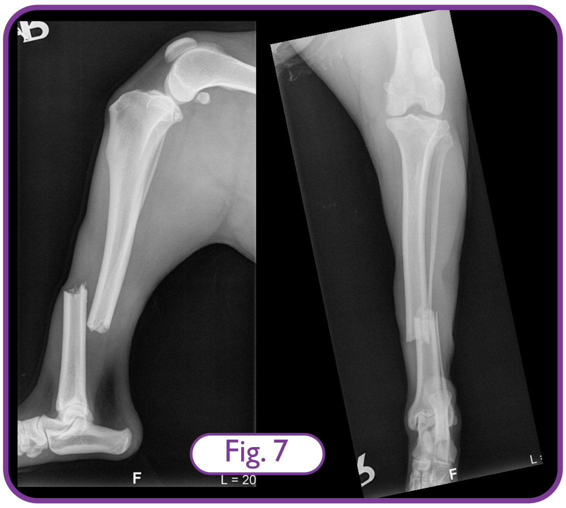


Fig. 7

Fig. 7 shows a transverse fracture of the distal tibial diaphysis.

(Simple) Oblique fractures: Oblique fractures are oriented 30 degrees or more from the perpendicular to the long axis of the bone. Oblique fractures cannot be axially compressed, as the fracture ends would shear against each other. Instead, oblique fractures are:

- Compressed; usually with lag screws, or with bone holding forceps then positional screws, or with cerclage wires, and:
- A neutralisation device is placed, usually a plate. An intramedullary pin can be used as a neutralisation device for a long oblique fracture compressed with cerclage wires.

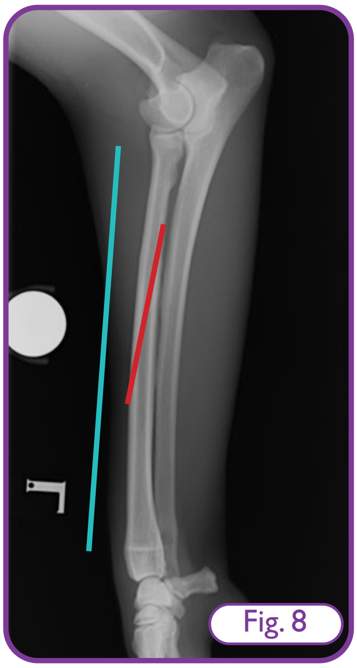


Fig. 8

Fig. 8 shows an oblique fracture (red), which is more than 30 degrees from the perpendicular to the long axis (light blue).

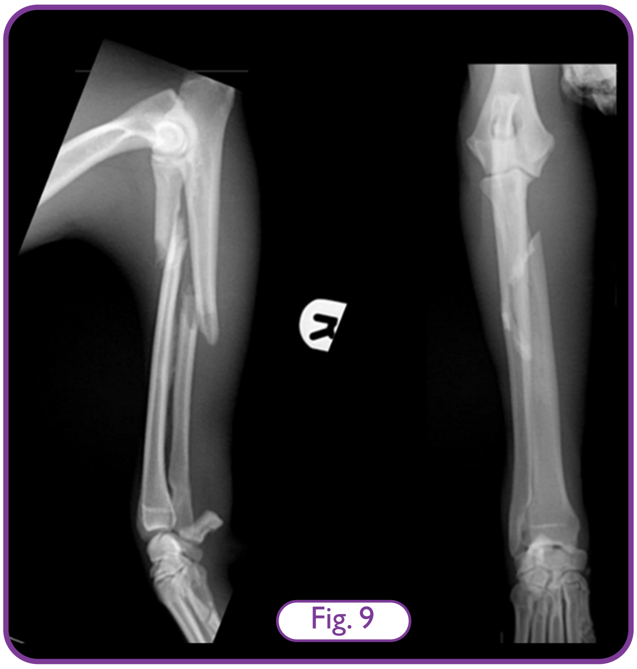


Fig. 9

Fig. 9 shows oblique fractures of the proximal radius and proximal ulnar diaphysis.

(Simple) Spiral fractures: these are a special type of oblique fracture where the oblique fracture "spirals" up/down and around the cortical diaphyseal bone. This is seen on radiographs when an oblique fracture can be seen on both orthogonal views i.e., an oblique fracture is seen on the craniocaudal and the mediolateral view. The principles of stabilising a spiral fracture are the same as for an oblique fracture i.e. direct compression **and** a neutralisation device.

A spiral fracture is the lowest "energy" type of fracture i.e. it is caused by low forces. Pathological fractures often manifest as spiral fractures; when a spiral fracture occurs (particularly if there was no or very low trauma involved) it is worth inspecting the X-rays carefully and looking for pathology e.g. a bone tumour or cyst.

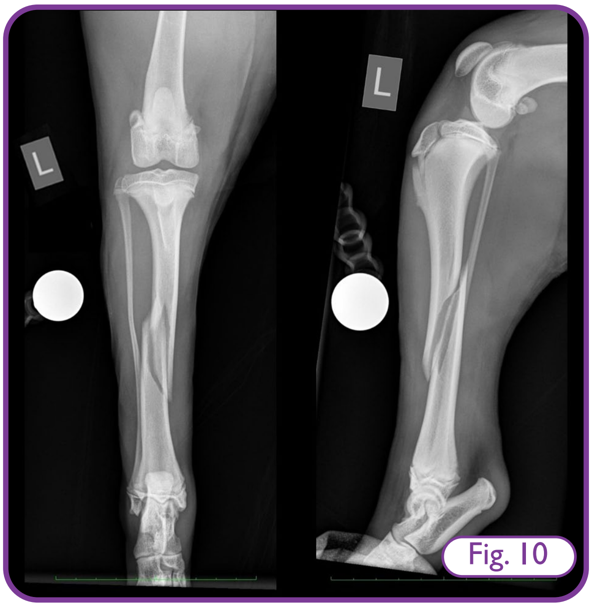


Fig. 10

Fig. 10 shows a spiral fracture of the distal tibial diaphysis; this is seen as an oblique fracture in both views.

Comminuted fractures: there are two or more fracture lines, and therefore three or more separate pieces of bone. The fracture can be classified as mildly, moderately, or severely comminuted, depending on how badly comminuted the fracture is. The more pieces of bone, the more severely comminuted the fracture is.

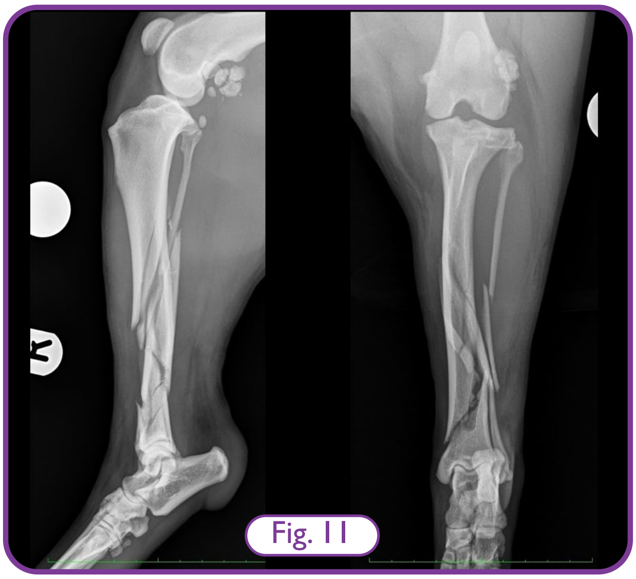


Fig. 11

Fig. 11 shows a moderately comminuted tibial fracture with adjacent segmental fibular fracture.

The more comminuted a fracture is:

- The more energy was impacted onto the bone, causing the fracture. The surrounding soft tissue will be similarly traumatised by high energy. If the soft tissue is seriously traumatised, so is the blood supply to the bone. If the blood supply to the bone is damaged, the potential of the bone to heal is compromised, i.e. healing may be delayed.
- The lower the likelihood it can be successfully reconstructed. Additionally, the less desirable it is to spend time painstakingly reconstructing the fracture with implants, as perfect reconstruction (and therefore load-sharing) becomes increasingly impossible. To attempt such reconstruction means the surgeon causing lots of additional damage to the bone and soft tissue attachments. To inflict this additional biological trauma (without gaining the mechanical advantage of bone-implant load-sharing) is detrimental.
    - To avoid such additional biological damage, the surgeon must make an early decision whether attempting reconstruction is justifiable or not. As a general guide, if there are four or more pieces of bone, the fracture is non-reconstructable.

If a comminuted fracture is reconstructable, the task is divided down into multiple simple fractures (transverse, spiral or oblique) as described above, and each one is reconstructed step by step. This can be very challenging and is often prone to failure. It is usually better to classify a comminuted fracture as non-reconstructable as early as possible.

Once a comminuted fracture is classified as non-reconstructable, the decision is made to "bridge" the fracture. A "bridging" construct is attached only to the proximal and distal segments of the bone, and bridges the comminuted fracture in between. The "look-but-do-not-touch" principles are applied to the comminuted fracture; this is to preserve the fracture haematoma, minimise further bone and soft tissue trauma by the surgeon, and therefore maximise the chances of bone healing without complication. There are several types of bridging construct:

- Plate-rod construct: an intramedullary pin combined with a "bridging" plate.
- Interlocking nail.
- External Skeletal Fixator.
- Orthogonal plating (two plates applied to the same bone).
- Double plating (two plates applied to adjacent bones e.g. radius and ulna).

Classifying the Fracture - Complete or Incomplete Fracture?

A complete fracture is one in which there is a full fracture with displacement. This is the most common type of fracture, particularly in adult patients. Incomplete fractures can also occur, although they are much less common. Typically, there are two types of incomplete fractures:

- Greenstick fractures; these happen in skeletally immature puppies and kittens because young bone is more elastic and not as brittle as adult bone; it can bend without creating a full fracture or "crack". Such fractures can often be managed conservatively.
- Fissures in adult patients; a fissure is a "crack" in the bone; commonly a fissure will extend from a complete diaphyseal fracture peripherally to the cortex, or the epiphysis. Pre-operative radiographs should be examined carefully for fissures as failure to recognise these can result in the surgery making the fissures worse by splitting them open; instead the surgery should aim to control the fissures by placement of lag screws, positional screws, or cerclage wires.

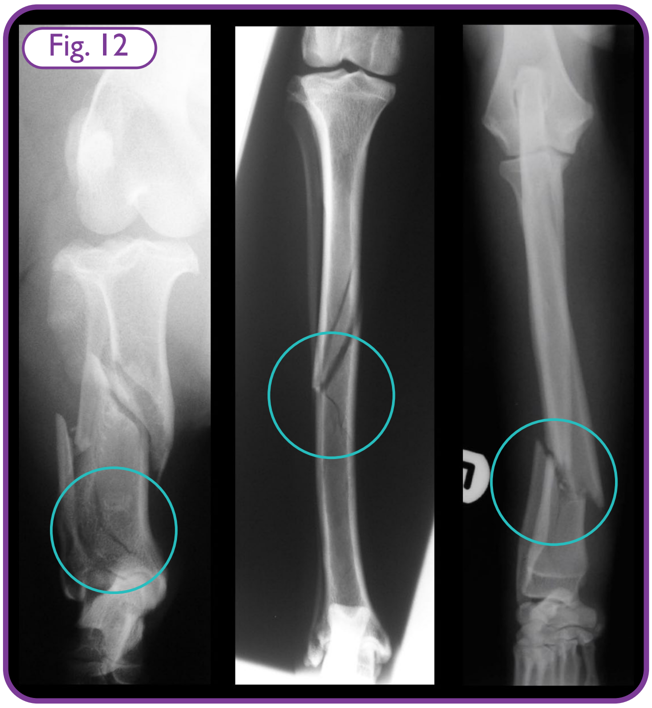


Fig. 12 shows 3 different examples of fissures visible on pre-operative X-rays.

Classifying the Fracture - Open/ Closed Fracture?

This defines whether the skin barrier is broken i.e. if the fracture directly communicates with the outside world or not. Most fractures are closed i.e. there are no skin wounds, and the fracture environment is not contaminated and not infected.

Open fractures are graded by the Gustilo Anderson classification system. The grading system helps to assess the degree of soft tissue injury, contamination, and therefore risk of complications:

- Grade 1: A clean wound less than 1cm in length.
- Grade 2: A wound 1-10 cm in length without extensive soft tissue damage.
- Grade 3: A wound more than 10cm in length and/or extensive soft tissue damage.
- Grade 3a: Adequate periosteal cover is present.
- Grade 3b: Extensive soft tissue loss, periosteal stripping & bone damage.
- Grade 3c: Arterial injury needing repair.

All open fractures require treatment as contaminated wounds, to include antibiotic coverage; usually starting with a 1st generation cephalosporin; until Culture & Sensitivity results are received.

Theoretically, grade 1 open fractures can be treated as closed fractures i.e. no need for prophylactic antibiotics.

Grade 3 injuries are uncommon in small animal orthopaedics. Injuries up to and including grade 3a can be treated with local soft tissue wound management. Grade 3b & 3c require more aggressive surgery i.e. free/rotational flap repair, and vascular repair respectively.

Classifying the Fracture - Soft Tissue Swelling?

Soft tissue swelling can be classified as mild, moderate, severe: this gives an indication of how much trauma the bone /limb/patient suffered i.e. how much energy was involved. More energy means more severe soft tissue swelling, more damage to blood vessels and blood supply, and usually a more comminuted fracture.

More swelling = more energy = more soft tissue damage = more disruption to bone blood supply = slow/more complicated fracture healing.

Classifying the Fracture - Fracture Over-Riding?

Fracture over-riding; in the proximal-distal direction. More over-riding usually means harder work for the surgeon to distract the fracture fragments during surgery. This information can be used to plan ahead e.g. use a "hanging-limb" preparation prior to surgery, and/or consider using an intramedullary pin during surgery to ease bone distraction.

Classifying the Fracture - Fracture Displacement?

This describes in which direction the distal segment of bone has moved to relative to the proximal.

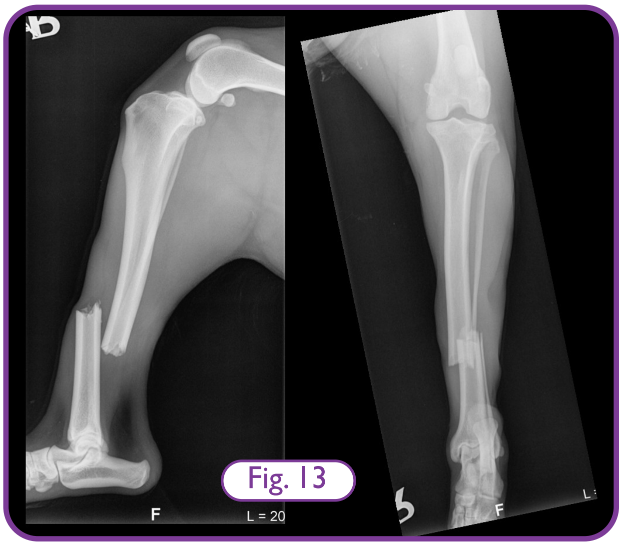


Fig. 13 shows distal tibial fracture with moderate soft tissue swelling and mild over-riding, also cranial and lateral displacement of the distal tibial segment relative to the proximal.

Classifying the Fracture - Cause of the Fracture?

Most fractures are caused by extrinsic (external) causes i.e., some sort of trauma. A minority of fractures are caused by intrinsic causes i.e. no external cause. These are usually:

- Physeal fracture in puppies and kittens (internally generated forces of locomotion); this happens as the physis is made of cartilage, and therefore relatively weak compared to the bone so can fracture with minimal trauma e.g. an awkward fall.
- Pathological fractures i.e. those caused by bone tumours, bone cysts, or metabolic bone disease causing bone weakening e.g. nutritional or renal secondary hyperparathyroidism.

Bone Healing

Bone healing is a complex event that can be influenced by a number of factors; some of these factors are directly influenced by the surgeon who has a responsibility to positively affect fracture healing; poor surgical technique and choices are likely to result in worsened fracture healing.

Factors that influence bone healing are considered together to reach a Fracture Patient Assessment or Fracture Healing Score. This gives an indication of how likely the fracture is to heal with or without a complication. Mechanical, Biological and Clinical factors are considered separately:

Mechanical Factors

These include:

- How big is the patient? (Smaller is better).
- How many limbs are injured? (Less is better).
- Is the fracture reconstructable or not? (Reconstructable is better).

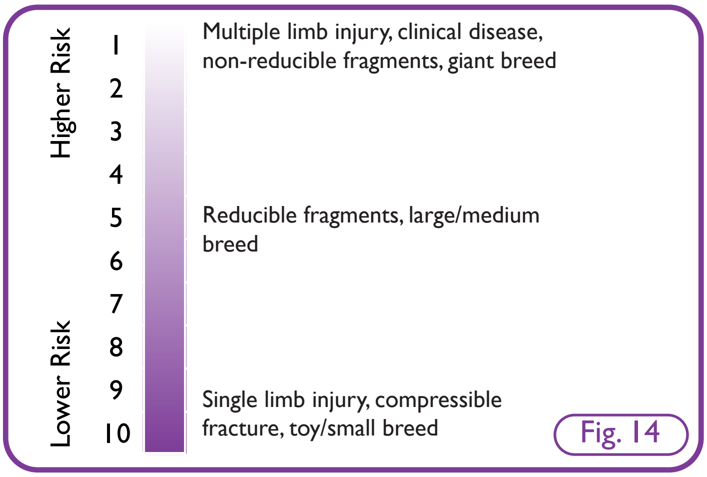


Fig. 14 illustrates the mechanical factors that influence the Fracture Healing Score.

Biological Factors

These include:

- Age of patient? (Younger is better).
- Is concurrent disease present? (No disease is better).
- Is soft tissue cover available? If so, how much? (More soft tissue cover is better).
- Energy of fracture? (Low is better).
- Cancellous vs cortical bone involvement? (Cancellous is better).
- Surgical approach? (Non- to minimally-invasive is better than full open).

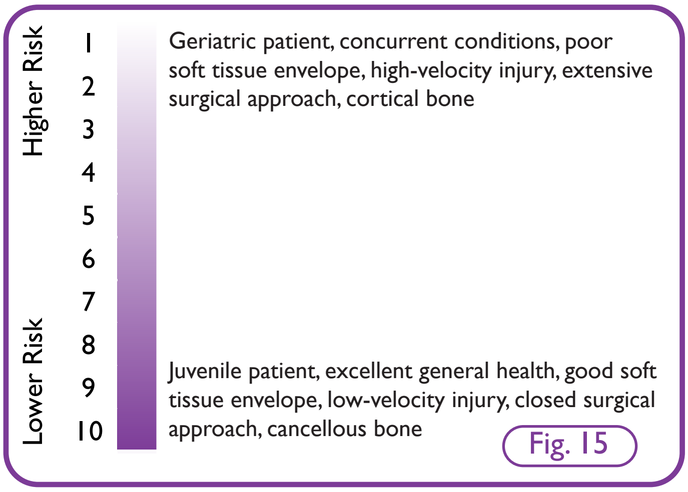


Fig. 15 illustrates the biological factors that influence the Fracture Healing Score.

Clinical Factors

These include:

- Patient temperament? (Calm/well behaved is better).
- Owner compliance? (A compliant owner is better).

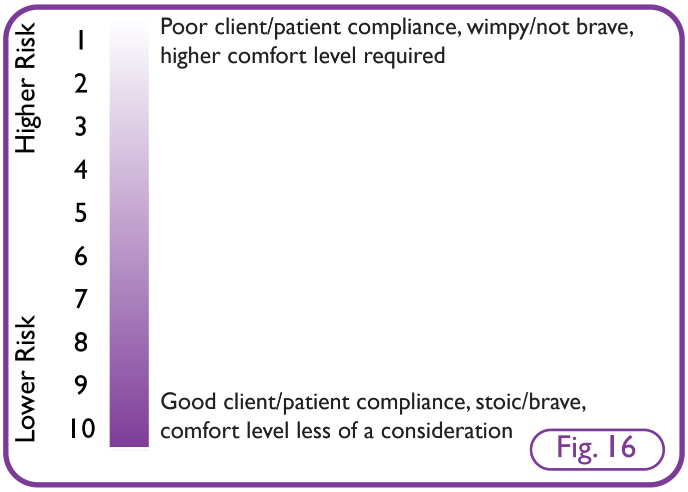


Fig. 16 illustrates the clinical factors that influence the Fracture Healing Score.

The Mechanical, Biological and Clinical factors are combined to create an overall "Fracture Patient Assessment" score, or a "Fracture Healing Score". The cumulative score takes account of all factors and gives an overall indication of the likely healing potential. A low overall score is a higher risk patient. A high overall score is a lower risk patient.

The higher the fracture healing score, the more likely the fracture is to heal without a complication. The lower the fracture healing score, the more likely the fracture is to suffer a complication rather than heal successfully.

The risk of complication needs to be mitigated by the surgeon and accounted for in the treatment/surgical plan. Fractures with low healing scores could be considered as such:

- Not using linear external fixation as pin tractcomplications are very likely to develop (with time) prior to the bone healing (which will be slow).
- Upgraded internal fixation to withstand the increased forces of weight bearing for the extra period of time taken for slow bone healing e.g. choosing orthogonal plating or plate-rod constructs.

Bone healing physiology: bone can heal by two distinct biological processes ie. primary or secondary bone healing. In the clinical patient, a blend between the different processes can occur. Which type of bone healing process will occur depends on:

- The type of fracture: simple or comminuted.
- Whether the fracture is reconstructed or not.
- How much movement there is at the fracture site. This depends on the stiffness of the fixation construct and whether the fracture is reconstructed or not.

Primary bone union: the bone heals by Haversian remodelling across the fracture line. Haversian remodelling is the remodelling of bone that naturally occurs every day in response to normal weight bearing. Haversian remodelling is a very slow process.

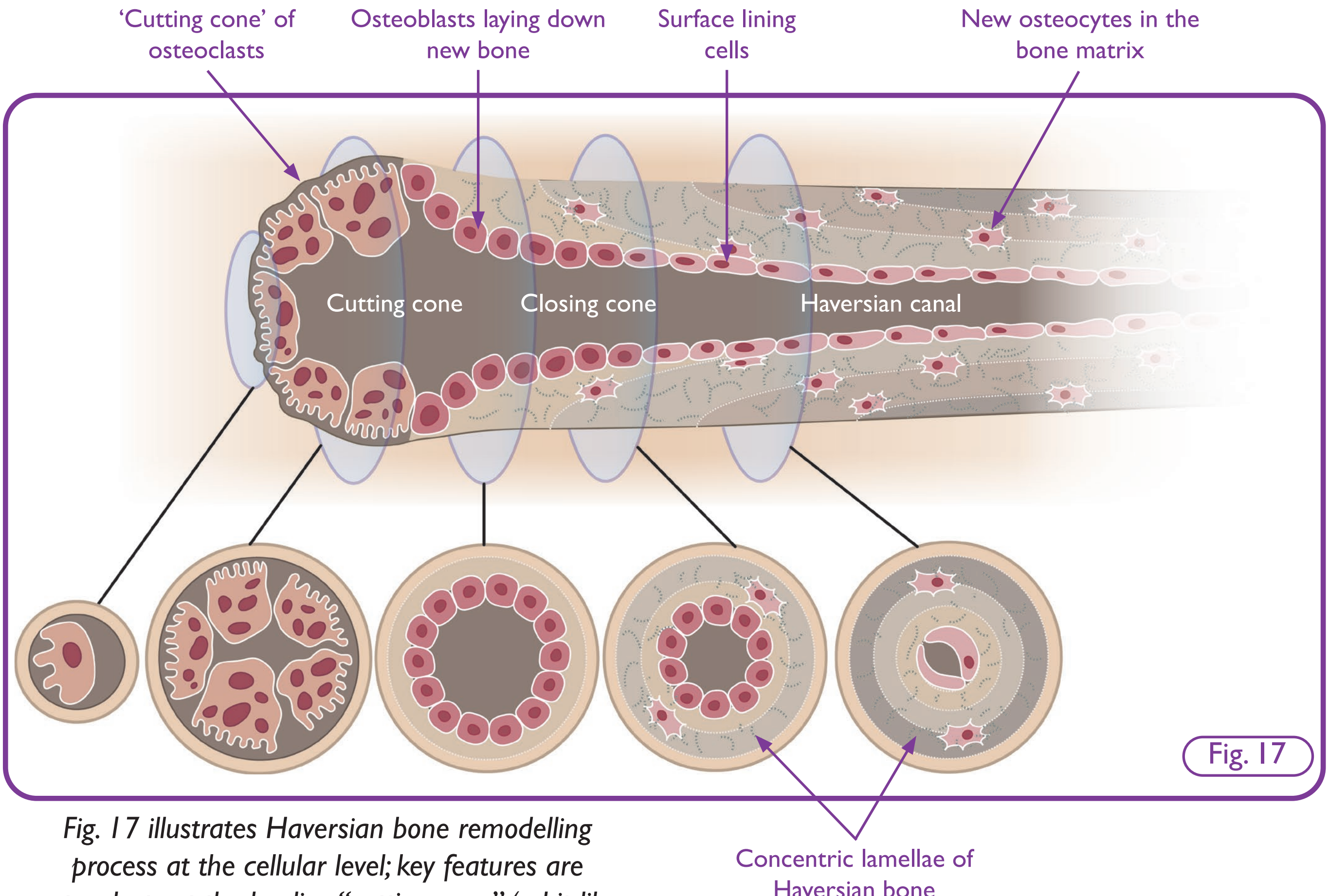


Fig. 17 illustrates Haversian bone remodelling process at the cellular level; key features are osteoclasts at the leading "cutting cone" (a bit like a tunnel-boring machine) and osteoblasts in the trailing "closing cone" (filling in after cutting).

Contact healing occurs when:

- The bone is in perfect contact with minimal gap (less than 0.01m) at the fracture site.
- The fracture is rigidly stable; this means no movement at the fracture gap.

Contact healing is typically achieved when a simple fracture is perfectly reconstructed and compressed i.e.

- A transverse fracture. A dynamic compression plate is applied, the plate is contoured and pre-stressed, and at least one screw is placed in axial (dynamic) compression.
- An oblique or spiral fracture. The fracture is compressed with lag screws, and a contoured neutralisation plate is applied.

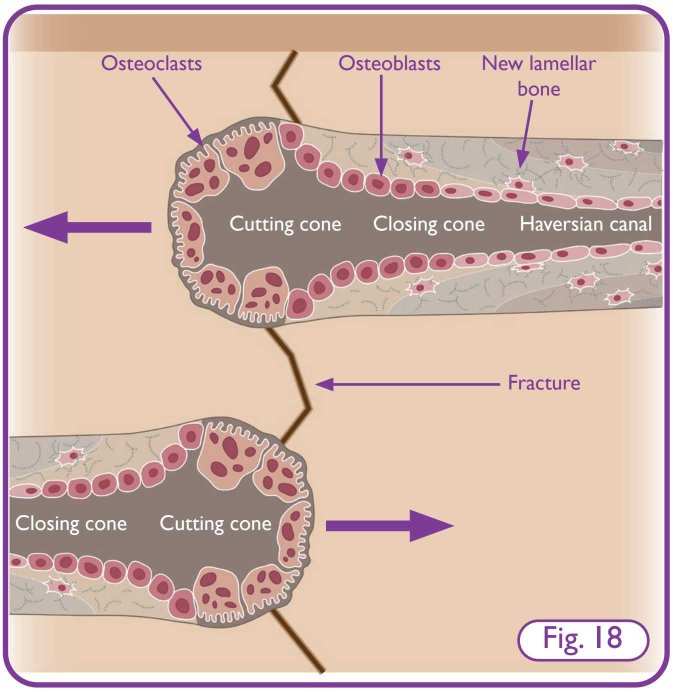


Fig. 18

Fig. 18. shows primary bone union/contact healing occurring across a fracture that is perfectly reduced with no gap, and rigid with no movement. Haversian remodelling occurs across the fracture.

It is important to realise with contact healing, when post-operative and follow-up X-rays are taken, no change is seen at the fracture site. The post-operative X-rays show no gap; follow-up X-rays show no change.

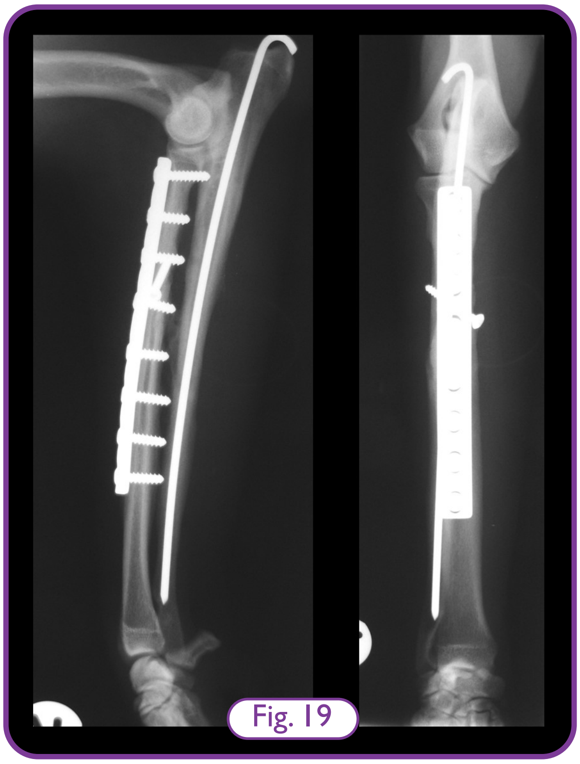


Fig. 19

Fig. 19 shows 6 week post-op radiographs demonstrating direct primary (contact) bone healing of an oblique radial fracture that has been repaired with a lag screw and a cranial neutralisation plate. At 6 weeks post-op, the fracture site is unchanged in appearance compared to immediately post-op.

Gap healing is a process whereby lamellar bone is initially laid down perpendicular to the long axis of the bone i.e. in the wrong direction, therefore it is weak. Subsequently this lamellar bone is (slowly) remodelled by Haversian remodelling.

Gap healing occurs when:

- A small gap of 0.01 to 1mm exists at the fracture site.
- There is absolute stability at the fracture site i.e. gap strain is less than 2%.

When a fracture heals by gap healing, a small gap is initially seen on the immediate post-operative radiographs; as time passes, this gap gradually disappears on subsequent follow-up radiographs.

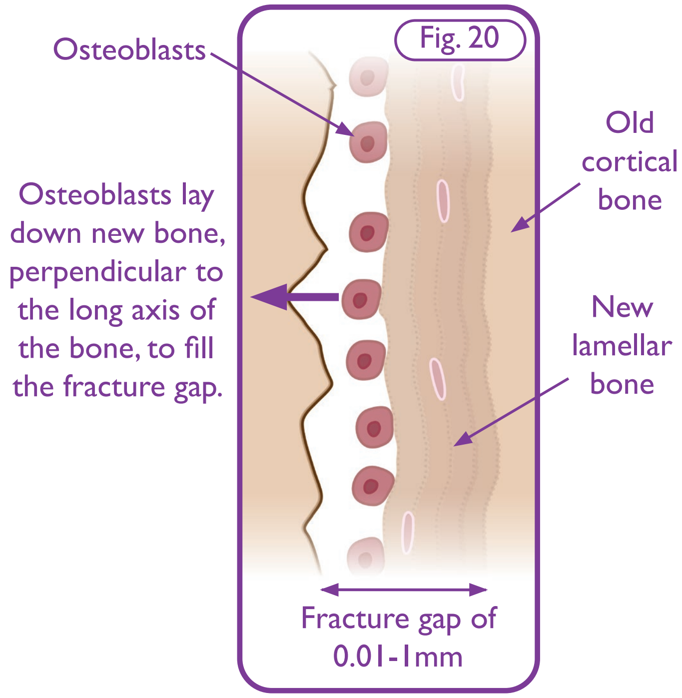


Fig. 20 illustrates the process of gap healing; the orientation of this lamellar (layered) bone is initially inappropriate; but subsequently with time, this is correctly remodelled by Haversian remodelling.

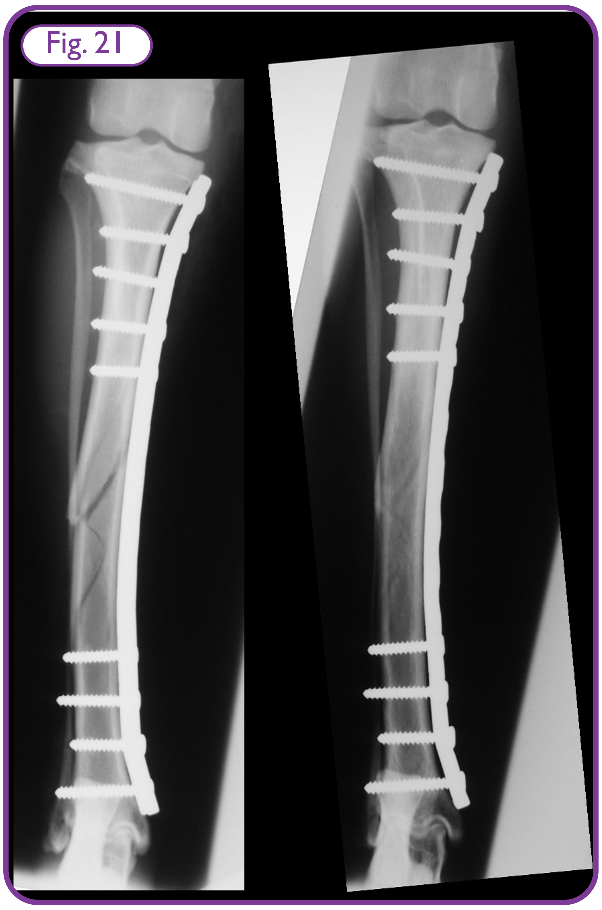


Fig. 21 shows a mid tibial diaphysis fracture healing by gap healing (primary bone union). The image on the left shows a gap at immediate post-operative X-rays; the image on the right is 6 weeks later post-op; the gap can be seen to be disappearing. There is no callus.

Secondary bone healing (callus):
Callus is a complex transformation of tissue types at the fracture site; it starts with fracture haematoma and ends with healed bone. Each phase is not distinct; rather a slow overlap of multiple phases, with a gradual transformation from beginning (fracture haematoma) to end (remodelled new bone) in this order:

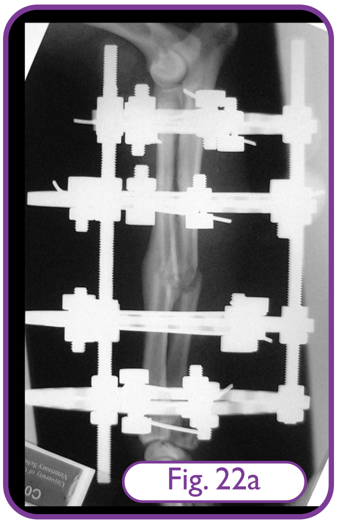
- The bone fractures and bleeds.
- The fracture haematoma releases multiple growth factors that start the process of bone healing.
- Cells are recruited and differentiation starts.
- Granulation tissue forms.
- Fibrous tissue forms.
- Cartilage forms.
- Bone forms; not organised and relatively weak.
- Remodelled bone forms i.e. organised and strong cortical and cancellous bone.

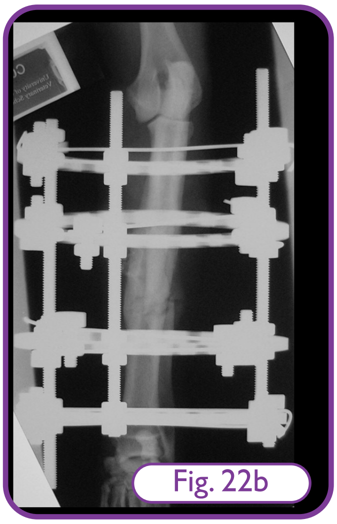
Conditions for secondary bone union (callus healing) include:

- A fracture gap of more than 1mm.
- Instability of the fracture gap may be more than gap strain of 2% initially, but as the callus matures, it becomes stronger and stiffer which limits movement at the fracture site; gap strain reduces to less than 2% and bone is successfully formed.

A fracture that is not reconstructed and has minor instability at the fracture gap will heal by callus formation. Examples would include:

- A fracture that is not reconstructed.
- A facture that is stabilised with:
    - An external skeletal fixator.
    - A plate-rod construct (IM pin & plate).
    - An interlocking nail.





Figs. 22a and b show secondary (callus) bone healing; a mid radius and ulna diaphyseal fracture has been stabilised with a circular ESF. At 6 weeks post-op, a "ball" of mineralised tissue is visible overlying each end of the bone and the ends of the bone are gradually "disappearing" into the ball of mineralised tissue; this is callus bone healing.

Speed of Bone Healing

Secondary bone healing (callus):
Primary bone union is slow, so implants cannot be removed for a relatively long time until bone healing and remodelling is complete.

Secondary bone union is faster, so implants (or ESF) can be removed sooner. However, callus is disadvantageous in certain types of fracture e.g. spinal fractures and articular fractures.

Age of Animal	Primary Bone Union 1. Axial compression (DCP) 2. Lag screws & neutralisation plate	Secondary Bone Union (callus) 1. ESF 2. Plate-Rod 3. Interlocking nail
<3 months	4 weeks	2-3 weeks
3-6 months	6-12 weeks	4-6 weeks
6-12 months	12-16 weeks	5-8 weeks
>1 year	16-30 weeks	7-12 weeks

Fig. 23

Fig. 23 illustrates the types of bone healing that occur, and average/approximate healing times in dogs and cats for different patient age groups.

Problems of Fracture Management

Multiple problems can occur with fracture healing. These include:

- Wound breakdown.
- Superficial surgical site infection (not involving implants).
- Deep surgical site infection (involving implants).
- Implant failure (breakage or bending).
- Implant loosening.
- Failure of the bone to heal at all = non-union.
- Failure of the bone to heal within expected time = delayed union.
- Bone does not heal in correct alignment = malunion.

More commonly than not, the reason for these failures is surgical technique and/or under-estimation of the fracture by the surgeon and failure to use correct or sufficiently robust implants.

Other reading material:

- Surgery Guide - Linear External Skeletal Fixation
- Surgery Guide - Fixation of long bone (diaphyseal) fractures using non-locking plates and screws.
- Surgery Guide - Fixation of long bone (diaphyseal) fractures using locking plates and screws.

With thanks to Gareth Arthurs PGCertMedEd MA VetMB CertVR CertSAS DSAS(Orth) FHEA FRCVS RCVS Recognised Specialist in Small Animal Surgery (Orthopaedics) for his invaluable assistance with this Surgery Guide, new for 2023.

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