AOVET North America

Principles in Small Animal Fracture Management

LECTURE ABSTRACTS

Columbus, OH
April 16-19, 2015
AOVET North America

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THURSDAY LECTURE ABSTRACTS
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Fracture Classification and Biomechanics

Noël M.M. Moens DVM, MSC, Dipl ACVS/ECVS
Fracture Classification and Biomechanics
Noël M.M. Moens DVM, MSC, Dipl ACVS/ECVS

Learner Objectives:

- Accurately describe a long bone fracture
- Describe Unger’s classification and the reason for its development
- Recognize the different forces acting on a fracture and have a basic understanding of the different fracture patterns generated by those forces
- List the different forces acting on a fracture and be able to select a fixation method that addresses those forces
- Explain the concept of viscoelasticity and anisotrophy
- Recognize high and low energy fractures and explain the biomechanical and biological consequences associated with each
Fracture Classification and Biomechanics
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University of Guelph

There are two types of force act on bones: Intrinsic and extrinsic. **Intrinsic forces** are static or dynamic. They are usually limited in magnitude and limited as for their orientation. Intrinsic forces are transmitted by tendons, ligaments and joint surfaces. **Extrinsic forces** originate from outside the body. There is no limitation in their orientation and magnitude. Although intrinsic forces are capable of causing fracture, extrinsic forces are usually responsible for most fractures.

The effect of a force on a bone can be measured and recorded in a **Load/Deformation** graph. These graphs generally consist of a straight portion called “elastic phase”, followed by the yield point and a short “plastic phase”, during which the bone permanently deforms before catastrophic failure. The slope of the elastic portion of the curve represents the stiffness of the bone and the area under the curve is the amount of energy absorbed by the bone before fracture. It is expected that different bones or bones from different individuals will have different load / deformation curves. The curve can be standardized in order to represent the mechanical properties of the “bone” itself (as a material as opposed to a structure). These curves are known as the **Stress/Strain** curves.

The forces acting on the bones can be either basic or complex: There are three basic forces: **Tension**, **compression** and **shear**. They can be further subdivided into **normal forces** (acting parallel the long axis of the bone) and **shear forces** (acting at an angle relative to the long axis of the bone). **Bending** and **torsion** are complex forces and usually result from the combination of compression, tension and shear.
Bone is extremely resistant in compression but is weak in tension and shear. The difference in strength and stiffness of the bone relative to the direction of loading is called “anisotropy”.

Bone also reacts differently depending upon the rate of loading. This property is called “viscoelasticity”:

*Cortical bone that is rapidly loaded has a greater elastic modulus, greater ultimate strength, absorbs more energy before fracture and is more brittle than bone loaded slowly.*

A “low energy” projectile (i.e. gun pellet) will cause a simple or slightly comminuted fracture. A “High energy” projectile (i.e. bullet from a military rifle) will create a highly comminuted fracture and will generally be associated with greater soft tissue damage.

**Fracture classification**

Several classification methods were developed in the past. Some more useful than others, they all achieve the same basic purposes: Complete, precise description of the fracture. An accurate description of the fracture will generally provide important information about the major forces at play and provide important information about which method of fixation would be the most appropriate.

**Description of the fracture**

1) Bone involved
2) Location within the bone
   - Epiphyseal,
   - Physeal,
3) Complexity of the fracture
   - Fissure (incomplete fracture)
   - Simple (1 fracture line, 2 fragments)
   - Comminuted (more than one fracture line, connecting)
   - Segmental (more than one fracture line, not connecting)
   - Greenstick (incomplete fracture with plastic deformation of the bone)
4) Type of fracture (describe the orientation of the fracture line(s))
   - Transverse
   - Oblique
     - Short (<2Xbone diameter)
     - Long (>2Xbone diameter)
   - Spiral
   - Butterfly fragment
5) Displacement
6) Close / Open (type 1-3)

**Unger’s classification**

Each long bone is assigned a number:
- Humerus 1, radius/ulna 2, femur 3, tibia 4.

Each bone is divided into segments:
- Proximal 1, midshaft 2, distal 3.

Each fracture is given a letter as a measure of the severity:
- Simple A, wedge B, comminuted C.

Each group is then further subdivided into three degrees of complexity: 1, 2 and 3

Example: A diaphyseal fracture of the humerus with one reducible wedge (butterfly) fragment would be classified as “1 2 B1”

For successful fracture fixation, most forces acting on a bone must be counteracted and the main fragments must be stabilized. It is essential for the surgeon to understand which forces are acting on the fracture, to understand their direction and magnitude and to select the type and size of implant that will best suit his needs. Different implants have different abilities to counteract forces and should be selected accordingly.

Although reference tables are provided in the literature to help with the selection of the type and size of implants, those tables only provide rough guidelines and many factors, generally not included in those tables, should influence your selection. Some of those factors may be: age and health of the animal, activity of the animal, complexity of the fracture and ability to reconstruct the fragments, position of the plate on the bone, owner and client compliance, etc.
Failure to identify those factors pre-operatively will likely lead to disappointing results. Although one may be tempted to choose the strongest implant available, it is however
wise not to “overpower” the bone with the implant as stress protection may cause delayed healing and osteopenia. Soft tissue trauma, expected outcome, availability, cost, expertise and personal preferences also influence implant selection.

Ability of different implants to counteract forces:

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<th>Compression/Collapse</th>
<th>Rotation</th>
<th>Bending</th>
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Reference:

Bone Structure, Vascularity and Function

Kenneth A Johnson, MVSc PhD FACVSc Diplomate ACVS Diplomate ECVS
Learner Objectives:

- Describe how the gross and microscopic structure of bone facilitates the load carrying capacity of normal long bones
- Explain how the blood supply of bone can be compromised by fracture or open reduction and internal fixation
- Describe one clinically relevant example of how Wolff’s Law applies to bones in animals or humans
Bone Structure
The skeletal system provides support and protection for all the other body organs. It also acts as a reservoir for minerals, fat and haematopoiesis, and as levers and fulcrums for the musculature. The entire canine skeleton consists of about 319 bones that can be classified according to their shape as being long (limb), cuboidal (carpus and tarsus), flat (head and ribs), irregular (vertebrae and pelvis) and sesamoid bones. The shape of individual bones is largely under genetic control, but bone shape is also modified by loading. On a structural basis, bone is either cortical (compact) or cancellous (trabecular) and the mechanical and biological differences between these two have important implications for the holding power of orthopaedic implants and the rate at which fractures progress to union. Cortical bone is mainly found in the diaphysis and flat bones, but it also contributes a thin shell around the cuboidal and irregular bones such as the vertebrae. Cancellous bone is mainly found in the epiphyses and metaphyses of long bones and within the cuboidal bones. The internal three dimensional lattice work of trabeculae are aligned along lines of stress, and allow cancellous bone to best resist compressive loads.

At the microscopic level, bone is organized as either lamellar or woven bone. Woven bone is considered immature bone because it is present in the new born, but soon remodelled to lamellar bone. It is only present later in life at sites of fracture repair, bone growth, neoplasia and other bone diseases such as panosteitis. Woven bone is more cellular and isotropic when tested mechanically because the collagen fibres have a random orientation. Lamellar bone has collagen fibres that have parallel alignment, and mechanically it performs as an anisotropic material. In cancellous bone, the lamellae are aligned parallel to the direction of individual trabeculae. In cortical bone, the outer (periosteal) and inner (endosteal) regions consist of circumferentially orientated lamellar bone, called primary lamellar bone. Internal remodelling of cortical bone gives rise to more highly organized structures of osteons or Haversian systems. These have a central canal and circumferential layers of lamellae. The matrix of bone consists of 60-70% mineral and the rest is organic matter and water. The major collagen of bone is Type I, and this is unique because it permits deposition of hydroxyapatite crystals within interfibrillar pores, giving bone its unique structural properties.

Blood Supply of Bone
Blood supply, and its preservation during surgery, is of paramount importance to the outcome of orthopaedic procedures. Impairment of blood supply is a critical factor in the pathogenesis of osteomyelitis, ischemic necrosis, delayed union and non-union of fractures. Vascular damage can occur as a result of an initial traumatic injury such as fracture, during the surgical approach and exposure of the bone, from heat necrosis with drilling and sawing, and due to the application of implants such as bone plates. In the long bones, the three main sources of blood supply are:
- **Nutrient artery** that enters the medullary cavity through nutrient foramina in the diaphysis, and then branches into ascending and descending vessels that provide for endosteal blood flow to the cortex that is centrifugal in direction.

- **Metaphyseal vessels** provide blood supply to the cancellous bone in this region, and form anastomoses with terminal branches of the medullary vessels. In immature animals, there are separate arcades of multiple arterioles supplying the epiphyseal and metaphyseal bone, and these do not cross the cartilaginous growth plate. However, after closure of the growth plate, these become confluent as one system.

- **Periosteal vessels** also contribute to the blood supply of the outer 1/3 of the cortex in regions of muscle and fascial insertion. An example of this type of blood supply would be the linea aspera along the caudal border of the femoral diaphysis where the adductor muscles insert. In other regions of the cortex with only loose periosteal attachment, the supply of blood by centripetal flow is normally quite limited. However, the cortical bone vascularity has great plasticity, because when the nutrient artery has been destroyed by injury or surgery, there is reversal of blood flow to the cortex, and the periosteal vessels take over a greater role in centripetal flow of blood.
The flow of blood to cortical bone is about 2-7 ml/minute/gram of bone, and to cancellous bone is 10-30 ml/minute/gram of bone tissue. At the local level, flow is controlled by vasoactive substances. When systemic blood pressure falls below 80 mmHg, then flow of blood to cortical bone is temporarily shut down. The haematocrit of blood flowing through bone is not the same as in the central circulation. It can be in the range of 50-75%, and tends to be lower in regions of higher flow rates.

**Function**

The principle that the shape or form of bone is influenced by functional loading was embodied in the hypotheses put forward by Julius Wolff of Berlin, around 1892. **Wolff's Law** (as translated loosely from German) states that bone adapts its size and shape in response to the loads that are applied to it. Stated another way, bone is laid down where it is needed, and removed from sites where it is not. Although we recognize many exceptions to this law in orthopaedic practice, it is generally held to be correct. For example it was observed by Wolff and Koch that the organization of trabeculae in the human femoral head was similar to the mathematically calculated stress patterns in Culman’s crane.

The removal and reformation of bone, called **remodelling**, is due to the activity of osteoblasts and osteoclasts. All of this remodelling activity within bone occurs on pre-existing bone surfaces (trabeculae of cancellous bone, or under the periosteum or endosteum of the diaphyseal cortex), or by extension of internal vascular channels (osteonal remodelling of cortical bone). An example of this process is seen in the metacarpal bones of racing greyhounds that undergo an adaptive remodelling after racing on circular tracks in an anticlockwise direction. The left fifth and right second metacarpal bones are susceptible to fatigue or stress fractures in these dogs, due to the accumulation of microcracks caused by repetitive loading of these bones during racing. In dogs in which these bones undergo a functional adaptation before fracture, there is increased remodelling and thickening of the cortex which results in an increase in torsional strength. Similar adaptive remodelling occurs in the right central tarsal bone.
References:


Orthopaedic Implant Design and Performance

Simon C. Roe, BVSc, PhD, Diplomate ACVS
Learner Objectives:

- Describe the most important factors of implant design influencing their performance
- List the factors describing implant performance and mode of implant failure
- Recognize the impact of the surgeon compared to design on implant performance
- Explain the terms stress, strain, modulus, yield, ductility and brittleness, and fatigue
- Illustrate the concepts of area moment of inertia (AMI) and stress concentration
- Evaluate and compare implants based on expected performance
To be able to select the most appropriate implant for a patient from the many alternatives available, the surgeon must understand the biological and anatomical limitations, and estimate the mechanical needs of the implant for the specific situation that they must address. They must then combine that information with their understanding of the design and performance criteria for the various implant choices when making their final selection. The role of the design engineers is to provide the surgeon with range of choices. This presentation will introduce some of the design and performance concepts that the surgeon needs to critically evaluate implants.

It is important to understand the engineering terms that are used to describe implant performance. There are different sets of terms for characterizing the material (i.e. the steel) and the structure (i.e. the plate). Stress and strain are used to describe how a material behaves. Stress develops in the material when a force is applied. Its units are force/mm$^2$. Strain is the give within the material, expressed as a percentage of its original length. The slope of the stress vs. strain response is the modulus of the material. The modulus for most materials is different depending on the type of force applied. Tension and compression are frequently used to compare materials, but for implants, bending is usually the most important. Torsion causes shear within the material, which may be a weak mode. The initial portion of the stress vs. strain response is elastic – the deformation is fully recoverable. Once the material deforms, it passes the yield stress point, and the response is plastic. Deformation is permanent. The modulus usually decreases. Failure occurs when the material breaks. This is unusual for metals because they are ductile – they undergo significant plastic deformation before failure. Ductility of metals can be influenced by manufacturing techniques. Materials that break soon after the yield point, like cortical bone, are brittle.
Fatigue resistance is an important performance parameter for implants, as they are subject to cyclic loading, usually below the yield load. The microstructure of the material, which is significantly influenced by manufacturing processes, plays a major role in how well it resists crack initiation and progression. The surgeon must remember that they are the ones that define what the applied stress will be – they select the implant and educate the owners regarding patient activity.

Most implants are made from 316L medical grade stainless steel alloy. Chromium, nickel and molybdenum are additives that virtually eliminate corrosion and enhance biocompatibility. Carbon and sulphur compounds are reduced as low as possible. The way in which this material is processed influences the performance of the implant. Extruded, un-worked steel, like orthopaedic wire, has a macrocrystalline structure. It has the lowest bending yield stress, making it the most malleable. As the material is cold-worked (pressed and rolled at room temperature), the crystalline structure becomes more dense, defects are removed, and the yield stress and fatigue resistance increase. A balance must be achieved because the ductility decreases, which increases the manufacturing difficulties and makes the implant more difficult to contour. For plates and screws, a medium cold-worked level is reached, whereas pins and K-wires are made from highly worked steel.

Of more importance to the surgeon is how the whole implant performs. To compare structures, a Load vs. Deformation curve is generated. This is similar to the stress vs strain curve, but shows the effect of the dimensions and shape of the structure. The slope of the elastic portion of the curve is termed the stiffness of the implant. This will be different for the different ways in which the load is applied, and, particularly for bending,
how the implant is oriented. The yield load is also an important parameter, both for contouring and ability to not bend when loaded by the patient. The ability of a structure to resist pure tension and compression is influenced by its cross-sectional area, but this is a rare situation in a patient. A structure's ability to counter bending forces is determined from its Area Moment of Inertia (AMI). When a structure is subjected to bending load, its upper surface is under tension and lower surface under compression. There is a neutral plane along its “center”. AMI describes how the structure is distributed around that neutral plane. The thickness of a structure perpendicular to the neutral plane has the most effect on bending strength, because it is raised to the 4th power for cylinders, and 3rd power for rectangles. An example of how this understanding is applied by a surgeon is in the selection of a screw for stabilization of a lateral humeral condylar fracture in a Spaniel that is secondary to Incomplete Ossification of the Humeral Condyle. Because healing of the condyle will be either very protracted or not occur at all, the screw will be subjected to a larger number of bending cycles compared to a screw in a dog where the condyle heals in 6 weeks. For this sized dog, a 4.0 mm partially threaded screw might seem like a good choice. However, the core diameter of the shaft of this screw is only 1.9 mm. A 3.5 mm cortical screw has a core diameter of 2.4 mm, so, based on the AMI, it will be 2.5 times stronger in bending. However, clinically, these screws will also frequently break. A 4.5 mm cortical screw has a core diameter of 3.0 mm, which gives it a bending strength 2.5 times that of the 3.5 mm screw. Although this screw seems large for the bone into which it is being placed, after consideration of the loading history that the surgeon expects, it is the appropriate one to select.

For rectangular structures (ie. bone plates), the direction of bending relative to the implant becomes important. AMI \( \approx \text{width} \times \text{height}^3 \) A clinical example is in the selection of a plate for stabilization of a distal radius fracture. Using the assumption that the primary bending direction is in the cranio-caudal direction, a 3.5 mm DCP placed on the cranial (dorsal) surface would be on the “compression” side of the fracture, and would therefore experience bending forces. In this orientation, the thickness of the plate is the working dimension. Another approach for this fracture would be to apply the plate on the medial aspect. The surgical approach is easier, but, because of the narrow profile of the bone in this plane, 3.5 mm bone screws are too big. A 2.7 mm DCP is the appropriate sized implant for the bone. While this seems like a weaker implant, if we remember that it will be oriented so that its width is aligned with the primary direction of bending, based on the AMI for this direction of loading, it is actually 3.6 times stronger than the 3.5 mm DCP.

These comparisons are easy to demonstrate for simple geometries. AMI is more difficult to calculate for more complex shapes. Bending usually comes from many directions in real life. But the principles are still valid, and can be applied by the surgeon to help in the assessment of the suitability of an implant design or estimate its performance criteria for a specific situation.

Understanding AMI helps highlight the weakening effect of a screw hole in a plate. There is less material that is available to counter bending, so the AMI is reduced. For a 3.5 mm DCP, the AMI drops from 29.9 mm\(^4\) for the solid portion to 14.8 mm\(^4\) through the hole –
a 50% decrease! The classic clinical example is the plate applied with an empty hole over the fracture. The surgeon must appreciate this potential issue before plate application and develop an approach that improves the AMI of the repair choice. Selecting a lengthening plate to span the comminuted area would be one choice. Adding a rod (IM pin) is another way to increase the AMI.

A structure’s yield and fatigue performance is reduced at any location where there is an abrupt change in dimension. Stress within the material is concentrated by the rapid reduction AMI. Two common examples in orthopaedics are the DCP and negative-thread profile pins. One of the considerations in the design of the Limited Contact-DCP (LC-DCP) was to eliminate this concentrating phenomenon. By cutting out the underside of the solid portion of the plate, the AMI is virtually unchanged along its length. Stress concentration is eliminated and implant contouring is more accurate because the plate bends wherever the surgeon needs it, rather than at the screw hole.

Stress will also concentrate at the junction of the shaft and the thread when the thread is cut into the pin (negative thread profile), because there is a rapid reduction in the core diameter. For this reason, positive thread profile pins are now most commonly used in external fixation.

Implants are also subjected to rotational forces. The torsional strength of the actual implant is related to its Polar Moment of Inertia (PMI), which, like AMI, is influenced by how the material is distributed around the centroid of the implant. However, when applied to a fracture, the ability of an implant to prevent fragment rotation is determined by how well it engages the bone, not by its PMI. An IM pin has a good PMI but is not able to control rotation because it doesn’t lock to the bone fragments.

The ability of an implant to resist cyclic loading while stabilizing a fracture in an active patient is determined similarly to the fatigue test for materials. A “Load vs Number of cycles” curve is generated. For loads exceeding the yield load, the number of cycles will be small. As the load decreases, the number of cycles to cause failure increases exponentially, with a lower limit below which failure will not occur. The surgeon can prevent fatigue failure by selecting a suitable sized implant, educating the client regarding the importance of limiting patient activity (lowering the applied load), and by careful handling of the implant. Large nicks or dents act as initiation points for fatigue cracks.
Bone Healing Under Stable and Unstable Conditions

Amy S. Kapatkin DVM, MS, Dip ACVS
Bone Healing Under Stable and Unstable Conditions
Amy S. Kapatkin DVM, MS, Dip ACVS

Learner Objectives:

- Define the different types of bone healing
- Discuss how rigid internal fixation versus biological fixation affects bone healing
- Apply direct and indirect bone healing to clinical case examples and case outcomes
Bone Healing Under Stable and Unstable Conditions
Amy S. Kapatkin DVM, MS, Dip ACVS
University of California- Davis

Fracture of bone causes instability and loss of mechanical support of the skeleton. Fracture fixation ideally restores the bone to its original structure and material properties thus returning the limb to full function. Some of the factors that affect fracture healing are: location of the fracture, the blood supply to the bone, the soft tissues integrity (from initial trauma or surgical approach), the age of the animal, the stability of the bone fragments, the presence of infection, and overall metabolic health of the patient. Bone can heal under both stable (direct bone healing) and unstable (indirect bone healing) conditions but the biology is different.

**Bone healing under stable conditions:**

Direct bone healing, or bone healing without significant callus formation **requires anatomical reconstruction and rigid fixation of the fracture**. Even when fractures are meticulously reconstructed, there may be areas of small gaps. It is the size of this gap that influences how the direct bone healing occurs. Lamellar bone cannot cross a contact area or small gap if the strain is > 2.5%. Any gap > 1 mm will exceed this strain from limb loading and muscle contractions, even with rigid fixation and therefore, direct bone healing will not occur. Two situations exist for direct bone healing:

- **Contact ( < 200µm) bone healing:**
  In areas of the fracture that have less than a 200µ gap, cutting cones cross the contact zone of the fracture. They bring with them the osteoclasts that reabsorb bone, capillary buds that revascularize bone and osteoblasts that lay down osteoid that becomes mineralized later. The new bone is lamellar bone and is concentric around the vessels that unite the fragments. These osteons are parallel to the long axis of the bone so that remodeling is not necessary to bridge the small gap. This type of direct bone healing has no obvious callus formation on radiographs and appears as if the fracture gradually disappeared.

- **Small gap (> 200µm but < 1mm) bone healing:**
  In areas with small gaps (>200µm & < 1mm), bone healing occurs by direct new bone formation like the contact healing but instead of the lamellar bone, woven bone is formed in a haphazard fashion. This phase of small gap bone healing is often complete by 4-6 weeks after fracture. Anywhere from 3 to 6 weeks post fracture, the woven bone undergoes Haversian remodeling and is replaced with lamella bone via osteoclastic cutting cones. This second phase of small gap bone healing lasts approximately 8 weeks. Small gap bone healing has minimal callus on radiographs. The fracture site fills in gradually.

**Bone healing under unstable conditions:**

Indirect bone healing or bone healing with callus formation is the most common form of fracture healing. It is a combination of endochondral and intramembranous bone healing. Indirect bone healing occurs because of micromotion at the fracture site and is the expected form of bone healing with some fixations and when reconstruction of the
fracture should not be attempted. Indirect bone healing has three overlapping phases, similar to wound healing: inflammatory phase, repair phase and remodeling phase.

**Inflammatory phase:**

The fracture disrupts the medullary blood supply, leading to hemorrhage and clot formation at the fractured ends. The clot is a source of growth factors for angiogenesis. This acute inflammatory phase peaks at 24 hours after injury and lasts approximately 7 days.

**Repair phase:**

Inflammatory cells (neutrophils and macrophages) are recruited to the fracture site to remove necrotic tissues and osteoclasts are recruited to clean up necrotic bone ends. The granulation part of the repair phase has fibroblasts laying down haphazardly arranged collagen within the blood clot to join the fracture ends. At the same time, chondrocytes are recruited and they deposit a cartilage matrix, fibrocartilage, adding stiffness to the callus. This primary new bone is woven trabecular bone that is replaced by lamellar bone as the callus becomes stiffer. The soft callus to hard callus stage of the repair phase is continued by differentiation of connective tissue to cartilage and cartilage to bone. Primary bone formation can occur when the callus achieves a certain degree of stiffness.

**Remodeling phase:**

This final phase of indirect bone healing is when the hard callus is reorganized by intracortical remodeling leading to replacement of primary bone with lamellar bone. This is the longest phase of indirect bone healing and is regulated by Wolff’s Law. Indirect bone healing is characterized by gradual filling of the fracture site with bone and bridging of the fracture site on radiographs. The amount of callus will vary depending on the stability of the fracture and the fragment displacements.

**Summary:**

Both direct and indirect bone healing can be successful outcomes. Advantages of indirect bone healing are that the callus will make the fixation stiffer earlier and that the techniques used in fracture fixation are often biological. Excessive callus can be a disadvantage in that it may interfere with function. Advantages of direct bone healing is the lack of callus formation (which could affect function) yet the biology of the bone may be sacrificed in achieving fracture contact or a small gap. Having the bone share the load has mechanical advantages when this is an option. If done correctly, both techniques are useful. The biological and the mechanical aspects of fracture fixation must be adjusted and tailored for each individual fracture situation in order to ensure the best success for that patient.

**References:**

Principles and Clinical Application of Cerclage Wiring

Simon C. Roe, BVSc, PhD, Diplomate ACVS
Learner Objectives:

- List the guidelines for use of cerclage
- Describe how the twist, single loop, and double loop knots are formed
- Compare the mechanical characteristics of the different knots for wire
- Describe how to correctly apply cerclage wires and differences in application
- Discuss/identify potential difficulties in the application of cerclage wires and potential complications
Cerclage wiring is used to pull bone fragments together so that the shaft is re-built. Rebuilding the shaft so that functional loads can be shared between the bone and the implant will generally produce a very strong repair. It is important to understand the guidelines for wire application so that they will perform in the intended manner.

Orthopaedic wire is a malleable form of 316L stainless steel. It comes in a range of diameters, with the more common ones used in orthopaedics being 20 and 18 gage (0.8 and 1.0 mm diameter). The choice of wire size depends on the expected load on the wire, and this will be influenced by the fracture location, the size of patient and patient activity during recovery. For all the knots described below, the tension generated and the ability to resist un-tying will be greater with larger diameter wire. However, thicker wire is more difficult to work with, so the surgeon must weigh the advantages versus the disadvantages.

For most applications, the length of wire is cut from a spool or reel. For single loop cerclage (see below), wires with a preformed eye are available in 1, 1.25 and 1.5 mm diameter. When handling wire, it is important not to scratch, notch or kink it, as this will reduce its ability to withstand the multiple loading events it will experience in the body.

The ideal fracture for cerclage is a long oblique, single fracture line, where the length of the fracture is greater than twice the diameter of the bone. Cerclage may also be used to stabilize a fracture with a large butterfly fragment. As the number of fragments increases or the obliquity decreases, cerclage provide less secure fixation, and they should be considered more as maintaining alignment than contributing mechanically to stability.

Cerclage wire should not be used as the sole means of fracture repair. They are frequently used as an adjunct to intra-medullary (IM) pin fixation. The IM pin provides resistance to bending, while the cerclage prevent collapse and rotation of the fragments. Cerclage should be spaced approximately a half a bone diameter from each other. It is important that soft tissues be removed as completely as possible from the bone surface in contact with the wire. If tissue is caught between the bone and the wire, it will shrink and be resorbed. This will reduce the effective diameter of the bone, and will often result in the wire no longer being tight.

For the same reason, it is essential that the full shaft of the bone be accurately reconstructed for application of cerclage. If a piece is missing, or a fragment is out of alignment, the remaining fragments can move slightly. Even for a very tight cerclage, a loss of diameter of the bone inside the cerclage of 1% will likely cause the wire to be loose.¹
Cerclage wire causes little disruption of cortical blood supply. The primary flow is centripetal, not longitudinal, so the encircling pressure has little effect. Elevation of the periosteum may delay healing or devitalize fragments, so care must be taken to only expose the track needed for each wire.

The method of tightening and securing the cerclage has a significant effect on the tension generated and the resistance to loading events. Twist and single loop methods are most popular. The double loop method has been shown to have some advantages. There are aspects of application of each that are important to maximize their performance.

A twist knot has the advantage that it can be formed with simple equipment that is readily available in most practices. Everyone has used a twist-tie to seal a bag, and therefore knows the general principles. Another advantage of the twist knot is that the process of tightening the wire to generate the tension also secures it. The instruments for tying a twist wire range from old needle drivers or pliers to twisters specifically for that purpose.

To tie a good twist knot (for cerclage, interfragmentary wire, or tension band wire), it is best to pull firmly on the wire to remove all the excess. The twist should be started as close to the bone as possible. After the first two twists are done by hand, the instrument for tightening is attached close to the bone. If the instrument is too far from the bone, the length of the twist will be too great, and it will be more difficult to fully tighten without it breaking.

No matter which instrument is used, it is important to pull VERY firmly on the wire while the making the twist. This causes the newly forming twist to be added at the BOTTOM of the twist, which translates into tightening. It is also ESSENTIAL that the two arms of the wire twist around each other. The pull, therefore, needs to be even.

Once the wire is tight (see more comments below), there are two approaches to finishing. One is to carefully cut the twist leaving 2 to 3 twists with the cerclage. It is important to do this carefully, as wiggling will cause the tension to be reduced. Many are tempted to then push the twist down flat to the bone - doing this will cause the tension in the cerclage to be very significantly reduced. If you wish to lay the twist down, then it is best to stop tightening about ½ a twist before the end, cut the twist with 5 to 6 twists remaining (enough to grasp firmly with the instrument) and then, with the last ½ twist, the knot is pulled, rotated and flattened in the same motion. If this is done successfully, the tension will be preserved in the wire.
The **single loop** knot is formed using a length of wire with an eye at one end. The free end is passed around the bone and through the eye, and pulled snug. It is then passed into a wire tightener with a rotating crank. The wire is threaded through the crank, and cut short to reduce tangling. The crank is then rotated to tighten the wire. Once the desired tension is achieved, the wire tightener is bent over to lock the free end in the eye. It is VERY IMPORTANT that the tension be maintained in the crank while the tightener is being bent over so that the tension is retained in the cerclage. The wire tightener is loosened and the free end pushed down so that it is bent back completely on itself. The wire is then cut, and the arm flattened further if needed.

The **double loop** knot is formed using a length of wire (approximately 13 inches for a ¾ inch diameter bone) that is folded nearly in half. The fold is compressed but left open enough to be able to pass two strands of wire through. The folded end is passed around the bone, and the two free ends passed through the loop. The wire is pulled tight. The free ends are passed into the wire tightener that has two cranks. Each end is loaded into one of the cranks in the same manner as for single loop cerclage. The two cranks are tightened simultaneously until the tension “feels” appropriate, and the wire tightener is bent over – **while maintaining tension in the cranks**. Once the bend is sufficient, the cranks are loosened, and the bending completed so that the wire ends lie flat to the bone. The wires are cut, and the arms flattened further if needed.

The optimal tightness of a wire is unknown. Most surgeons try to maximize the tension they can generate, and accept that they will break a wire every now and then. The only advice given to novices is to tighten the wire until it breaks – then back off a little, because you’ve gone too far!! In the clinical situation, a wire is checked by pushing on it with an instrument. If it doesn’t move – it’s tight. However, this only sets a minimum and is probably only in the region of 30 N of tension.

The initial tension that can be generated by most surgeons with the twist knot is 70 – 100 N. Most surgeons will generate 150 - 200 N of tension with the single loop knot. The double loop knot generates the highest tension – 300 - 500 N – even in the hands of novice surgeons.
Twist knots loosen by untwisting, and the loop style knots loosen by the arm unbending. When I compared the ability of each of these knots to resist load (18 g wire), the twist and single loop behave similarly (~ 260 N) whereas the double loop knot resisted 666 N before being loose.¹

References:


Principles and Clinical Application of Tension Band Wiring

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Principles and Clinical Application of Tension Band Wiring
Jonathan Dyce, MA, VetMB DSAO MRCVS Diplomate ACVS

Learner Objectives:

- Identify fracture, luxation or osteotomy that would be amenable to stabilization with pins and tension band wiring
- Recognize specific properties of individual fractures that mandate modification of tension band wiring technique
- Plan and execute repair of an apophyseal fracture using pins and tension band wiring
PRINCIPLES AND CLINICAL APPLICATION OF TENSION BAND WIRING
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**Principles**
The tension band principle is used to convert a tensile or bending force into a compressive force. The technique may be applied to bone segments which, following osteotomy or fracture, are distracted because of the pull of attached muscle, tendon or ligament.
In order to neutralize these distractive forces the implant must be correctly orientated on the tension aspect of the bone. An intact buttress on the compression aspect of the bone is also required for tension band function.

A figure-of-eight wire is the implant of choice. The vector of force resulting from the soft tissue insertions and the tension in the wire should be orientated perpendicular to the fracture plane, and thereby cause interfragmentary compression. Supplementary fixation with two K-wires is usually necessary to provide rotational stability and maintain axial alignment of the fracture fragment. The K-wires are inserted parallel to the compression vector and serve as anchors for the tension band wire. The small dimensions of a bone fragment may only allow placement of a single K-wire.
Tension band repair should provide rigid fixation and bone healing will proceed with minimal callus formation.

**Technique**
1. A transverse hole is drilled through the tension aspect of the metaphyseal cortex and a cerclage wire is placed. This prevents drill or wire impingement on the K-wires, which might occur if the order of insertion was reversed. The distance of the transverse hole from the fracture plane is calculated to locate the crossing point of the figure-of-eight wire over the fracture plane.
2. Two parallel K-wires are driven across the fracture plane to align the fragment. It is recommended that the wires be driven into the far cortex to reduce the risk of implant migration. However, seating the wires in the compact trabecular bone of the metaphysis may provide satisfactory fixation. Wires should be directed to avoid joint penetration and soft tissue interference.
3. The figure-of-eight is constructed from one or two lengths of wire. Use long wire segments to avoid deforming the wire prior to tightening. Wires should be of appropriate strength 0.8mm (<10kg bodyweight) to 1.25mm diameter (>20kg). Single or double twists can be used to tighten the wire. Wire twist knots are easier to apply than AO loops. Double twists are recommended if there is high drag that would prevent the wire conforming.
4. Site knots to avoid the K-wires and bone tunnel. Care is taken not to compromise soft tissues during wire tightening.
5. Cut the wire to leave at least two turns on the knot, and fold toward bone.
6. Bend the K-wires in the direction of the muscle pull on the fragment, and cut short.

**Application**
This technique is applicable to the management of fracture (or osteotomy) repair of the greater trochanter of the femur, tibial tuberosity, medial and lateral tibial/fibular malleolus, tuber calcanei, acromion process, supraglenoid tubercle, greater tubercle of the humerus and olecranon. Transverse fractures of the patella may be repaired by a figure-of-eight tension band anchored
about K-wires, which extend beyond the proximal and distal patellar cortex. The technique should also be considered for other collateral avulsion injuries. Avulsion fracture of the traction apophyses, eg. tibial tuberosity, occur particularly in the immature animal. The compression resulting from tension band application is certainly sufficient to cause premature growth plate closure and resultant limb deformity. Consequently, the tension band should be used with great caution in the immature animal and early removal of the figure-of-eight wire is indicated (at circa 3 weeks) if there is the potential for significant further growth. When using TBW in the tibial tuberosity, consider seating the transverse proximal portion around K-wires caudal to the patellar tendon to avoid severance of the patellar tendon.
Proximal intertarsal and tarsometatarsal arthrodesis can be stabilized using pin and figure-of-eight tension band. Proximal intertarsal subluxation with plantar instability, associated with plantar tarsal ligament rupture, is the most common indication for calcaneoquartal arthrodesis. After articular debridement, a pre-measured I/M pin is inserted (retrograde or orthograde) into the (predrilled) calcaneus and advanced through T4 to the level of the tarsometatarsal joint. Bone tunnels are drilled transversely through the calcaneus proximally and plantar tubercle of T4 distally. Note that the body of T4 offers more substantial distal anchorage. The figure-of-eight tension band wires are pre-laid prior to insertion of the I/M pin, which may otherwise obstruct their placement.

Postoperative care and rehabilitation are routine. Implants may remain in situ unless complications relating to their presence develop.
Principles of Bone Screw Function: Plate Screw, Position Screw and Lag Screw

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Principles of Bone Screw Function: Plate Screw, Position Screw and Lag Screw
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Learner Objectives:

- Compare the important physical characteristics of different screw types
- Explain the difference between a plate screw, a lag screw and a position screw to a colleague
- Identify the principles for applying lag screws
Bone screws are surgical devices that are widely used in orthopedic surgery. The screw thread converts the rotational force of insertion into linear motion advancing the screw through the bone.

There are a wide variety of screw types and screw uses. This section will outline the key features that are relevant to screws commonly used in veterinary orthopedic surgery.

Screws can be classified by several characteristics. It is important to understand these differences to be able to use screws effectively.

The screw characteristics that are key in being able to effectively apply bone screws are:

- screw size parameters – thread diameter, core diameter, thread pitch and length
- screw thread type – cortical, cancellous or locking
- screw tip - self-tapping or non-self-tapping
- screw head type and drive recess
- screw material – stainless steel or titanium
- screw function – plate screw, lag screw or positional screw

**Screw size**

The two descriptive size parameters of screws are the thread diameter of that type of screw and the thread length of the individual screw.

Screw size is the thread diameter of the screw. This is the total width of the screw and is marked as A in Figure 1. The length of the screw includes the screw head.

Other important dimensions of a screw are the core diameter (B) and the thread pitch (C).

The core diameter defines the screw profile or the effective depth of the thread. For example a 3.5mm cortical screw with a 3.5mm thread diameter has a core diameter of 2.4mm. The effective thread depth is 0.55mm.

The core diameter of the screw determines the drill bit that should be used for that screw. The drill bit for screw insertion (with the exception of lag screw insertion) is approximately the same diameter as the core diameter of the screw. The core diameter is also important as it determines the resistance of the screw to bending and breaking.
The core diameter is also important as it determines the resistance of the screw to bending and breaking.

The thread **pitch** is the axial distance between adjacent threads. For each 360° revolution the screw advances the distance of the thread pitch.

**Screw thread type: Cortical, cancellous or locking thread**

**Cortical screws** have a narrow or “fine” thread pitch and are designed for use in hard cortical bone. Cancellous screws have a larger or “coarse” pitch and are intended for use in soft metaphyseal and epiphyseal bone. Locking screws are designed for use with locking plates.

This image shows a 3.5mm cortical screw with a 1.25mm pitch on the left and a 4.0mm cancellous screw on the right with a 1.75mm pitch.

The narrow core diameter (1.9mm) of the 4.0mm cancellous screw means that it has decreased bending and torsional strength compared to the smaller 3.5mm cortical screw with a core diameter of 2.4mm.

Locking screws have a larger core diameter, shallower thread and finer pitch than an equivalent diameter cortical screw. Figure 4 shows a 3.5mm locking screw compared to a 3.5mm cortical screw. The locking screw has a 2.9mm core diameter and a 0.8mm thread pitch. The increased core diameter results in increased relative strength.

**The type of screw tip (non-self–tapping or self-tapping)**

The tip of the screw determines how the screw needs to be inserted. The two tip types used in veterinary orthopedics are non-self-tapping and self-tapping. **Non-self-tapping screws** have a round tip and require a pilot hole to be drilled and then a tap to cut a thread in the bone before screw insertion. Non-self-tapping screws used to be the most commonly used screw type and may have some theoretical advantages over self-tapping screws. The clinical reality is that the speed and simplicity of self-tapping screws means they have become far more commonly used than non-self-tapping screws.
**Self-tapping screws** have cutting flutes at the tip and after drilling a pilot hole may be screwed directly into bone as they will cut their own thread. Figure 3 shows the cutting flutes of a self-tapping locking screw.

The main advantages of self-tapping screws are speed and simplicity. Two clinical differences compared to non-self-tapping screws should be considered. The tip of the self-tapping screw is not fully threaded due to the cutting flutes (Figure 4) so slightly more of the screw tip needs to protrude through the far / transcortex to have full thread engagement in the bone when compared to non-self-tapping screws. Secondly if a self-tapping screw is removed and replaced in the same hole there is the potential for it to cut a second thread which may reduce screw security.

**The type of screw head**

The screw head has a central recess that allows attachment of a screwdriver to insert the screw. The two common shapes of recess are star-shaped or hexagonal. The star drive has better torque transmission than the hex drive and increased resistance to “stripping” of the drive recess.

The other advantage of star drive over hex drive is that there is no need for a screw holding sleeve.
Obviously it is essential to have the right size and shape screwdriver for the screw being inserted or removed. (For Synthes screws with the StarDrive recess these are T15/3.5mm, T8/2.7mm and 2.4mm and T6/2.0mm).

In addition to providing drive access the screw head also functions to exert the effect of the screw through contact with the bone or the plate.

Conventional (non-locking) bone screws have a non-threaded head with a rounded profile for engagement with the plate or with the bone.

Locking screws have a head that is designed to lock into the plate and produce an angle stable construct. There are several designs for achieving this. The most commonly used design is pictured in Figure 5. The Synthes locking screws have a threaded head that engages with threads in the LCP plate.

**The material the screw is made from.**

The more commonly used material is 316L stainless steel. Titanium screws are also available in veterinary surgery. It is important to match the correct screw material with the plate material indicated for combined use.

**Screw function (plate, lag or positional screws)**

Bone screws can be used in three main ways.

1. **Plate screws** - designed to fasten a bone plate to the bone. In cortical bone conventional (non-locking) cortical screws are used with conventional plates and locking screws are used with locking plates.

   In metaphyseal / epiphyseal regions cancellous screws have been suggested as more appropriate than cortical screws. In most cases in small animals the routine use of cancellous screws in metaphyseal bone is not necessary. Conventional bone plates rely on the screw head compressing the plate firmly against the bone when the screws are fully tightened to provide stability. This works very well when:
   - fractures heal fairly quickly
   - the plate and screws are not under great loads postoperatively
   - the bone is of good quality
In cases where bone quality is poor and/or fracture healing is likely to be prolonged and/or where biomechanical loads are going to be high then conventional plate screws may loosen / the plate is then no longer tight against the bone / the fracture then becomes unstable and non-union is likely to occur. Locking bone plates have been developed to address these problems. Locking plates have replaced conventional plates in human orthopedics. In veterinary orthopedics locking plates are being increasingly used.

There are a variety of mechanisms available in veterinary orthopedics for locking the plate screw to the plate. AO locking screws are most commonly uses and have a thread on the outside of the head that “locks” into a thread in the plate hole (picture below from Synthes®). This makes a more stable connection between the plate and the screw that can last longer, is more secure in poor quality bone and is less likely to loosen under large loads or prolonged healing.

2. **Lag screws** are designed to produce **interfragmentary compression**. They are placed in such a way that the threads only engage the far cortex. Screw threads in the near cortex do not engage the bone because the hole drilled in the near cortex is the same diameter as the thread diameter. This is called a **glide hole**. A smaller diameter **thread hole** is drilled in the far cortex. As the screw is tightened and the head of the screw contacts the cortex the bone fragments are compressed producing interfragmentary compression and frictional stability.

Figure 6. Synthes Combi Hole® of an LCP plate. This allows the use of either a locking screw or a conventional plate screw.

Figure 7. This image shows a fully threaded cortical screw placed through a bone plate as a lag screw to achieve interfragmentary compression of an oblique fracture.
Anatomic reconstruction is essential for effective use of lag screws. Maximum interfragmentary compression is achieved when the screw is placed perpendicular to the fracture line.

Partially threaded screws are less commonly used as lag screws. Partially threaded screws do not require a glide hole to be drilled as the smooth part of the shaft does not engage the near cortex.

Lag screws can be used through a bone plate as illustrated in Figure 7 above or can be used independent of bone plates. When lag screws are placed independently (not through a bone plate) in cortical bone it is essential to countersink the near cortex to more evenly spread the load of the screw. Failure to do this can produce microfractures and fissure fractures on tightening the screw, which leads to screw loosening and loss of stability. This is illustrated in Figure 8.

3. **Positional screws** are used to maintain the relative positions of smaller bone fragments when extensive anatomical reconstruction is attempted. They do not produce interfragmentary compression as screw threads engage both cortices. With the increasing trend towards “biological” (open-but-do-not-touch) fracture methods rather than extensive anatomical reconstruction the use of positional screws is increasingly less common.
This section outlined the characteristics of screws commonly used in veterinary orthopaedic surgery. Beyond these common screw types there are a variety of screws with special design features for specific uses. These are outside the scope of this section on screw principles.

Attention to detail is fundamental for consistently successful application of bone screws. Each manufacturer has published guidelines on the equipment required for application of an individual screw type. Surgeons must be familiar with the requirements for insertion of the particular screw type they are using.
Principles of Treatment of Diaphyseal Fractures

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Principles of Treatment of Diaphyseal Fractures

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Learner Objectives:

- Identify the primary goals for long bone fracture repair
- Appreciate the biological, biomechanical and clinical factors to be considered in fracture decision making
- Appreciate the relative pros and cons of different stabilization techniques
The primary goals of long bone fracture repair are:

- to obtain acceptable anatomic alignment
  - approximate restoration of limb length
  - <5° rotation
  - <5° angulation
  - >50% overlap of the main bone fragments
- which restores structural continuity of the bone
- provides sufficient stability to achieve fracture union
- with the least amount of biological damage necessary
- allowing early return to weight-bearing and early soft tissue rehabilitation of the fractured limb

Fracture Assessment and Decision-Making

Fracture assessment is a clinical skill that clinicians should use in deciding how to most appropriately manage a particular fracture case. It considers the various biologic, biomechanical and clinical factors that will influence how a particular fracture in an individual animal will heal.

This information is then used by the clinician to inform their decision-making. An accurate fracture assessment will help you identify any contraindicated or relatively contraindicated options for fracture repair and highlight which options are likely to be successful.

Like any clinical skill fracture assessment improves with practice. It is important to recognise that the majority of complications in fracture healing result from decision-making errors and so occur before surgery begins. Informed fracture assessment can greatly reduce these complications.

The key considerations in the biologic assessment are:
- age of the animal
- blood supply to the soft tissue envelope of the fracture
- location of the fracture / type of bone
- infection
- concurrent injuries or disease
The key considerations in the biomechanical assessment are:
- the type of fracture and whether anatomic reconstruction / load-sharing can be achieved
- single or multiple limb injury
- patient size and activity
- method of fracture stabilisation

The key considerations in the clinical assessment are:
- owner capacity to provide appropriate postoperative care
- owner financial capacity
- animal’s temperament
- surgeon’s experience / equipment / expertise

Biologic factors to be considered in fracture decision-making

Age of the animal
Immature animals are “healing machines” and they typically heal relatively quickly. Once they reach skeletal maturity (usually about 12 months of age) their healing potential slowly and progressively declines. The obvious extreme is a geriatric animal (or person!) that will heal much more slowly. Unless there is major trauma to the soft tissue envelope around a fracture (eg a badly contaminated open fracture), an immature animal will usually have a good to at least moderate biologic fracture assessment. It would be very unusual for a puppy to have a poor biologic assessment unless it has suffered major open trauma.

Blood supply to the soft tissue envelope of the fracture
Remember that when a long bone is fractured the intramedullary blood supply is almost always disrupted for some time. The healing fracture has to rely in the short to medium term on the extravascular blood supply of healing bone. This blood supply, from surrounding muscle attachments to the periosteum of the fractured bone, is very important.

There are three aspects to consider here with regard to how good the soft tissue envelope and therefore how good the extravascular blood supply is:
I. Soft tissue envelope prior to the fracture.
This depends on the location of the fracture. The more muscle around a bone the better the soft tissue envelope. The best envelope is around the femur. The worst envelope is around the distal radius, distal tibia and metacarpals, tarsals. So the higher up the limb (humerus, femur for example) the better and, within the distal limbs (antebrachium/forearm and crus/tibia), the higher up within that segment the better.

II. Soft tissue envelope after the fracture.
This depends on how much damage has occurred to the soft tissue envelope at the time of the fracture. High-energy fractures (i.e. comminuted fractures) will have quite major damage to the surrounding muscles, which will compromise the extraosseous blood supply. Low energy fractures (e.g. spiral or simple transverse fractures) will have limited damage to the surrounding envelope.

III. Soft tissue envelope after the fracture repair
This depends on whether the fracture repair is done closed or open and, if it is done open, how much soft tissue damage you as a surgeon cause.

For example fracture repair with a cast, or a closed placement of an external fixator, or a closed placement of a plate through a minimally invasive approach (“MIPO” – pictured below) will cause minimal or no additional damage to the soft tissue envelope.

The other extreme to this is a full open approach where the surgeon does not respect Halsted’s principles and does considerable iatrogenic damage to the soft tissues.
**Size of the fracture gap**

It used to be thought that the larger the fracture defect the longer a bone would take to heal. This lead to the older style fracture repair methods of always trying to get perfect anatomical bone alignment regardless of how much soft tissue damage this caused.

In many cases this “carpenter’s approach” lead to delayed healing or nonunion as this approach to comminuted fractures often created a high strain environment of devascularised fracture fragments. High strain, avascularity and bacterial contamination are the three requirements ideal for sequestrum formation.

More recently we have learned that the size of the fracture gap is less important than the biologic environment that the fracture is in.

In comminuted fractures it is usually better to take a “gardener’s” or biologic approach and stabilise the fracture with some sort of threaded bridging fixation (bone plate, interlocking nail, external fixator) and not further increase the damage to the soft tissue envelope. (Remember though that articular fractures must have anatomic reconstruction. We can’t take a “gardener’s approach” to articular fractures as these need absolute stability to heal through direct bone healing.)

**Location of the fracture / type of bone**

Location of the fracture is mostly about the soft tissue envelope but is also related to the type of bone that predominates at that location.

In long bones the mid-diaphysis is predominantly cortical bone while the metaphyses are predominantly cancellous bone with a thin cortical shell.

Cortical bone is very strong but tends to “shatter” or comminute more under high energy and is slower to heal than the more highly vascular metaphyseal bone. Metaphyseal fractures are faster healing than diaphyseal fractures.

The distal tibia and distal radius are slightly different in that they have relatively small metaphyses and so are predominantly cortical bone. This and the small soft tissue envelope contribute to the distal radius and distal tibia being relatively poor biologic sites.

Conversely bones with a high cancellous to cortical ratio, such as the pelvis and scapular, tend to heal rapidly.
Infection

The presence of infection at the fracture site delays healing, and increases the risk of delayed union or non-union resulting.

Given that the majority of orthopaedic infections arise following internal fixation of closed fractures, this is an area that the surgeon has some control over. The importance of Halsted’s principles and “respect” for the biology of the fracture site can’t be overstated.

Use of sterile waterproof drapes when doing orthopaedic surgery is strongly recommended. Implants provide a safe haven for bacteria to survive away from antibiotics and the immune system. Minimising the degree of contamination and the degree of tissue trauma during surgery is fundamental to consistent success.

Concurrent injury or disease

Animals with traumatic fractures may have poor tissue perfusion or other systemic problems that increases the likelihood of infection and delayed bone healing. Similarly animals with significant concurrent systemic disease (eg diabetes, renal failure) may have impaired bone healing.

Any animal that has suffered a traumatic fracture should be assessed for the presence of concurrent injuries and be properly stabilised before definitive surgical correction of the fracture is undertaken.

Biomechanical factors to be considered in fracture decision-making

The key considerations in the biomechanical assessment are:

- the type of fracture and whether anatomic reconstruction / load-sharing can be achieved
- single or multiple limb injury
- patient size and activity
- method of fracture stabilisation

Bone requires rigid stability (<2% strain) to form directly. If the fracture fixation method you choose is not sufficiently stable the fracture site will be filled with tissue that can withstand greater deformation than bone. This is the essence of the Interfragmentary Strain Theory. This is that pluripotential cells at the fracture site
respond to the degree of local deformation (i.e. strain) at the fracture gap that determines the type of tissue they will develop into.

**Different tissues tolerate different strains**

- **Bone** < 2 % strain - direct bone healing is possible
- **Fibrous tissue & cartilage** < 10 % - indirect bone healing through the production of a fracture callus is possible
- **Granulation tissue** - can tolerate up to 100 % deformation but will not provide sufficient stability to allow bone formation

It is important to understand two fundamental principles of fracture fixation – **absolute stability** and **relative stability**.

**Absolute stability** (<2% strain) is infrequently achieved, as it requires anatomic reconstruction and interfragmentary compression.

Absolute stability can be achieved through:
- static interfragmentary compression (lag screw or plate applied in compression)
- dynamic interfragmentary compression or “compression through function” such as a tension band or tension band plate repair where perfect anatomic reconstruction is achieved

Where absolute stability is achieved direct bone healing will occur.

**Relative stability** is much more commonly achieved as it includes all fracture fixations that don’t achieve the challenging requirements of perfect anatomic reconstruction under interfragmentary compression.

Where relative stability (<10% strain) is achieved indirect bone healing through callus will occur.
Relative stability has become synonymous with “biological fixation” and implies more flexible bridging fixation with preservation of fracture biology.

If stability of a fracture repair is really poor (and interfragmentary strain >10 %) then granulation tissue is the only tissue that can readily survive in that environment.
Granulation tissue can not produce sufficient stability for fracture healing to occur.
Nonunion is the typical consequence of marked instability.

Prolonged instability usually leads to inevitable implant failure and may predispose to osteomyelitis.
The degree of stability achieved in a fracture repair largely depends on:

- the nature of the fracture and whether the fracture can be anatomically reconstructed
- whether it is a single or multiple limb injury
- patient size and activity
- method of fracture stabilisation

These four factors that affect stability are explained in more detail below.

- the nature of the fracture and whether the fracture can be anatomically reconstructed

Anatomic reconstruction of the fractured bone allows the bone and the method of fracture repair to work together and “share the load” of weight bearing while the fracture heals. Anatomic reconstruction allows load-sharing to occur between the reconstructed bone column and the method of fixation (e.g. bone plate, cast, external fixator, IM pin etc).

This “sharing” of the load produced by weight-bearing means that the fixation method used (external fixator in the example pictured) does not have to withstand the same degree of load as it would if anatomic reconstruction had not been possible.

Load-sharing is an ideal situation as it increases the stability of the fracture repair and decreases the likelihood of implant failure.

Remember that in many long bone fractures anatomic reconstruction and load-sharing can’t be achieved (e.g. comminuted fractures) or is only achievable at the expense of considerable damage to the soft tissue envelope and muscle attachments.
In these cases it is preferable to use a method of fixation that **bridges** the fracture site without attempting to reconstruct the fracture fragments. This approach is known as **biological or bridging fixation**, and is the preferred repair strategy in comminuted diaphyseal fractures.

Because bridging fixation will take the entire load of weight-bearing it must be sufficiently strong to remain biomechanically competent for the duration of bone healing. This usually requires **threaded fixation**.

Threaded fixation is when the implant is screwed or bolted to the bone. These methods are the “heavyweights” of fracture repair and include bone plate, plate-rod, interlocking nail, and threaded external fixators (ESFs).

The alternative to threaded fixation is **friction** (IM pins and cerclage wire, smooth pin ESFs) and **immobilization** (casts and splints) **fixation**, which are the “lightweights” of fracture repair.

- **whether it is a single or multiple limb injury**

This makes a big difference. If more than one limb has been injured or if a significant pre-existing lameness is present in another limb, an increased load will need to be taken on the fractured limb immediately post-operatively.

Remember that limping is a luxury that can only be afforded if you have another good leg to take the load.

Multiple limb injury increases the likelihood of fracture repair complications. A fracture fixation method of **greater strength** than would otherwise be necessary is required if multiple limb problems exist.

- **Patient size and activity**

Particularly large breeds of dog and particularly active dogs place an increased load on the fracture repair and tend to have increased complication rates. Similarly dogs that are inappropriately exercised post-operatively are more prone to complication. Likelihood of owner compliance to a restricted exercise program needs to be considered. In cases where you think the owner or the dog wont “respect” the fractured leg while it is healing you are better to take a fracture repair option that is stronger than would otherwise be necessary. These aspects also form part of the **clinical assessment** (see later in this section) but must be considered when making a biomechanical assessment.
Method of fracture stabilization

This is the “end goal” of decision-making and what we are trying to decide on by doing the fracture assessment. Different methods of fracture repair have differing abilities to neutralise these fracture forces.

- **Bone plates, interlocking nails** and **external skeletal fixators** (ESF) are able to neutralise all of the fracture forces if properly applied.

- **Intramedullary (IM) pins** offer good resistance to **bending** forces however offer little resistance to the other physiologic forces and are particularly weak at neutralising torsional forces. Resistance to axial compression with intramedullary pins relies largely on **frictional** purchase at the pin-bone interface. For this reason IM pins are not suitable methods of fixation where large axial compressive forces will occur.

- **External coaptation** methods such as full casts are reasonably good at neutralising **bending and torsional forces of low magnitude**. Casts rely on immobilisation of the adjacent joints and soft tissue envelope to hold the fracture fragments stable. Casts rely on the ability of the animal to build a big enough callus fairly quickly to achieve sufficient stability necessary to achieve bone healing before cast complications inevitably occur. Remember that casts will eventually cause problems. The longer they need to be kept in place the more likelihood of complications. The main complications with immobilisation are muscle wastage from disuse and friction &/or pressure sores. Friction and pressure sores can be a major problem and at times can necessitate **amputation**. Casts are best reserved for radius/ulna and tibial fractures in (usually young) animals with a good biologic and good biomechanical assessment where healing will be complete in <4-5 weeks.

Remember that in growing animals you will almost certainly have to change the cast to prevent the cast becoming too tight as the animal grows. The owners need to be made aware of this. Casts require very close veterinary attention and owner attention to prevent complications. Written instructions and regular (at least weekly and ideally twice weekly) rechecks will help reduce complications.

- **Pin and tension band wire** techniques if properly applied convert the axial tension (distraction force) in an avulsion fracture or osteotomy to a compressive force and are ideally suited for repair of these fractures.
Clinical factors to be considered in fracture decision-making

Clinical assessment is a lot more subjective and perhaps “vague” than the biologic and biomechanical parts of fracture assessment.

The key considerations in the clinical fracture assessment are:

- owner capacity to provide appropriate postoperative care
- owner financial capacity
- animal’s temperament
- surgeon’s experience / equipment / expertise

**Owner capacity to provide appropriate postoperative care**
Some owners lack the ability to provide the care we as veterinarians would consider to be necessary. This should be factored into fracture decision-making.

**Owner financial capacity**
Clearly the solution to the problem of a pet having a fracture must be within the owner’s financial capacity. Where the owner is unable to afford any treatment for their pet it may be appropriate to offer euthanasia free of charge on humane grounds. Other charity options may exist. This will obviously vary in different states and countries. In most regions veterinarians have a professional responsibility to not offer an option for repair that would be considered contraindicated on the justification that “it was all the owner could afford”. Contraindicated options should not be offered as it is not in the animal’s or owner’s best interest and may contravene your professional responsibilities.

**Animal’s temperament.**
How well do you think the owners will be able to make an animal comply with the necessary exercise restrictions in the healing period? Does the animal’s temperament mean that one treatment option is preferred over another? For example with a bitey/aggressive dog placing some form of internal fixation (e.g. bone plate or interlocking nail) would be preferable to placing an external fixator which will need numerous dressing/bandage changes and rechecks.

**Clinician’s experience, equipment and expertise**
As a professional you should be realistic with your own abilities and limitations. A complex fracture case with a poor fracture assessment is not the case to be trying out new surgical techniques or equipment that you are not very familiar with. Referral may be a more appropriate option in that case.
Principles and Clinical Application of Dynamic Compression Plate (DCP) and Limited Contact-Dynamic Compression Plate (LC-DCP) Stabilization

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Principles and Clinical Application of Dynamic Compression Plate (DCP) and Limited Contact-Dynamic Compression Plate (LC-DCP) Stabilization
Kenneth A Johnson, MVSc PhD FACVSc Diplomate ACVS Diplomate ECVS

Learner Objectives:

- Describe the step wise process by which the insertion of screws in a compression plate produces interfragmentary compression
- Compare and contrast the design and clinical application of the DCP and LC-DCP for stabilization of long bone fractures
- List the pros and cons of using a compression plate to stabilize shaft fractures
Plate Function and Design

Dynamic compression plates (DCP) can be used to stabilize shaft fractures, corrective osteotomies, nonunions and arthrodeses. Depending upon how a plate is applied to the fractured bone, and also the type of fracture, the DCP can have different functions.

- static and dynamic compression
- neutralization
- buttress or bridging

Therefore, although the name DCP implies that it produces interfragmentary compression at the fracture gap, it can also be used in these other ways, without compression.

DCP used in veterinary surgery are made of 316L stainless steel. The undersurface of the plate is concave and smooth while the top surface is convex.

Originally the intent of this design feature was to allow the plate to have better contact with the periosteal surface of the diaphyseal cortex. The newer Limited Contact-Dynamic Compression Plate (LC-DCP) is designed to have less contact with the bone (see later).

The geometry of the plate hole of the DCP and the LC-DCP allows these plates to be used as self compressing plates. Each plate hole is oval rather than round, and is a combination of inclined and horizontal cylinders that permit the downward movement of the screw head during tightening, until it reaches the junction of the two planes. Axial movement of the screw head does not occur, unless an additional load screw is inserted, in which case there is adequate room for the screw head to move horizontally in the plate hole.

Screw head, like a ball, slides down inclined plane. Cut-away view of plate hole
and screw with inclined plane to the right of the screw head.

![Diagram showing screw inclination](image1.png)

The oval shape of the plate hole allows a 25-degree inclination of the screws in a longitudinal plane, and up to 7 degrees in the transverse plane.

**Plate Selection**

DCP are available in a range of sizes to fit different bones and various sized animals. The name used to designate each plate corresponds to the diameter of the cortical screws used for its application.

<table>
<thead>
<tr>
<th>DCP</th>
<th>2.0</th>
<th>2.4</th>
<th>2.7</th>
<th>3.5</th>
<th>3.5 broad</th>
<th>4.5</th>
<th>4.5 broad</th>
</tr>
</thead>
</table>

As a guide, the width of the plate will be about 50-75% of the bone diameter. Broader or stiffer plates are needed for plates with buttress or bridging function. The length of the plate should be sufficient to have at least two, and preferably three screws in the bone fragments either side of the fracture. Longer plates are needed in osteoporotic bone or soft bone (young animals), and in larger or more active animals where greater loading is anticipated.

After reduction of the fracture, the plate is contoured (shaped) to the normal shape of the bone. A radiograph of the opposite normal limb can be useful to aid contouring.
Indications and Application
The DCP can be applied as a compression plate in transverse or short oblique fractures of the diaphysis. It can be used to generate both static and dynamic compression at the fracture site.

Static Compression is interfragmentary compression that is generated at the time of surgery, and it remains relatively constant and only diminishes with normal healing and remodelling of the bone. If implant failure occurred, such as screw loosening, there would be immediate loss of compression. Interfragmentary compression does not result in faster, better or stronger healing. All it does is increase friction at the fracture site, between the fragments, which increases stability of the bone-implant composite. The three methods of generating static compression are as follows:

1. Tensioning Device can only be used with a 4.5 DCP. It is attached to the end of the plate, and so needs a longer incision and about 3-4 cm more bone. It is rarely used in dogs and simple fractures are still best reduced and stabilized by use of “classical” DCP using load screws. However, when needed, the tension device can compress a fracture site by up to 2 cm, and is useful for compressing soft tissues within the gap in nonunions.
Articulating Tension Device

Tension device applied to oblique shaft fracture

Tightening of the tension device results in interfragmentary compression.

2. Load Screws. Insertion of screws in the load position, using the yellow load guide is the most common method of obtaining static compression with a DCP. Holes in the DCP are oval-shaped, and have a glide path for the screw head. Use of the load guide permits a hole to be drilled at the end of this oval hole. As the screw is tightened into this hole, the screw head binds on the glide path in the plate hole, and moves the bone towards the fracture. Provided that the fracture has been anatomically reduced, this will cause interfragmentary compression.

Up to two screws each side of the fracture can be inserted in the load position. In a 4.5 DCP, each load screw produces 1 mm of compression.
Neutral guide (green) and screw

Load guide (yellow) and screw

Dynamic Compression Plate Principle
3. **Prestressing the plate.** Slight overbending of the plate, such that a gap of 1-2 mm exists under the plate over the fracture site, will cause compression of the trans-cortex, as the plate screws are tightened.

**Dynamic Compression**  
Application of the plate to the tension surface of bone causes interfragmentary compression as the animal bears weight on the limb, and so this is cyclic in nature. On the femur, the tension surface is lateral, and because the bone is loaded eccentrically, the fracture site tends to "close" (dynamic compression), and correspondingly the plate will be in tension.

**Limited Contact - DCP**  
Uniform contact of the regular DCP with the bone is considered to be responsible for disturbed vascularity in the bone cortex under the plate. To alleviate this problem, a new compression plate called the Limited Contact-DCP has been made. It has cut-outs under the
plate, between the screws, to reduce contact of the plate with the bone. Also this ensures the plate is of uniform stiffness throughout its length, and it is not weaker at the screw holes. This plate is made in both titanium and stainless steel, and is applied in the same way as the regular DCP.
Principles and Clinical Application of Neutralization Plate Stabilization

Laurent P. Guiot, DVM, Diplomate ACVS and ECVS
Principles and Clinical Application of Neutralization Plate Stabilization
Laurent P. Guiot, DVM, Diplomate ACVS and ECVS

Learner Objectives:

- List the indications for and limitation of neutralization plate application
- Describe the surgical technique for neutralization plate application
  List the techniques allowing interfragmentary compression with neutralization plate application
- Describe the cost/benefit associated with neutralization plating
**Definition:** A neutralization plate is a bone plate applied to neutralize the disruptive forces acting at a fracture site. In this function, the plate is applied as a supplementary fixation following anatomical reconstruction and interfragmentary compression. Most commonly, compression is achieved through lag screw fixation but cerclage wires could alternatively be chosen in some cases. The neutralization plate is then used as an internal splint to protect the primary fixation by counteracting bending and shear forces acting at the level of the fracture. It is also important to understand that a neutralization plate does not refer to a specific implant but rather to the way the plate is applied. As such, most bone plates could be used as a neutralization plate including the DCP, LC-DCP, LCP, VCP, SOP and ALPS.

**Indications:** By definition, a neutralization plate may only be used in cases where anatomical reconstruction and interfragmentary compression can be achieved. This means that only simple / reconstructible fractures may be addressed with this plating technique. In addition, the fracture should be oblique to long oblique or spiral in order to be suitable for lag screw fixation or cerclage wiring.

**Surgical technique:** The application of a neutralization plate starts with anatomical reconstruction of the fracture and temporary stabilization using bone holding forceps. Fracture compression is then achieved using lag screw fixation and/or cerclage wiring. Careful selection of screw(s) insertion plane(s) is critical. The screws should be inserted at an angle greater than 45 degrees to the fracture line and be centered over both fragments to optimize interfragmentary compression and prevent secondary fractures, respectively. In cases where optimal screw location will interfere with adequate placement of the bone plate, the lag screw(s) may be inserted directly through a plate hole. Note that locking screws cannot be used in such cases and that perfect contouring of the bone plate is necessary in order to prevent primary loss of reduction during screw tightening. The bone plate selected should be long enough to span the entire fracture site, leaving room for 3 or more screws proximally and distally. If a dynamic compression plate is applied the screw holes are drilled in the neutral part of the plate holes to avoid shear stresses at the fracture site.

Most surgeons choosing a neutralization plate fixation for a fracture repair will elect an open reduction technique to ease reduction and stabilization maneuvers. It should be noted, however, that such constructs may be achieved using minimally invasive approaches with closed reduction techniques and percutaneous implant insertion. True neutralization plating requires anatomical reconstruction of fragments and interfragmentary compression. This mode of fixation is falling off favor with the advent of biological osteosynthesis. Modern fixation methods emphasize the preservation of blood supply and of the soft tissue envelop surrounding a fracture site and both are violated *de facto* if an implant is placed across the fracture line. Therefore, we encourage the surgeon to carefully weigh the cost/benefit ratio before dissecting a fracture site to achieve interfragmentary compression.
Figure 1: Example of a neutralization plate where the fracture was compressed using cerclage wires and augmented with an intramedullary pin. Note that two double loop cerclage wires were used, which offer the strongest configuration.

Figure 2: Interfragmentary compression may be achieve though independent (left) or through the plate (right) lag screw fixation.
Principles and Clinical Application of Buttress/Bridge Plate and Plate/Rod Stabilization

Prof Bruno Peirone
Principles and Clinical Application of Buttress/Bridge Plate and Plate/Rod Stabilization
Prof Bruno Peirone

Learner Objectives:

- Recognize fracture types repairable using bridging plate and plate and rod stabilization
- Describe how the IM pin (Rod) of the Plate/Rod construct acts to minimize the stress and strain that a plate alone would encounter in fracture repairs.
- Recognize common complications of buttress plate fixation.
Principles and Clinical Application of Buttress/Bridge Plate and Plate/Rod Stabilization

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Abstract courtesy Prof Randy Boudrieau

Introduction
There are many fractures whereby there is either a large gap due to missing bone, or a similarly large gap spanned by significant comminution. In either case the fracture gap cannot (or should not) be reconstructed. The primary aspect to consider with some form of buttress/bridge plating is that the soft-tissues have already undergone a great deal of compromise; therefore, techniques that add to this compromise (e.g., excessive surgical dissection, long surgical time) will result in additional vascular compromise that leads to decreased osteogenesis, with the added consequence of impaired stability and increased infection rates. In such instances the “direct reduction techniques” are replaced with “indirect reduction techniques”.

The former embraces an anatomic (mechanical) reconstruction, whereas the latter embraces a more biologic reconstruction. The indirect techniques have been promoted as “open, but do not touch (OBDNT)” and more recently the minimally invasive techniques. In these indirect techniques there is a more limited stability to the fixation – the bone no longer shares any of the load with the implants, re: buttress/bridging fixation, but there is better preservation (the emphasis on biology) of the vascular (soft-tissue) envelope; the tissues are spared further trauma by a closed or “OBDNT” approach. Thus the bone healing capability is enhanced.

There is a direct trade-off between the direct vs. indirect surgical techniques. This is the “concept of balance”, or a trade-off between mechanics & biology. This balance may be shifted towards one side or the other, where the absence of one requires more of other, but within reasonable limit. The absolute absence of either factor results in a lack of healing; thus, the proposed requirements for utilizing each of these techniques must be fully appreciated.

Bone plates function in a buttress (or bridging) fashion when a gap exists at the fracture site such that the bone fragments do not share in load bearing. The plate supports the fractured bone, maintains normal limb length, and prevents collapse at the fracture site. The plate bears the entire functional load applied through the bone until healing occurs. This technique provides stability at the fracture site with minimal disruption of the fracture hematoma and soft tissues surrounding the fracture.

Clinical Indications – Buttress Plate Fixation
This method of fixation is used to stabilize large fracture gaps, e.g., highly comminuted non-reconstructable fractures, infection, non-union, malunion or angular limb deformities (with re-establishment of limb length), or bone resection due to neoplasia. Various types of plates can be used in buttress fashion, including regular dynamic compression plate (DCP), limited-contact dynamic compression plate (LC-DCP), limblengthening plates, and more recently the locking compression plate (LCP).
Because of the more uniform bending of the LC-DCP (as compared to the DCP where stress-risers exist at the open screw holes), this plate type is preferred. Screw placement is modified such that they are placed at the far ends of the screw hole (“buttress position”); thus positioning the screw near the steep wall of the plate hole (as opposed to the neutral or compression position). This rigidly fixes the plate and screw to minimize collapse of the fracture gap.

When applying the LC-DCP, the drill guide is used with the arrow pointing away from the fracture line. Despite these plates improved uniform bending characteristics (as compared to standard plates), the empty screw holes present over any bone void may still result in a local area of weakness (stress riser) where the plate may subsequently break. One method to offset this problem is to utilize >1 plate, either placed opposite or orthogonal to the first plate, thus minimizing the stress placed on a single device. The limitation to this approach has been the ability to secure a sufficient number of bicortical screws to secure the plates (interference is present between the screws, and/or plate, that oppose each other). This problem recently has been minimized with the advent of the locking plate systems where monocortical screws may be placed.

Because of the limitation with open screw holes when using a single plate, an alternate plate design has been manufactured for spanning gaps, the limb lengthening plates, which are specifically designed for use in buttress fashion. The central portion of the plate is devoid of holes to eliminate this potential stress riser and weakness. There are some concerns, however, that these plates are too stiff. They have largely been replaced by the plate/rod technique, and more recently by the locking plates.

**Clinical Indications – Plate-rod Fixation**

From a mechanical perspective, the implant system must limit the strain to a level that will continue to permit bone union. Comminuted fractures distribute strain over a large surface area, which lowers interfragmentary strain to a level compatible with direct or indirect bone union. However, if the bony column is not reconstructed, an implant is placed under considerable stress since it must carry the entire physiologic load until callus (bio-buttress) is formed. If a standard bone plate is used, empty plate holes will be present overlying the area of comminution. In that an empty plate hole serves as a stress concentrator, plate failure can occur in this area.

One method to reduce plate strain is to combine the bone plate with an addition of an IM pin. This technique involves the combination of an intramedullary (IM) Steinmann pin and a plate used in concert. This technique, in addition to providing additional stability to the bone, facilitates reconstruction. The IM pin not only adds to the strength of the repair, but allows for alignment and length correction to be performed with ease before plate placement. The major remaining requirement of appropriate rotational alignment requires appropriate knowledge of the spatial arrangements and anatomic keys when aligning such a non-reconstructable fracture.

In performing this technique, an IM pin is first inserted normograde to restore proper bone length and alignment, and to maintain distraction while the plate is applied (often the pin tip is cut once the pin is located at the fracture site; in this manner there is less risk that the pin will traverse the distal bone fragment when used to re-establish bone length).
This IM pin only fills 35-40% of the medullary cavity. An IM pin that occupies 40% the diameter of the marrow cavity reduces the stress on the primary implant (plate) by 50% or more. More importantly, this extends the fatigue life of the primary implant at least 10-fold. Alternatively, a smaller IM pin that only occupies 25% of the marrow cavity only reduces the stress in the primary implant by a factor of 10%; therefore, appropriate pin size is critical. The smaller pin size (as compared to primary IM pin fixation, which fills ~2/3 of the medullary canal diameter) provides ample room to insert the screws for plate fixation without interference, and also and eliminates any excessive rigidity to the plate/rod construct if a much larger pin would be used.

The bone fragments and fracture hematoma are not disturbed; however, if large fragments are far from the bone column, they may be brought closer to the bone shaft, better approximating overall alignment and subsequent healing, using absorbable suture material (i.e., some re-apposition of the soft-tissue envelope only). No attempt is made to anatomically reduce the fragments. A bone plate then is contoured to the surface of the bone and applied in buttress fashion. Radiographs of the contralateral normal bone may be helpful when contouring this plate. The most proximal and distal screws are inserted to engage both cortices of the bone (bicortical). There is ample flare of the metaphysis/epiphysis where all screws can be placed bicortically. The remaining screws need only engage the near cortex (monocortical). A minimum of three monocortical screws and one bicortical screw should be used on each side of the fracture. The presence of the IM pin reduces strain on the plate and significantly increases the plate’s fatigue life, as noted above.

**Clinical Indications – Locking Plating**

Bridge plating also can be effectively performed using the locked plating systems. Because these plates have screws that lock to the plate, a fixed angle construct is created identical to an external skeletal fixator, albeit as an internal device. A fixed angle construct eliminates the need to contour the plate exactly to the bone surface (standard plates require compression of the plate to the bone in order to obtain a “mixed mode” of force transfer, i.e., utilizing the frictional forces between the plate and bone in order to obtain construct stability), as loads are maintained with a “screw-only” mode of force transfer. This aspect permits the minimally invasive fixation techniques to be more successfully utilized, where plates can be inserted percutaneously. Additionally, the fixed angle constructs allow fewer screws to be utilized; e.g., epiphyseal fractures.

Regardless, the limitation of a single plate spanning a gap needs to be appreciated due to the lack of any load-sharing with the bone, as the plate may be subject to overloading (see above: rationale for the plate-rod technique). For this reason, a supplemental IM pin or a second plate should be considered to provide additional support. A second plate (opposite or orthogonal to the first plate) can be applied without concern for screw interference since monocortical screw fixation may be used. Because these plates are not compressed to the bone surface, there is additional sparing of the vasculature (under the plate) that permits application of multiple fixation devices without compromising the biology.

This approach again favors the preservation of the soft-tissue envelope. Despite this apparent advantage using minimally invasive techniques, they should be used judiciously, as the mechanical advantage of a plate is lessened with increasing distance present.
between the plate and bone. Furthermore, anatomic knowledge of the unseen soft-tissues is imperative. Similarly, limited screw purchase of a single device (limited screw purchase with a periarticular fracture, for example) may not be of sufficient strength to neutralize the applied loads, and additional support (a second device) may be necessary. Although these techniques have been used successfully in human orthopedics, they need to be applied with caution in animals where immediate full weight-bearing postoperatively is the expectation.

References


Introduction to Locking Plates

Kenneth A Johnson, MVSc, PhD, FACVS, Diplomate ACVS and ECVS
Introduction to Locking Plates
Kenneth A Johnson, MVSc, PhD, FACVS, Diplomate ACVS and ECVS

Learner Objectives:

- Describe the locking plate design and why it is fundamentally different than the DCP or LC-DCP
- Potential advantages of choosing a locking compression plate instead of a DCP or LC-DCP
- Name some potential complications or limitations of the LCP
Introduction to Locking Plates
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Locking Plates
The need for implants that could be used with minimally invasive surgical technique following the philosophy of ‘biological osteosynthesis’ was a driving force behind the development of locking plates. In addition, plates that had improved mechanics and less impact on bone blood supply were considered to be desirable. It should be appreciated that the Zespol external plate fixator developed in Poland in the 1980’s was a concept that was ahead of its time. In principle, the Zespol was exactly the same as modern locking plates, because it had screw heads that could be locked into plate. These screws were applied perpendicular to the plate, and were “fixed angle”. The Zespol did not rely on friction between the plate and the bone for stability. Indeed, the plate was situated just outside the skin, similar to an external fixator.

There are currently several different types of locking plates available that they may be useful for fracture fixation in small animals, including the No Contact Plate, the String of Pearls, the ALPS, the Fixin and the Locking Compression Plate (LCP). The LCP has combination locking and compression holes, or so called “Combi hole” (Fig 1). This allows the plate to be applied with either fixed angle locking screws in the threaded part of the Combi hole, or standard cortical screws that are placed in the dynamic compression unit (DCU) part of the Combi hole (Fig 2).

Figure 1: The LCP Combi hole
Figure 2: Locking head and standard screws

Application of the LCP with entirely locking screws results in fixed angle construct. Used it this way, there is not any compression of the plate to the bone, or between the fracture fragments. The most important use of this device comes in non-reducible shaft fractures when the plate is acting as a bridge plate. Once the locking screws engage the plate, no further tightening of the screw is possible. Therefore the implant locks the bone fragment in their relative position, regardless of the degree of reduction. Accurate contouring of the plate to the bone is not essential (Figure 3). Furthermore, by locking the screws to the plate, the risk of loss of reduction due to screw toggling and fracture collapse is reduced (Figure 4).
Since the plate can sit off the bone, and locking of screws prevents compression of the periosteum by the underside of the plate, then blood supply to the bone may be improved (Figure 5). In case of reducible fractures, once the metaphyseal fragment has been fixed with locking screws, the fracture can be compressed using standard screws in the DCU portion of the Combi hole (Figure 6).

**Complications**

1. Need to be able to reduce the fracture, or obtain correct alignment of the bone, prior to application of the LCP.
2. The plate needs to be positioned so that screws are centered over the intramedullary space. If there is axial malalignment of the plate and bone, then some of the screws near the end of the plate will not have adequate bone purchase, and thus fail (Figure 7).
3. Cross threading of screws can cause permanent locking of screws especially with titanium implants (Figure 8). While cross threading of locking screws does not necessarily compromise the stability of the fixation, implant removal may involve cutting of the plate.

The threaded portion of the combi hole in the straight LCP only allows for placement of screws that are perpendicular to the plate. This can be problematic in the metaphyseal region. Development of ‘anatomically’ contoured plates has overcome this problem, for example the distal tibial plate for humans, although currently there are no such implants for animals.

![Figure 8: Cross threading of locking screws](image)

**References:**


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Principles in Small Animal Fracture Management

FRIDAY LECTURE ABSTRACTS
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Principles and Clinical Application of Intramedullary Pins and Wires

Charles E. DeCamp
Principles and Clinical Application of Intramedullary Pins and Wires
Charles E. DeCamp

Learner Objectives:

- Integrate knowledge of fracture biology and biomechanics with application of intramedullary pins as fixation
- Develop anatomic knowledge of canine long bones for use in application procedures of intramedullary pins as fixation
- Develop strategies for use of intramedullary pins as primary fixation or in combination with other fixation methods
Principles and Clinical Application of Intramedullary Pins and Wires

Charles E. DeCamp

Veterinary orthopedic surgeons are fortunate to have many highly developed fracture fixation systems available for application to diverse fractures in dogs and cats. There are now available generations of intramedullary devices, linear and circular-framed external fixators, and bone plates. The surgeon must have an intimate knowledge of each fixation system, so as to make the best choice of principle and application for each fracture circumstance. Although pins and wire represent one of the earliest and simplest of systems available, there continues a definitive role for this system in orthopedic practice. Intramedullary pins remain an essential part of our “fixation language.” Long before there was the Imex S/K, Interlocking Nail, and the LC-DCP, there was the intramedullary pin. Surgeons such as Drs. Dick Rudy and Wade Brinker were masters at pin application because there were few other choices, but also because they made the right choices and they could succeed.

Important Properties and Principles of Intramedullary Pins

The greatest mechanical virtue of the intramedullary pin is its resistance to bending forces at a fracture site. The strength and stiffness of an intramedullary pin is in part determined by its area moment of inertia, which is proportional to its radius to the fourth power. As pin diameter increases, stiffness and resistance to bending greatly increases. The stiffness of intramedullary pins also relates to a process of manufacturing the stainless steel. Steel used for pins is “cold worked,” a manufacturing property that increases stiffness. Compared to cerclage wire and bone plates, the steel used for pins is more resistant to bending and less ductile.

Although intramedullary pins resist bending forces well at a fracture site, they do not resist physiologic torsion (rotational forces) or compression forces. Comminuted fractures collapse in compression, with the consequence of a shortened bone. Rotational forces result in serious and dramatic rotational instability at most fracture sites unless addressed with other fixation methods. This concern is serious enough that intramedullary pins are rarely used alone, except in simple and stable fractures in rapidly healing young animals. The surgeon must almost always look to other fixation methods to control rotation at the fracture site and the simplest such method is to combine the use of cerclage wire with intramedullary pins.

Another positive property of intramedullary pins is the ease and simplicity of application and how this relates to healing biology of fractures. Intramedullary pins are generally applied with minimal or no surgical approach and minimal disruption of the soft tissue envelope surrounding the bone fragments. The healing potential of early callus is
preserved, as long as the surgeon does not disrupt it with inappropriate cerclage or other fixation.

The rules of cerclage wire application have been described in a previous lecture and will not be repeated here. If cerclage wire is to be used in combination with intramedullary pins, the single most important principle of cerclage application is not to break the rules. Inappropriate cerclage wires cause severe iatrogenic damage to fracture healing potential. Common errors of cerclage application include inappropriate disruption of tissue attachments, loose cerclage at fracture sites, and use of cerclage wire in complex fractures or larger animals, where other stronger ancillary fixation would be more appropriate. If the assets and liabilities of intramedullary pins and cerclage are well considered, excellent fracture fixations can result. As soon as the limits of pins and wire are exceeded, the surgeon should choose other combinations of pins with other systems. Intramedullary pins combined with external fixators, or with bone plates, create strong fixations that are respectful to healing biology.

Types and Applications of Intramedullary Pins

Intramedullary pins are either larger Steinmann pins (5/64 to ¼ inch diameter) or smaller Kirschner wires (0.028, 0.035, 0.045, 0.062 inch diameter). They are circular in cross section and have trocar or chisel points. Pins with negative profile threads are available, but commonly break at the thread-pin junction and should not be used. Intramedullary pins are most commonly inserted with a hand chuck, although slow speed power (<150 rpm) is also acceptable. Pin diameter selection is specific to the anatomy of each bone, but most commonly 60-75% of the medullary canal is selected at its narrowest point. This diameter is reduced if pins are used combined with external fixators or plates. Also, the canine tibia is a notable exception requiring a smaller diameter. “Stack” pinning refers to the use of multiple pins for the purpose of increasing torsional stability, compared to single pin stability. The mechanical advantage is marginal at best and if this technique is selected, care must be taken to avoid additional morbidity from pin migration, tissue irritation, and poor placement. Pin location and seating within the bone is specific to anatomic requirements of each bone. Either normograde insertion (proximal to distal) or retrograde insertion (inserted from fracture site in a proximal direction) must be selected. The humerus, ulna, and to some extent the femur are amenable to retrograde insertion. The femur and tibia are most amenable to normograde pin insertion. The radius does not receive intramedullary pins well, either normograde or retrograde, because of the articular surfaces. Intramedullary pins are not generally used in bones with too much curvature, such as the mandible or ilium. If used in the canine femur, a bone with a mild cranial bow, slight over-reduction of the fracture may improve seating of the pin distally. After successful insertion of an intramedullary pin, care must be taken to seat the pin as far as possible to achieve purchase in the cancellous bone without penetration of a joint surface. Estimates of pin length from radiographs
are useful, but intraoperative imaging with standard radiographs or c-arm are also useful. Pins are generally cut with a pin cutter as short as possible to avoid tissue irritation. Counter sinking may be of benefit.

**Summary**

Intramedullary pins continue to be an important fixation method for fractures of dogs and cats. Careful understanding of properties and principles allow successful use of intramedullary pins, either along or combined with other fixation systems.
Principles and Clinical Application of Interlocking Nailing

Laurent P. Guiot, DVM, Diplomate ACVS and ECVS
Learner Objectives:

- List the indications for and limitation of interlocking nails (ILN)
- Describe the components of the dedicated instrumentation used for ILN insertion
- Describe the surgical steps followed during ILN implantation
- Describe the biomechanical properties of modern ILN
Principles and Clinical Applications of Interlocking Nails

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Introduction: As learned in the lecture on fractures classification and biomechanics, the forces acting through a fracture site include compression, tension, shear, bending and torsion. The implants used to stabilize a fracture must resist these forces adequately in order to support bone healing. Intramedullary implants such as Steinman pins and Kirschner wires have been discussed in previous lectures. Remember that they provide excellent resistance to bending, but are intrinsically unable to resist the other forces acting at a fracture site and should never be used as a sole mean of fixation in metaphyseal and diaphyseal fractures. For this reason, surgeons often combine them with other implants such as bone plates or external fixators.

Intramedullary implants offer unique intrinsic properties such as the ability to restore axial alignment of a bone following insertion. They also offer the unique mechanical advantage of being placed along the neutral axis of the bone and the biological advantage to minimize interference with surrounding tissues since they are encompassed within the medullary cavity. To capitalize on these advantages, the designs of intramedullary implants progressively evolved to improve their ability to resist torsion and compression. In the early 1950’s, Modney and Bambara introduced the use of interlocking screws inserted through holes placed along the nail length to enhance its stability. This design is the hallmark of modern interlocking nails which are essentially large diameter intramedullary rods featuring a series of transverse holes allowing for the placement of locking devices. The locking devices are screws or bolts, depending on models. They are inserted from the cis cortex of the bone, into a corresponding nail hole within the medullary cavity and through the trans-cortex. Several dedicated veterinary systems have been independently designed since the early 90’s by Duhautois (France), Durall (Spain), Dueland (USA) and Dejardin (USA).

Figure 1: ILN are capable to resist all forces acting through a fracture site thanks to the insertion of locking bolts (or screws) in the main fracture segments. Nails size is maximized in length and diameter to take full advantage of its mechanical properties. One of the most recent advance in interlocking nail technology is the use of angle stable locking bolts that share a mechanical link with the nail and prevent postoperative slack.
**Instrumentation:** Nail insertion and placement of locking screws/bolts require specific instrumentation that is not interchangeable between systems. The dedicated instruments include 1) an insertion handle, to allow intramedullary placement of the nail, 2) an alignment guide or Jig, used to accurately identify holes location within the nail once it is in its intramedullary location 3) coupling extension rots, to link nail and jig together and 4) drilling sleeves.

![Image of instrumentation](image)

**Figure 2:** Interlocking nail mounted on an extension and with the jig assembly in place. Note the use of drill sleeves inserted through jig holes facing the corresponding nail hole positions. A temporary fixation bolt has been inserted in position 1, 2 and 4. The temporary bolts are used to stiffen the frame during drilling and prevent inadvertent polar bolt placement. The hammer and hammering peg (right side of the picture) are used to impact the nail deep into the metaphyseal region.

One of the key components to ILN placement resides in the accurate insertion of the locking devices. The most common technical mistake during interlocking nail fixation of fractures is the placement of locking bolts outside the corresponding nail hole resulting in a lack of construct stability. This is due to the inability for the surgeon to identify the exact location of the transverse nail holes once the nail is inserted into the medullary cavity. Mainly two techniques allow for proper and consistent identification of the nail holes: 1) the use of the alignment jig and 2) the use of intraoperative fluoroscopy. Note that the jig technique is used in the vast majority of veterinary applications.

**Biomechanics:** The efficacy of ILNs rests on several mechanical and biological advantages intrinsic to the fixation method. First, ILNs are made of heavily cold worked 316L stainless steel, which accounts for their high resistance to bending moments. In addition, ILNs have a relatively larger area moment of inertia (AMI) than comparable bone plates. Furthermore, and unlike solid
IM nails, ILNs are capable of resisting both torsional, compressive and shear forces by using screws or bolts passing through both bone cortices and nail (locking effect).

The interaction between the nail and the locking screws/bolts is responsible for the locking effect in ILNs. In older designs, this interaction is not rigid, leading to the presence of acute construct instability, also referred to as slack. The slack has been identified in a series of in vitro and in vivo studies as the leading cause of inter-fragmentary motion and has been correlated to delayed bone healing seen in clinical cases. An angle-stable ILN (AS-ILN) was subsequently developed to improve the stability of the nail-locking device interface and thus that of the repaired bone. The AS-ILN locking design consists of a threaded and tapered nail holes and size matched threaded dedicated locking bolts featuring a triangular section designed to engage the cis-cortex, a central threaded taper designed to create a mechanical lock with the nail hole and a smooth cylindrical end-section that engages the trans-cortex. The AS-ILN also features an hourglass profile designed to limit damages to the endocortices and medullary blood supply by the nail, thus preserving the biological advantages of ILN fixation, as well as an oblong bullet-shaped distal tip designed to optimize nail insertion in the distal metaphysis without risk of iatrogenic damage to the adjacent articulation. The direct benefits of improving ILN’s mechanical properties through the development of the AS-ILN was demonstrated in an in vivo study showing improved healing rates and enhanced functional outcome when compared to non-locking ILNs.

**Clinical applications:** ILNs are indicated for the treatment of long bones fractures, with the exception of the radius that does not allow for non-articular entry of an intramedullary implant. While the presence of slack in standard nails has traditionally limited the safe and reliable application of ILNs to the treatment of diaphyseal fractures, the development of AS-ILN has broadened their applications to include:

- **Primary fracture repair:** all simple and comminuted diaphyseal and metaphyseal fractures affecting the femur, tibia, humerus. Ulna fracture (large breeds)
- **Non-union/malunion:** Stabilization of critical size defects
- **Angular deformity correction:** Femoral varus (valgus) deformity and secondary medial (lateral) patellar luxation; uni/multi apical tibial deformities
- **Pathologic fractures:** Osteosarcoma of proximal femur and humerus (palliative treatment)
Surgical technique: The choice of an appropriate nail is based on pre-operative radiographs of the opposite intact bone segment. Templates are used to verify that 1) enough bone is available proximally and distally to secure the nail via at least one locking device in each main fragment and 2) that the bone medullary diameter can accommodate the chosen nail. During surgery, the nail may be implanted using closed (Figure 6) or open techniques. Normograde preparation of the bone medullary cavity using Steiman pins of increasing diameters is performed until it can accommodate the nail. While the use of the largest possible nail has been recommended to improve construct stability, such choice often requires aggressive reaming of the medullary cavity. Conversely, using a smaller nail presents several advantages including easier placement without need for intramedullary reaming in bone of various sizes and shapes, better preservation of the medullary blood supply and reduced risk of fat embolization and infection. The hourglass profile of the new AS-ILN allows implantation without reaming. The use of a dulled or specifically designed bullet-nose nail helps with restoration of the bone initial length while preventing accidental penetration of the distal joint. With the nail seated in the distal metaphysis, the inserting tool is removed from the nail, which is then rigidly attached to the dedicated alignment guide via an extension piece. A series of specialized sleeves, drills, measuring and/or tapping guides are then used to properly insert the locking device through the corresponding nail holes.
Alignment in all dimensions is corrected if necessary prior to final placement of the locking devices. The holes for locking bolts insertion are drilled in sequence from proximal to distal while temporary stabilizing bolts are used to rigidify the frame and reduce the risk of polar bolt placement (i.e. missing the nail hole). The jig is then removed and stabilizing bolts are replaced sequentially with permanent locking bolts. The use of additional cerclages and bone graft is left to the discretion of the surgeons but in the author’s opinion is rarely recommended if at all necessary.
SUGGESTED READING

Principles and Clinical Application of External Fixator

Prof. Bruno Peirone
Principles and Clinical Application of External Fixator  
Prof. Bruno Peirone

Learner Objectives:

- Explain the biomechanics of various construct and types of linear external fixator
- Develop a basic understanding of external fixator application including insertion of fixation pins, proper fixator configuration and post-operative management
- Distinguish potential advantages and disadvantages of external skeletal fixation in fracture repair compared to other methods of stabilization
Principles and Clinical Application of External Fixator
Prof. Bruno Peirone
School of Veterinary Medicine - Turin

Introduction
Whenever a decision to use the ESF is made, two considerations dictate the choice of frame. First - the biomechanical problems produced by the fracture and secondly biological aspects of the fracture. The ESF is an extremely versatile method of producing fracture stabilization and as such almost any mechanical situation can be provided for. Of greater concern are problems produced by the fixator traversing the soft tissue surrounding the bone. Problems can be produced if major vessels or nerves are damaged either by insertion of the pins or as a result of pins penetrating muscle bellies. The first of these complications is disastrous and must be avoided at all costs.
The second, penetration of muscle bellies by pins, may be unavoidable depending on the configuration of frame used. Because the primary aim of fracture stabilization is early weight bearing and mobility muscles penetrated with pins will be compromised as the animal uses the leg. The result of this interaction is either premature loosening of the pins and/or excessive discharge from the pin tracts. All these facts must be accounted for before selecting a frame type for fracture stabilization.

Biomechanics
When a surgeon creates an external fixator, the aim is to provide optimal stability for the vascular and cellular events of fracture healing to proceed as rapidly as possible. If the fixator is too robust, there will be little motion of the fracture fragments, and, potentially, delayed healing. If the fixator is too flimsy, the fragments may move excessively, causing pain, disruption of the soft callus, and, again, delayed union. Any method of fracture fixation must counter the axially aligned forces of weight bearing and muscle contracture, bending forces from eccentric loading, and rotational forces from turning. There are a number of factors in frame construction and design that influence how well a fixator will be able to control these forces. Bending is the primary way in which the elements of a fixator resist the various loads being applied and two engineering concepts are useful in the understanding of their performance.

The first is that “SHORTER IS STIFFER”. If you have two pins of the same diameter, the shorter one will deflect the least when the same load is applied to the system.

The second is “THICKER IS A LOT STIFFER”. This concept is best appreciated by understanding the parameter – Area Moment of Inertia (AMI). AMI is a little like cross-sectional area but goes further, as it describes how the material of a structure is distributed around its neutral axis. The neutral axis is a variable axis that is determined by the direction of bending. The important thing to understand about AMI is that, for round structures (like pins and connecting bars), it is calculated using the radius raised to the FOURTH power. That means that, for small increases in diameter, there will be a very significant increase in the pins’ ability to resist bending.
For structures of more complex dimension, the thickness in the direction of bending will have the greatest influence on the AMI.
Understanding the concept of AMI also helps with appreciating why a frame with a more 3-D geometry is capable of resisting bending forces better than a simpler frame. When the structural elements are distributed around the bone, rather than just on one side, the AMI is greatly increased. It is essential to have at least two pins per fragment to prevent rotation of the fragment. Stability and longevity of the pin-bone interface will be improved by using 3 or 4 pins per fragment. An old adage was that pins needed to be angled at 70 degrees to one another. This often made it difficult to place more than two pins. With positive profile threaded pins, angulation is rarely necessary, and a stronger fixator will usually be created using three parallel pins than two angled pins. It also is often advantageous to select three smaller diameter pins rather than two larger diameter pins, particularly if the rule that the pin diameter must be less than 25% of the bone diameter is being compromised. In most cases, it is best to build a frame that spans the whole length of the bone. Care must be taken in positioning the pins that are closest to the fracture. The pin should be placed 2 to 3 of its diameters away from the fracture to minimize the chance that further splitting of the fragment will occur. If fissures are suspected on pre-operative radiographs, this distance should be increased. The pins closest to the fracture should be angled a little to reduce the length of the connecting bar that spans the fracture.

Because the pins are the smallest diameter element of a frame, overall stiffness will be improved if they are kept as short as possible. The primary plane of the fixator should be chosen so that the least amount of soft tissue is penetrated. The clamps should be oriented so that the gripping bolt is closest to the patient. The clamp should be positioned so that it is sufficiently far away from the skin so as not to touch, but not too far that pin length is unduly long. In some instances, the clamps might be moved closer to the bone after the initial swelling has resolved.

The number and distribution of the connecting bars also influences the ability of the frame to resist the loading forces. Using our engineering principles, the span and the diameter of the connecting bar will influence the stiffness. There is little choice in connecting bar size, but adding a second connecting bar can greatly increase frame stiffness. Moving to more complex frame configurations has the greatest effect on frame stiffness. Using full pins proximal and distal and creating a partial bilateral frame, greatly increases the AMI of the frame (for medio-lateral bending) because load bearing elements are now distributed on either side of the bone. Bending in the medial-lateral plane is greatly reduced. Bending in the cranio-caudal plane is also reduced because there are now two connecting bars in the frame. However, placing a connecting bar in the cranial plane, to form a triangular configuration, can stiffen the frame even further. The AMI of a triangular frame is increased no matter what bending direction is considered.

**Clinical Advantages of External Fixation**

External skeletal fixation (ESF) is an extremely versatile form of bone and joint stabilization in cats, dogs, and exotic species, allowing for early use of the operated limb. ESF can be used to stabilize fractures and osteotomies, as well as provide joint immobilization for the treatment of tendon repairs, luxation or arthrodesis. It can be used as the sole form of fixation or as a secondary stabilization for internal bony or soft tissue...
repair. ESF allows for additional and often flexible options for challenging fracture configurations, particularly those adjacent joints. As the fracture heals, portions of the frame and pins can be removed to allow for increased micromotion and enhanced fracture healing, so called staged disassembly or sometimes dynamization.

**Limiting Factors for ESF**

While external fixators are extremely versatile, the individual fracture configuration, location, affected bone, and available equipment will play a role in the usefulness of a particular form of external fixation. Additionally, one must consider the available soft-tissue corridors for pin and connecting bar placement. The most common limiting factors are joint interference and the body wall for humeral and femoral fractures. One must not underestimate the importance of patient and client selection and consultation. Owners must be informed and educated on the post-op appearance, home care, and recheck requirements for external fixators. Temperament and lifestyle of the patient must also be considered. If the animal is feral, aggressive, or unable to be kept confined and monitored while wearing the frame, the use of external fixation should be carefully considered.

**Frame Selection and Application**

The injury type (soft tissue injury versus open, closed, comminuted, simple, or transverse fractures), location (bone, metaphyseal, diaphyseal, intrarticular), patient characteristics (age, weight, activity level) all play a role in planning the frame application. The biomechanics of ESF have been reviewed previously, and variables which may be altered to tailor the frame to the specific case include pins (type, number, configuration, the shank and thread diameter, the thread shape and pitch), fixator type (Ia, Ib, II, III), and connecting rods (material, number, configuration). Pins should be placed through ‘safe corridors’ in order to avoid important structures including neurovascular bundles, large muscle masses, and the body wall. The ideal placement of unilateral frames is medial for the tibia, medial or craniomedical for the radius, craniolateral for the humerus and lateral for the femur. The body wall prevents bilateral frames in the humerus and femur, except in very leggy dogs. ESF allows for a completely closed approach to the fracture site which enhances healing due to preservation of the hematoma and blood supply. When applied in a closed or minimal approach, alignment of the limb is of utmost importance. Placing the proximal and distal pins parallel to their respective joints and then aligning those two pins parallel to each other can achieve alignment. Assistance with alignment and limb length restoration can be had by using the hanging-leg technique and through the use of fluoroscopy.

**Pin Placement**

To ensure maximal stability, pins should be placed in the center of bone. Threaded pins are preferred to smooth pins, as they have a stiffer bone-implant interface and resist loosening. Smooth pins must be at angled to the surface of the bone in order to reduce pull-out, maximize stiffness, and decrease loosening. Adequate placement of smooth pins can be challenging in small dogs or with small fracture segments. Pins must be placed no less than 2-3x’s the pin diameter or greater than 1/2 diameter of bone from fracture planes. At least 2-4 pins should be placed in each fracture segment. The pin clamp connection should be
placed close to the skin but with enough room to allow for soft tissue swelling. Shorter pins are stiffer. Stiffness can also be increased by adding connecting bars. Prior to pin insertion, a 1 cm longitudinal skin incision should be made and blunt dissection performed to the level of the periosteum. With the aid of a drill guide and a stickette drill bit, the hole should be pre-drilled to approximately 80% of the pin diameter (typically 0.1mm smaller) under low speed (<300 rpm). The pin can then be inserted with power, under low speed. For linear frames, it is often easiest to insert the most proximal and then most distal pins first, then attach the connecting bar and finally place the subsequent pins by drilling through clamps attached to bar. Specialized aiming devices are available for Type II frames.

Post-Operative Care

After frame application, leave pins long prior to initial post-op radiographs, so that adjustments can be made if needed. The bolts should then be retightened and pins cropped. A bandage should be placed on the limb with sponges placed between the skin and frame to provide light compression, decrease swelling and edema. Pain management typically consists of NSAIDs and opioids and should be tailored to the specific patient. Animals should be confined for the duration of fixation and care taken to protect the frame. Pin tracts may be gently cleaned with a dilute 0.05% chlorhexidine solution. The frame should be assessed weekly and radiographs performed every 3-5 weeks until the fracture or osteotomy has healed. If a limb is being distracted, radiographs should be taken more frequently, typically every 7-10 days during adjustments, and then every 3-4 weeks. Linear frames can undergo staged disassembly to enhance bone healing. Such planned removal of fixator bars and pins decreases the rigidity of the frame and increases micromotion at the fracture site, which in turn may accelerate healing. Pins with morbidity should be removed first. Typically, frames may be down-staged at 4-6 weeks post-operative, but timing should be based on the degree of bone healing present on radiographs. Frame removal can typically be performed under heavy sedation with the use of a pin cutter and hand chuck. A light wrap may be placed on the limb for 8-12 hours if bleeding occurs from the pin tract sites. Exercise should be restricted for an additional 3-4 weeks after frame removal to allow bone to fill in the pin tracts.

Literature


Fracture Planning and Basic Instrumentation Needs

Marc Wosar, DVM, MSpVM, DACVS
Learner Objectives:

- Describe the steps involved with planning for operative fracture repair
- Identify the tools and techniques available to aid in fracture planning
- Describe the various instrumentation needs for basic and advanced operative fracture repair
Fracture Planning and Basic Instrumentation Needs

Marc Wosar, DVM, MSpVM, DACVS
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Orthopedic surgery lends itself to detailed planning, since imaging allows for a detailed understanding of the fracture before surgery. Because of the variety of implant/bone combinations, such planning is fundamental to the success of the procedure.

Planning proceeds in several steps, addressing:

1) the patient
2) the fracture
3) the instrumentation
4) the surgeon

First, the patient’s needs must be evaluated. Shock and other injuries must be tended to, particularly in high energy trauma events. The integrity of internal organs like the diaphragm, urinary bladder and spleen must be ensured or repaired. Open wounds, including open fractures, must be addressed. Pain must be adequately controlled. During this phase of patient management, fractures take a secondary priority; damage control can take the form of a temporary splint, if applicable to the bone. After the patient is stable and higher priority injuries are repaired, then the fracture(s) can be addressed and operation(s) prioritized.

The fractured bone is evaluated in context of its anatomy. The health of the soft tissue envelope is necessary to bone healing, and must be critically evaluated as it will influence the choice of fixation. Open fractures or trauma that disrupts the integrity of the soft tissue attachments to bone (e.g. gunshot wounds) must be individually evaluated and addressed, either before or at the same time as fracture fixation. The neurovascular status of the limb must be assessed, since any deficits may render a successful orthopedic surgery useless.

The bone can then be evaluated with imaging, usually with radiographs or CT. When radiographing fractures, the fundamentals of radiology must be followed: at least two standard orthogonal views must be made, with additional oblique or skyline views obtained if needed. The joints on either side of an affected bone must be included, even if the injury appears to be limited to one extremity of the bone. Open growth plates can make evaluation difficult, so radiographs of the contralateral normal limb can be very useful. There are certain circumstances where additional projections are absolutely required. For example, standard extended leg ventrodorsal projections of the pelvis (the OFA view) can iatrogenically reduce capital physeal fractures in young dogs, making them appear normal. In this case, a flexed hip ventrodorsal view (frog-leg) is necessary to ensure that there is no physeal injury. Distal tibial fractures often involve the articular surface, but in the craniocaudal projection with the hock extended, that surface is
obscured by the overlying calcaneus. A flexed-hock skyline projection is required to assess for articular involvement.

CT scans can be very helpful in evaluating complex fractures, especially of the axial skeleton and pelvis. Transverse CT images can be reconstructed and viewed from multiple planes. This Multiplanar Reconstruction (MPR) is especially useful for evaluating extension of fracture lines and fissures into joints (acetabulum, carpus, elbow) or involvement of sensitive neural structures (sacral foraminae, articular facets of the spine). Three dimensional reconstructions are especially valuable for understanding the architecture of complex fractures.

Fractures must be evaluated relative to the forces acting upon them. Long bone shaft fractures are under compressive, bending and torsional forces. Other forces to be aware of are tensile forces (especially at the insertion of ligaments and tendons, like the olecranon and calcaneus). Patient factors to keep in mind are the interaction of other injuries (e.g. contralateral limb injuries, hip dysplasia, neurologic disease), the patient’s temperament, and owner capabilities that impact the patient’s recovery, and therefore may place greater stress on the healing bone.

With the imaging completed, the architecture of the fracture can then be understood using a variety of methods. The Direct Overlay method uses tracings of the individual fracture fragments. The tracings of the fragments are then “reassembled” to visualize a reconstructed bone in order to measure for implant fit and placement. A radiograph of the normal contralateral bone can be used as a template for this reconstruction (the radiograph must be flipped in order to match the orientation). Templates of various sizes and types of implants are available to overlay onto the reconstructed bone to evaluate fit relative to joint surfaces and fracture lines. If using digital radiography, there are several programs that allow this “tracing and reassembly” to be performed digitally, including templates of available implants for overlay.

Bone models, either prepared cadaver bones or plastic bones, can be used for a further three dimensional understanding of the fractured bone and how an implant may be applied. Fracture lines can be drawn onto the model in pencil using radiographs or CT scans as a guide, and if the bone is of the right size and conformation, implants can be pre-selected. The major limitation of bone models is finding a specimen of the same size, side and conformation as the patient’s. The temptation to pre-contour the implants too precisely on a generic bone model must be resisted — it should only be used as a guide.

Truly custom bone models precisely representing the patient’s bone, including all identifiable fractures and fissures, can be made via stereolithography, or rapid prototyping. Image data from a CT scan can be used to construct a life-sized three dimensional model of the fractured bone, and also of the normal contralateral bone. These models can be ordered from several companies, or can conceivably be printed on-site using a desktop 3D printer. These models are made out of ABS or PLA plastic, which can be drilled, tapped, and sawn just like real bone, allowing the surgeon to “practice” the surgery. After practice, implants like bone plates can be removed, sterilized and used in surgery. This
allows for more careful and leisurely selection and contouring of implants, without the 
fracture being obscured by overlying soft tissues, saving much time and frustration in the 
operating theater. The surgeon must be prepared for the possibility that fissure lines or 
other features of the fracture exist in the clinical patient that are not identified in the CT 
scan data. The price of desktop versions of these 3D printers is now in the range that is 
reasonably affordable for large hospitals ($1500-3000). Future innovations will likely 
allow custom implants to also be constructed using computer models of the fractured 
bone.

Operative fracture repair requires a large investment in instrumentation. Basic surgical 
instruments are needed for the approach and closure. Fracture-specific instrumentation 
include instruments to manipulate soft tissues. Retractors can be hand-held (Army-Navy, 
Senn, Meyerding, Hohmann) or self-retaining (Gelpi, Weitlaner). Instruments to 
manipulate bone include elevators (Freer, Keys, AO) bone holding forceps (Lane, Kern, 
Crab-claw) and reduction forceps (pointed reduction forceps of various configurations). 
Power instruments are not optional, as hand drilling with a Jacob’s chuck is imprecise 
and results in wobble which produces large holes and loose implants. Various additional 
instruments are also very valuable like aiming devices, fracture distractors, fluoroscopy, 
etc. There is a very large collection of implant-specific instrumentation that will also be 
needed, but will be covered separately.

The final step in fracture planning is an honest assessment of the surgeon’s abilities and 
equipment. The surgeon must not proceed with surgery if his/her abilities do not match 
the requirements of the surgery. All preoperative planning may have to be abandoned 
depending on real-time findings at surgery. It is very common to discover large fissures 
or other factors that were not apparent during preoperative planning, which render the 
plan invalid. The surgeon must have the ability to change course and seamlessly 
transition to a different technique intraoperatively. Resist the temptation to enter surgery 
with only one available implant or technique, or to have the available implants dictate the 
surgical plan. An honest surgeon will recognize their limitations, and avoid doing harm to 
their patients due to inadequate planning or limited instrumentation and implants.
Principles and Clinical Application of Cancellous Bone Grafting and Bone Graft Substitutes

Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS, ECVS
Principles and Clinical Application of Cancellous Bone Grafting and Bone Graft Substitutes

Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS, ECVS

Learner Objectives:

- Describe the functions and incorporation of autogenous cancellous bone grafts
- Describe the basic surgical application of bone grafting
- Recognize the potential advantages and limitations of bone graft substitutes
Introduction

Use of bone grafting to augment bone healing is an important technique in small animal orthopaedics that has been widely used for many years. Use of an autogenous bone graft remains the gold standard for stimulation of fracture healing. Here, bone graft is transplanted from donor to recipient site within the same individual. In recent years, use of bone allograft has also become more widely used, particularly since allograft bone has become available commercially. Here bone is transplanted from one individual to another of the same species. Allografts are particularly useful for reconstruction of large bone deficits.

Bone Graft Functions

Grafts can function in several different ways to support bone healing after grafting:

(1) Osteogenesis. Transplantation of viable osteoblasts and mesenchymal stem cells that can act as osteoblast progenitor cells during grafting will promote bone formation at the recipient site. In this regard, careful handling of the graft during transplantation is important to maximize survival of transplanted bone cells (McAnulty 1999).

(2) Osteoinduction. Release of growth factors from the transplanted bone matrix, such as bone morphogenetic protein (BMP), will facilitate recruitment of recipient osteoprogenitor cells into the graft site and further promote bone formation.

(3) Osteoconduction. The matrix of transplanted bone also acts as a scaffold that aids tissue in-growth, vascularization of grafted bone tissue, recruitment of recipient osteoprogenitor cells, and proliferation of osteoblasts within the grafted bone tissue.

Healing of Cancellous Bone Grafts

The process of envelopment and remodeling of the bone graft is termed incorporation. After transplantation of cancellous autograft, revascularization of the graft tissue is usually complete by approximately 2 weeks and osteoblast proliferation is well established. Necrotic bone trabeculae are rapidly remodeled and eventually will be fully incorporated into the parent bone. Osteogenesis peaks around 6 to 8 weeks and graft remodeling will continue for many weeks. With use of cancellous allograft, graft incorporation will be slower and less complete.

Indications for Cancellous Bone Grafting

Use of cancellous bone grafting, particularly autogenous grafting, is indicated for several different types of orthopaedic surgery:

(1) Fracture repair. Construct instability is the most common major complication of fracture repair in dogs and cats (Emmerson & Muir 1999). Therefore, rigid fixation and provision of an osteogenic stimulus to the fracture is a general goal during treatment of long bone fractures in all adult patients. Use of a bone graft is particularly important in patients that may have delayed bone healing, such as elderly patients, or patients with a fracture that is at higher risk of complicated healing, such as an open or highly comminuted fracture.
Arthrodesis. Use of cancellous bone graft is generally indicated for augmentation of joint arthrodesis. Union of the subchondral bone of joint surfaces can take a long time. Use of cancellous bone graft can significantly reduce the time to union of an arthrodesis (Johnson & Bellenger 1980), and therefore reduce the risk of complications with arthrodesis healing.

Delayed and non-union fractures. Patients with complicated fracture healing will also benefit from use of cancellous bone graft during revision surgery. Provision of a robust osteogenic stimulus to the fracture during revision can be critical to obtaining a successful outcome. Distal antebrachial fractures in toy breed dogs are a common site for delayed or non-union fracture.

Treatment of osteomyelitis. If osteomyelitis is associated with a delayed or non-union fracture or simply loss of bone tissue, cancellous bone grafting of the bone defect is an important component of a comprehensive management plan (Johnson 1994). Grafting is typically delayed until the bone infection has been controlled, usually 7 to 14 days after initial debridement (Johnson 1994).

Augmentation of osteotomy healing. Long bone osteotomies are often treated with cancellous bone grafting to stimulate osteotomy healing. For example, as tibial tuberosity advancement surgery has become more widely adopted, use of cancellous allograft has been widely used to reconstruct the tibial crest defect created by the osteotomy procedure.

Cortical allograft interface healing. Incorporation of large cortical allografts is very slow and union of the interface between allograft and host bone can also be slow. Cancellous bone autografting is indicated to augment interface healing during reconstruction of a large bone defect.

Revision arthroplasty. Loss of bone tissue is a common feature of failed prosthetic joint replacement. If revision arthroplasty is contemplated, cancellous bone grafting is often used during treatment of bone defects.

Collection and Transplantation of Cancellous Bone Graft

Aseptic technique should be used for collection of cancellous bone graft. If necessary, separate instruments and surgical gloves and attire should be used to prevent contamination of the graft site. The proximal humerus is the most commonly used donor site. Other sites include the proximal tibia and proximal or distal femur. Healing of the donor site is well advanced by 12 weeks, such that the graft site could potentially be re-used (Johnson 1988). Major complications associated with the donor site are rare, although fracture of the donor bone is possible. If a larger volume of autograft is needed, mixed cortico-cancellous graft can be collected from the wing of the ilium or a rib.

After collection, storage time should be minimized before the graft is placed in the recipient site. If fresh cancellous bone autograft is used, use of hypothermic organ preservation solution will increase survival of transplanted bone cells after warm reperfusion, by reducing temperature-dependent cell injury (McAnulty 1999).

Cancellous Bone Graft Substitutes

Artificial bone matrix substitutes. A variety of artificial or synthetic bone matrices are available. These often contain tricalcium phosphate or hydroxyapatite and are largely osteoconductive. Examples include Consil® (Nutramax Laboratories), or Cerasorb®
(Veterinary Orthopedic Implants). This type of ceramic material is often mixed with blood, bone marrow, or with cancellous bone autograft as a void filler for bone defects.

**Demineralized bone matrix.** Allograft bone is typically used for preparation of demineralized bone matrix and is processed so that the cells and the mineral content are removed. Preservation of growth factors means that this type of graft material has the potential to be both osteoinductive as well as osteoconductive. Again, this material can be mixed with autogenous tissues to increase the volume of the graft.

**Bone morphogenetic protein.** BMP signaling is complex and can provide a potent stimulus for undifferentiated mesenchymal stem cells to proliferate into chondroblasts and osteoblasts for endochondral ossification. Recombinant BMP-2 is typically used with a ceramic graft material as a bone graft substitute. Preliminary reports on use of this material suggest that it is a potent osteoinductive agent (Milovancev et al. 2007).

**Platelet-rich plasma (PRP).** Use of autogenous PRP in combination with cancellous bone grafting may further augment osteoinduction and clinical healing of fractures, osteotomies, or bone defects, based on experimental studies. The clinical value of this approach remains to be determined and experimental data are limited.

**References**
AOVET North America

Principles in Small Animal Fracture Management Course

SATURDAY LECTURE ABSTRACTS
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Principles of Joint Fracture Treatment

Steven C. Budsberg DVM, MS, Diplomate ACVS
Learner Objectives:

- List the fundamental principles of intra-articular fracture treatment
- Explain how the failure of anatomic reduction in the treatment of an intra-articular fracture might adversely affect long term joint function
- Describe examples of how specific implants are used to repair intra-articular fractures
**Principles of Joint Fracture Treatment**  
Steven C. Budsberg DVM, MS, Diplomate ACVS

**Introduction**
An intra-articular or joint fracture can be defined as one that extends inside the synovial cavity and involves the hyaline cartilage. In adult animals a wide variety of intra-articular fractures are encountered, and some occur in combination with diaphyseal fractures. Common examples include Y fractures of the distal humerus, lateral condyle fracture of the humerus, and acetabular fractures. In addition to the major adult intra-articular fractures, we also need to consider fractures of the immature animal, including Salter-Harris fractures (types III and IV).

**Consequences of Intra-articular Fractures**
Sharp bone edges of fracture fragments physically abrade the opposing articular surface. Also some cartilage surfaces may be subject to mechanical overloading leading to OA. Laxity of the joint permitted by the fracture and interruption of ligament support (e.g. malleolus) also allows instability, and later OA.

Intra-articular fractures treated by rest or coaptation, without accurate reduction or internal fixation, show little tendency to heal. Typically there will be widening of the fracture gap, resorption of bone, displacement of fragments and only a fibrous union. Bone in this region is covered by articular cartilage, not periosteum, so no periosteal bone callus forms. However, a fracture that extends to the metaphysis may reunite by bone in that region, albeit in a displaced position. Reasons for lack of union of intra-articular fractures include the continuous interfragmentary motion induced by joint movement, presence of synovial fluid in the fracture gap, and reliance on endosteal callus for union.

**Principles of Joint Fracture Repair**

1. **Surgical approach and arthrotomy**
   Approaches must allow adequate visualization of the joint cavity and cartilage surfaces, appropriate to the procedure planned.
   a) Skin incisions are made in the long axis of the limb to minimize tension on the suture line and avoid ischemia of the wound margins.
   b) Tendons in the lower limbs are often contained in synovial sheaths and are never transected, but the sheath can be incised longitudinally and the tendon carefully retracted. Ligament transection should be avoided. An alternative technique is osteotomy of the ligament attachment, and reattachment by a screw and spiked washer (e.g. medial epicondyle of the humerus containing the proximal insertion of the medial collateral ligament) or two Kirschner wires and a figure of eight tension band wire (e.g. medial malleolus of the tibia).
   c) Joint capsule is incised with a 10 or 15 blade, avoiding the underlying articular cartilage. Close with 4/0 or 3/0 simple interrupted sutures of synthetic absorbable material, placed in the outer fibrous layer of the joint capsule.
2. **Anatomic Reduction**

   Reduction of fractures should be perfect with anatomical alignment of the articular cartilage surfaces. Temporary reduction is maintained with small reduction forceps with points or Kirschner Wires. Protect articular cartilage from damage and drying during surgery by keeping it moist and avoiding putting pressure on it.

3. **Internal Fixation**

   1. Bone screws: If the fracture consists of 2-3 major fragments and these can be adequately reduced, then bone screws may be used for fixation. Screws are inserted so that they function as lag screws, causing compression at the fracture line. Either cancellous or cortical screws can be used, provided correct insertion techniques are followed.

   2. Kirschner wires can be combined with screw fixation to prevent rotation of fragments, or used as temporary fixation then removed, or used alone for fragments that are too small to be screwed.

   3. Bone plates are used to reattach the condyles to the diaphysis once the articular fractures have been reconstructed with lag screws (e.g. Y fractures of the distal humerus). Implants used for these reconstructions include standard and broad DC reconstruction and curved plates.

4. **Postoperative Management and Physical Therapy**

   Early mobilization of the joint is important to reduce fibrosis and scarring and to maintain or re-establish the normal range of motion. After a fracture and repair, the range of motion is usually reduced. Prolonged immobilization of the joint may result in permanent dysfunction. Rigid fixation is necessary in the early stages after fracture repair because motion of the joint is encouraged and the fracture must remain reduced. Methods of mobilization include intermittent passive motion, intermittent active motion, and continuous passive motion. Once the animal has recovered from surgery, the rehabilitation period begins. Perhaps one of the most common mistakes in this phase is stopping analgesic therapy (pain management) too quickly. Tapering the amount of medication is often not considered in our patients. Usually, postoperative drugs are halted within 12-24 hours postoperatively without additional therapy. A good example of how to correctly taper analgesia in an orthopedic patient after surgery would be to follow-up preemptive analgesics with the use of a fentanyl patch, dovetailed with nonsteroidal therapy as the patch starts to lose its potency. Proper use of analgesia will also help with the physical therapy, which you will begin almost immediately.
Physical Therapy

Physical therapy (PT) is a valuable part of the management of the articular fracture patient. PT can help with decubital ulcers, improve blood flow and lymphatic circulation, reduce pain and help the musculoskeletal system by maintaining muscle tone, and preventing muscle contracture and joint stiffness. PT includes thermal treatment, passive and active exercise.
Growth Plate Fractures

Jonathan Dyce, MA VetMB DSAO MRCVS Diplomate ACVS
Growth Plate Fractures
Jonathan Dyce, MA VetMB DSAO MRCVS Diplomate ACVS

Learner Objectives:

- Describe the anatomy of the physis and state why fractures commonly occur through this portion of bone in immature animals
- Identify and apply the Salter-Harris classification scheme
- Describe challenges in physeal fracture management
GROWTH PLATE FRACTURES
Jonathan Dyce, MA VetMB DSAO MRCVS Diplomate ACVS
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The growth plate

• The growth plate is a specialized region of cartilage that develops from the hyaline cartilage surrounding the enlarging secondary centre of ossification in the epiphysis. It is responsible for longitudinal bone growth, by the process of endochondral ossification. The diameter of bone is increased by appositional growth from the periosteum.

• There is an orderly progression in maturation of chondrocytes from the epiphyseal to the metaphyseal border of the growth plate. Germinal, proliferative, hypertrophic, and calcification zones are recognized within the chondrocyte columns of the growth plate. Stratified changes in the composition and distribution of extracellular matrix (predominantly type II collagen and proteoglycan) are permissive of calcification and metaphyseal vascular ingrowth.

• The open growth plate is the weak link of the skeleton, being only 20-50% as strong as the adjacent joint capsule and ligaments. The zone of chondrocyte hypertrophy is the weakest region, due to the relatively high ratio of cell to matrix volume. Transverse fractures through this zone do not damage the germinal zone and therefore, with appropriate management, growth should continue. Although this pattern of cleavage can be produced experimentally, it is uncommon for the germinal zone not to be disrupted, even in simple epiphyseal separation. Such mechanical injury of the germinal zone, or ischemia due to epiphyseal vascular compromise may irreversibly damage the potential for growth.

The Salter-Harris classification
The Salter-Harris classification is based upon fracture configuration and is related to the prognosis for subsequent growth disturbance.

<table>
<thead>
<tr>
<th>Type</th>
<th>Fracture</th>
<th>Common location</th>
<th>Prognosis for normal growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>physeal separation</td>
<td>proximal femur</td>
<td>good (if vasculature not compromised)</td>
</tr>
<tr>
<td>2</td>
<td>physeal with metaphyseal fragment (Thurston Holland sign)</td>
<td>distal femur</td>
<td>good</td>
</tr>
<tr>
<td>3</td>
<td>physeal with epiphyseal (intra-articular) fragment</td>
<td>proximal tibia</td>
<td>fair</td>
</tr>
<tr>
<td>4</td>
<td>metaphyseal, physeal, and epiphyseal (intraarticular)</td>
<td>distal humerus</td>
<td>good-guarded</td>
</tr>
<tr>
<td>5</td>
<td>physeal crush</td>
<td>distal ulna</td>
<td>very poor</td>
</tr>
</tbody>
</table>
• Growth plate injury involving transphyseal bridging by new bone has been designated a Type 6 injury. This phenomenon may be seen in association with hypertrophic osteodystrophy of and carries a poor prognosis because physeal crushing has frequently occurred by the time of diagnosis.

• A relatively poor outcome for Type 1-4 fractures may be the result of radiographically covert damage to the germinal zone.

• Growth plate injury can occur without massive trauma. Diagnosis may be difficult initially, especially for type 5 injuries, in which radiographic changes may be absent.

Other prognostic guides

Growth plate injury is common in small animals and can cause premature growth plate closure. The severity of resultant angular, rotational or length deformity, and the subsequent disability is dependent upon a number of factors which must be considered in association with the Salter-Harris classification.

1. **Age.** The age of functional closure of the growth plates varies with their location, however there is rarely significant growth beyond 7-8 months. The potential for massive deformity is obviously greatest in the younger animal with growth plate injury.

2. **Castration** in cats is associated with a delay to growth plate closure. Consequently Salter-Harris fractures can be seen in neutered males beyond the normal age of skeletal maturity. There is increasing scrutiny of early neutering of dogs in this regard.

3. **Breed.** Compare giant breeds, which are commonly presented for the investigation of growth plate abnormality, to chondrodystrophic breeds, which are characterized by growth deformity.

4. **Bone involved.** The degree of deformity that results from involvement of one paired bone, e.g. ulna, is likely to be relatively severe as residual growth in the other bone may magnify the deformity.

5. **Blood supply.** Degree of displacement, and regional anatomy should be considered. The vascular supply to the femoral capital epiphysis is particularly vulnerable because the entire epiphysis is intra-articular.

6. **Delay to surgery.** Ongoing germinal zone trauma will occur in unstable fractures. Early reduction and sparing of the germinal zone offers a favorable prognosis. Atraumatic fracture reduction becomes significantly more difficult with time.

7. **Quality of repair.** Prognosis is favored by stable repair that does not compromise the potential for growth. Anatomic reconstruction of joint surfaces is mandatory for Type 3 & 4 fractures. Post-traumatic osteomyelitis is a rare but devastating complication of physeal repair.

8. **Potential for joint incongruity.** Cases of premature distal +/- proximal radial growth plate closure are frequently presented without gross deformity, but for lameness secondary to elbow subluxation. Patients with chronic subluxation or joint malalignment are predisposed to secondary osteoarthritic pathology.
Physeal fracture management - General Principles

1. **Ensure that owners are informed**, in advance, of possible complications. Any case of pediatric trauma should be considered at risk of premature growth plate closure.
2. **Ensure that owners are informed**, in advance, of possible complications. Any case of pediatric trauma should be considered at risk of premature growth plate closure.
3. **Prompt diagnosis**. Consider radiography of the contralateral (normal) limb for comparison if a minimally displaced growth plate fracture is suspected.
4. **Early reduction**. Although closed reduction and external fixation / coaptation should be considered, most cases require open reduction. A delay to repair of several days will necessitate disruption of early callus, and vascular compromise, during reduction. Prompt fixation is especially important in cases with articular involvement.
5. **Preserve soft tissues**. Manipulate fracture fragments carefully. Levers should not be introduced into the fracture plane. NB. Germinal cells are on the epiphyseal surface.
6. **Internal fixation** is challenging because of small juxta-articular fragments of soft bone. Use small parallel K-wires / non-threaded Steinman pins placed perpendicular to the physis to avoid physeal compression. Implants should occupy <20% growth plate surface area, and should not interfere with joint function. Transphyseal plates will cause asymmetric premature growth plate closure and should not be used. Biodegradable devices e.g. polyglycolic acid rods, may offer significant advantages for internal fixation of physeal fractures. Consider adaptation osteosynthesis or transphyseal dynamic ESF (Type I/II distal radial growth plate fracture).
7. **Postoperative management**. Early controlled mobilization is the goal for preservation of growth plate and joint function.
8. **Monitor progress** at intervals <2 weeks, to enable early identification of complications. NB. Fracture disease i.e. muscle contracture, muscle atrophy, and joint stiffness, is a significant risk in such juxta-articular fractures in the young animal.
9. **Fracture healing is rapid** in the skeletally immature patient, with clinical union generally achieved <3-4 weeks. Consider implant removal beyond clinical union. Removal of implants which restrict potential growth e.g. Fig. of 8 tension band wire, is mandatory.

**Femoral capital physeal fracture**

- Almost exclusively Salter-Harris type I / Rarely type III.
- In the skeletally immature dog the femoral capital epiphysis receives blood from ascending cervical branches, derived from the anastomosis of circumflex femoral and caudal gluteal arteries. Due to the presence of the physis, there is no contribution from the intraosseous vessels. Blood supply via the teres ligament is insignificant in the dog and minor in the cat.
- The guarded prognosis for femoral capital physeal (FCP) fracture is largely a consequence of disruption of the extrinsic blood supply by the initial displacement, and subsequent iatrogenic trauma.
- Consider frogleg VD radiographic projection to supplement standard views in the diagnosis of minimally displaced FCP fracture.
- Conservative management of a displaced FCP fracture is unsatisfactory, almost invariably resulting in a pseudarthrosis.
Early surgical intervention is essential. Repair after 3 days has a progressively poorer prognosis and femoral head and neck excision may be the preferred initial approach. (Consider THR in suitable candidates).

Teres ligament section is not recommended and the epiphysis is generally reduced in situ by manipulation of the femur with a bone clamp.

Orthograde insertion of 2-3 small K-wires from the third trochanter prevents fragment rotation, and is my preferred treatment. Bend wires over to prevent backing out. Check range of hip movement for articular penetration.

Osteopenia of the femoral neck is a very common sequel of fixation, manifest as radiographic 'apple core' remodeling. The incidence and severity of this change with the technique of articular lag screw fixation is unacceptably high.

Distal femoral physeal fracture
- Usually Salter-Harris type I or II, with caudal displacement of the distal fragment. NB. Rule out intercondylar fracture. There is frequently a small proximal trochlear articular fragment attached to the distal metaphysis.
- A large number of fixation techniques are described e.g. single I/M pin, Rush pins, crossed K-wires, dynamic cross pins, closed reduction and Ehmer sling.
- The orthograde insertion of crossed K-wires, via a cranial surgical approach, is simple and effective. Fracture reduction is checked via lateral arthrotomy.
- The fracture should be over- rather than under-reduced to favor patellar glide. Malalignment in the frontal plane will predispose to patellar luxation.

Tibial tuberosity avulsion
- The tibial tuberosity is the apophyseal insertion of the quadriceps muscle. Salter-Harris type I injury is a common injury of the young racing greyhound and Bull Terrier types.
- Repair via a medial distal parapatellar approach, using two K-wires and a Fig. of 8 TBW. K-wires may be used as the sole fixation.
- The tension band should be removed at 2-3 weeks post op, as this will cause premature growth plate closure. Lag screw fixation is contraindicated due to similar interference with growth.
- Prognosis is good for return to athletic function.

Fracture of the lateral portion of the humeral condyle
- Typically Salter-Harris type IV fractures.
- Fractures of the medial portion of the humeral condyle occur ten times less frequently.
- Certain breeds e.g. Yorkshire Terrier, are over-represented.
- Radiography confirms the diagnosis and should rule out bicondylar fracture.
- Accurate articular reconstruction is required. Drilling the gliding hole from the center of the fracture surface outward facilitates placement of a transcondylar lag screw. The metaphyseal fracture plane should be exposed to confirm alignment. Consider use of a metal washer to distribute load to the lateral condylar cortex. Insertion of a lateral epicondylar K-wire confers rotational stability.
• The prognosis following accurate repair is good, however nearly 20% of small dogs with lateral condylar fractures may have residual lameness after treatment. Degenerative joint disease is the inevitable consequence of poor reduction.
• Malunion is the most frequent result of conservative treatment, whereas nonunion commonly follows surgical failure.
Fractures of the Elbow Joint

Thomas M. Turner DVM
Fractures of the Elbow Joint
Thomas M. Turner DVM

Learner Objectives:

- Identify the type and assess the fractures and involving the humeral condyle
- Determine the appropriate surgical approach and fixation method for repair of various fractures involving the elbow
- Analyze the fracture repair to determine joint function, potential for complications and the post-operative care
Fractures of the elbow may involve one of the three joints that compose the elbow. These fractures may have intra-articular or periarticular components. The aim of the treatment for elbow fractures is to obtain anatomical reduction of the fractures, particularly of the articular surface, restoring joint congruity and then provide rigid stabilization for the fractures to facilitate the healing process. Following surgery, the goal of achieving normal function is dependent upon obtaining successful stable fracture repair and upon rehabilitation of the limb to restore full joint motion. Fractures of the elbow may be classified as (1) distal humeral fractures, either supracondylar or condylar, (2) fractures of the proximal ulna, (3) fractures of the radial head intra-articular and periarticular, and (4) elbow fracture-luxation – “Monteggia fracture”.

The most common fractures involving the elbow are those of the supracondylar or condylar area. Humeral condyle fractures may be classified as (1) supracondylar, (2) epicondylar, (3) lateral condylar, (4) medial condylar, or (5) ‘T-Y’ fracture, a combination intra-articular and supracondylar. These fractures may be approached cranio-lateral, lateral, transolecranon, caudal medial, or medial. Fixation devices most commonly applied are plate or pin fixation, and very infrequently some distal humeral fractures may also be amenable to external fixation. Supracondylar fractures may be fixed with a plate typically applied to the lateral or medial metaphysis. Various pin configurations have also been described either as a central axial pin and 1 or more oblique pins or 2 similar small diameter pins inserted in a crossed technique. Alternatively, 2 pins of smaller diameter may be inserted from the lateral and medial areas in a ‘Rush pin’ technique. If sufficient condylar bone fragment is intact an axial intramedullary pin may be inserted and supplemental fixation with an external fixator. Condylar fractures may involve either the lateral or medial aspect of the distal humeral condyle. The ratio incidence of lateral to medial occurrence has been reported to be 20:1. The most critical aspect of any condyle fracture repair is the precise alignment of the articular surface which imperative for the restoration of elbow function. A cranio-lateral or cranio-medial approach provides the maximum exposure to the articular surface. Classically, these are approached from the respective side, anatomically aligned and fixed with a transcondylar lag screw and supplemental fixation using either a small diameter pin or an additional lag screw inserted obliquely into the metaphysis. Typically, these occur in immature animals 4 months of age and older. A unique incidence of condylar fractures occurs in Spaniel breeds due to failure of the condyle to ossify which is referred to as incomplete ossification of the humeral condyle (IOHC). These fractures can be seen in mature animals even into advanced age.

A combination of a supracondylar and intercondylar fracture is known as the “T-Y fracture”. These can be some of the more complex fractures involving the elbow requiring additional attention to assure precise anatomic reduction of the articular
surface. Although these fractures can be approached from any of the above described directions, this author prefers the craniolateral approach which allows maximal exposure to the articular surface and concurrent exposure of the metaphysis and diaphysis. Fixation can be achieved using a reconstruction plate that facilitates contouring to the irregular lateral bone surface. Lag screw fixation into the condyle can then be achieved through the distal 1 or 2 plate holes adding to the overall construct stability. Alternatively, for additional support a medial plate can also be placed in very large breeds or if needed for severely comminuted fractures. Another fixation method is use of a transcondylar lag screw through the condyle inserted from a lateral to medial or from a medial to lateral direction. Subsequently, once the condyle is reconstructed, a single plate is applied along the medial or caudo-medial surface of the distal metaphysis and condyle. At least two screws must obtain purchase in the distal fragment. In large breeds or very complex fractures, double plates can be placed along the caudal surface of the medial and lateral rami. In the immature animal with a prominent open growth physis, fractures of the condyle are treated with combination of intramedullary pin fixation and transcondylar lag screw. The transcondylar lag screw is inserted first then the distal fragment is fixed to the proximal segment with 2-3 smaller diameter pins inserted in a distal to proximal direction or in a classic ‘Rush Pin’ pattern.

Fractures of the proximal ulna may be extra-articular or intra-articular. The extra-articular fractures involve the olecranon and will distract proximal due to contraction of the triceps muscles. These distractive forces must be counteracted with internal fixation. The commonly used technique is stabilization with a tension band wire technique consisting of 2 Kirschner wires inserted axially through the olecranon into the medullary canal plus a ‘figure of eight’ wire applied over the caudal cortex and over the exposed pin ends. The ‘figure of eight wire’ is critical to counteract the distractive forces of the triceps. Alternatively, a plate may be applied to the caudal ulna surface. Intra-articular fractures present a greater challenge because the articular surface must be precisely reconstructed. Although an intramedullary pin and interfragmentary wire can achieve successful fixation, a plate and lag screws may provide a more secure fixation. While, a caudally applied plate can efficiently counteract the forces on the fracture and span the majority of the ulna length, it requires very precise plate contour to avoid over or under reduction of the ulna articular surface which can result in elbow impingment or laxity. Conversely, the plate can be applied to the lateral surface requiring less plate contouring but this placement is not on the tension surface of the ulna.

Radial head fractures occur very rarely, however when present, they are usually most easily treated with cross pin or parallel pin fixation or plate fixation. Frequently, a T-plate will be quite useful in obtaining purchase on the small radial head fragment.

The Monteggia fracture is a fracture of the ulna, technically proximal ulna, and concurrent luxation of the radial head and frequently injury or complete rupture of the annular ligament. This may be further classified by the direction the radial head displaces i.e. cranial, caudal, medial or lateral. These are treated by anatomical reduction of the radial head and ulna fracture and stabilization of the ulna with either a pin or plate fixation. The proximal radius is stabilized to the ulna usually with a
temporary transfixation pin (a pin inserted transversely through the ulna and radius) for ease of removal. In select cases, it may be possible to obtain primary repair of the angular ligament with suture techniques. If a transfixation pin or screw is used, it should be removed within 2-4 weeks which is sufficient time for the ligamentous structure to heal. Failure to remove the transfixation pin will result in loosening or breakage due to the inherent pronation and supination.

A fracture-luxation of the ulno-humeral joint, conventional elbow dislocation may result from avulsion of the collateral ligaments from either the lateral or medial epicondyle of the humerus or from the ulna or radial head attachment. These can be stabilized with primary suture techniques, short Kirschner wires or lag screw and spiked washer fixation to reattach the epicondyle or collateral insertion.

Fixation and restoration of joint motion and function can be obtained and expected with most fractures and luxations of the elbow. However, this does necessitate strict attention to anatomic approach, surgical technique and fixation techniques. A rapid return to motion and function is imperative in the treatment of elbow fractures to avoid ankylosis for which the elbow is predisposed.
Sacroiliac Luxation

Charles E. DeCamp
Sacroiliac Luxation
Charles E. DeCamp

Learner Objectives:

- Integrate knowledge of pelvic trauma with developing appropriate treatment choices for sacroiliac luxation
- Develop precise anatomic knowledge of the canine sacrum
- Use precise anatomic knowledge in application of lag screw fixation for sacroiliac luxation
Sacroiliac Luxation

Charles E. DeCamp

In a study of 92 cases of sacroiliac fracture separation, 38% of the followed cases developed loosened lag screw fixation. Those cases that had lag screws placed deeply into the sacral body did not loosen as frequently as other screw positions. No difference was found in the study, whether one or two screws were used in the fixation; however, we still recommend that two lag screws be used for sacroiliac fixation, with one screw deeply seated in the sacral body, and a second screw placed in the dorsocranial sacral wing.

Caution must be exercised in placement of the screws, especially the first one. A dorsal approach to the sacroiliac joint is completed. The sacral wing is identified by locating the cartilage of the auricular surface. A line is mentally drawn between the ventral and dorsocranial aspects of the sacral wing. The first screw hole is drilled just caudal to the line, about one-third of the distance from the ventral point. If the sacral hole is properly positioned, it should extend deep to the midline of the sacrum. If the position or angle of the screw hole is wrong, the hole will exit into the spinal canal or out through a shallow portion of the sacrum, yielding a weak screw. The sacral hole is tapped. A corresponding hole is drilled in the ilium, of sufficient diameter for lag effect by locating the roughened area of the sacroiliac joint on the medial surface of the ilium. The first screw is driven through the ilial hole and then directed by sight into the sacral hole. The screw is tightened. A second screw is placed slightly dorsal and cranial to the first screw. This screw is placed in the dorsocranial portion of the sacral wing and is shallow compared to the depth of the first screw, so as to avoid the spinal canal.

A study has been completed (Radasch, 1990) on the static strength of sacroiliac repairs. All screws in this study were placed to a depth of 60% of the sacrum; however, different screw sizes, number of screws, and pins were examined under bending, torsional, and shear loads. Reduction pins were not found to add any significant strength to the repair. Two screws were found to be stronger than one screw of the same size, and the largest possible screw diameter, as expected, maximized the repair strength. It was stated that a single screw placed accurately is probably stronger than two screws improperly placed. The results of the Radasch study seem to be consistent with our earlier recommendations.

Lag screw fixation may also be used for bilateral sacroiliac fracture-separation; however, screws directed from both sides of the sacrum may interfere with each other within the sacral body. Screw interference may be inconvenient; however, it rarely prevents completion of the fixation. An alternative technique has been devised (Kaderly, 1991) that uses an aiming device and a single transsacral screw to repair both sacroiliac joints.

A minimally invasive closed reduction technique for sacroiliac repair has been described that uses C-arm intra-operative imaging to locate the sacral body for screw placement (Tomlinson, Cook, et al 1999). C-arm technology may also be useful for some particularly difficult sacral fracture presentations.
Fractures of the Pelvis and Acetabulum

Ulrike Matis, Dr. med. vet. PhD, Professor of Surgery, Dipl. ECVS
Learner Objectives:

- Apply knowledge of pelvic trauma to management of pelvic trauma patients
- Describe and classify patterns of pelvic and acetabular fractures
- Develop key surgical strategies for fixation of common pelvic and acetabular fractures
FRACTURES OF THE PELVIS AND ACETABULUM

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Introduction:
Pelvic fractures are common injuries in dogs and cats. They are usually the result of traffic accidents, and often associated with polytrauma. Life-threatening injuries, such as blunt trauma to the thoracic and abdominal cavities and occult blood loss after injury to the numerous pelvic blood vessels, must be addressed first.

The decision to treat pelvic fractures surgically or conservatively depends on the location and displacement of the bone fragments and the stability of the fracture. A minimum of two radiographic views is required for decision making. The ventrodorsal projection provides a preliminary overview but must be followed by a laterolateral oblique view, in which the patient is positioned with the fractured side on a foam wedge at a 20° to 30° angle. Using this technique, the side of the pelvis closest to the radiographic plate will be visible on the radiograph above the other side of the pelvis, so that the course of the fracture can be identified. In rare cases, an additional mediolateral view (vaux-profile) and/or computed tomographic transverse images with three-dimensional reconstruction may be necessary for accurate assessment of the fracture.

Acetabular fractures may be managed conservatively in young animals with stable fractures that do not involve the weight-bearing zone of the acetabulum, and in animals with minimally displaced physeal separations. Surgical intervention is indicated when acetabular fragments are unstable or displaced. However, surgery will only be of long-term benefit if the joint is anatomically aligned and completely stable. Normal joint mechanism can be achieved by accurate reduction that leads to a congruent joint. On the other hand, poor reduction or subluxation of the hip joint leads to abnormal stress on the articular cartilage and subsequent arthrosis. Indeed, even when acetabular fractures have been reconstructed correctly, degenerative changes can still occur because of damage to the articular cartilage at the time of the injury. Nevertheless, the progression of arthrosis can be minimized when normal anatomical conditions are restored. A C-shaped acetabular plate or a reconstruction plate can be applied to stabilize fractures of the acetabulum. The plates should be pre-contoured to fit the shape of a similar sized pelvic bone. Pre-contouring reduces surgery time and aids in fracture reduction. Mini-plates and 1.5-mm screws are suitable for repairing stable fractures in cats. For small breeds of dogs, dynamic compression plates with 2.0-mm screws are suitable, whereas reconstruction plates with 2.7-mm screws are better suited to medium-sized and large breeds. Locking plates may ensure perfect reduction, even with small deficiencies in fit. In general, reconstruction of the dorsal acetabulum is sufficient. However, in cases where the femoral head luxates ventrally despite fixation of the dorsal acetabulum, osteosynthesis of the pubic area is indicated as well.

With the exception of sciatic nerve entrapment, surgical intervention should not be carried out too early, although rapid reconstruction of the hip joint is desirable to limit secondary
arthrosis. In cats in particular, there is a high risk of perioperative circulatory collapse if surgery is carried out within the first two days of injury. Sciatic lesions rarely occur with acetabular fractures but are more common with luxation of the sacroiliac joint or fracture of the ilial body.

**Ilial fractures** that are limited to the wing are usually treated conservatively unless there are cosmetic concerns. Pins, interfragmentary wire, lag screws or small plates may be employed. Because fractures of the ilial body frequently result in narrowing of the pelvic canal and/or an unstable hip joint, they are often treated by internal fixation. These fractures are most successfully stabilized using a plate. Reduction of transverse fractures is straightforward because the caudal part of the ilial body can be manoeuvred into position using a periosteal elevator between the fragments. In contrast, long oblique fractures require the aid of reduction forceps, which may injure the sciatic nerve if caution is not exercised. The use of a pre-contoured plate helps to restore the size of the pelvic canal. The plate is screwed first to the caudal fragment and then pulled to the wing of the ilium using plate holding forceps. At least one, preferably two, of the cranial plate screws are anchored not only in the thin wing of the ilium but also in the sacrum.

**Pubic and ischial fractures** comprise the majority of all pelvic-ring injuries in dogs and cats. They frequently occur in conjunction with fractures of the ilium, acetabulum, or a fracture-separation of the sacroiliac joint. If these injuries are reduced correctly and stabilized, the ischial and pubic fractures rarely require any treatment. Bony union of the ischium may take a long time, however, osteoarthritic changes will not develop provided that the fracture line does not involve the acetabulum. Fractures of the ischial body should be stabilized when the ischial ramus or the symphysis is separated as well. Otherwise, malposition of the ischium may develop, which would impede extension of the hip joint or cause painful non-union. The stability required for ischial fractures is often underestimated. When the ischial body is to be repaired with an intramedullary pin, the diameter of the Kirschner-wire or nail must be as large as possible to withstand bending stresses. In addition, plates should not be too flexible and should be long enough to be attached cranially with three screws and to the caudal fragment with two or more screws

**Complex pelvic fractures** involving the acetabulum, ilium and/or ischium on one side are difficult to repair. The ilium is most commonly involved whereby a triangular segment of the cranial part of the acetabulum may be isolated. This type of injury is preferably stabilized using a long pre-contoured plate. In our experience reconstruction plates are the best, because they have three-dimensional flexibility and their length makes them suitable for complex fractures. In cats, straight plates can be used because the pelvic bones are not as curved.

**Results:**
We have used the previously described techniques to repair 198 pelvic fractures in 93 dogs and 105 cats. Radiographic and clinical re-evaluations showed that 78% of these patients had no signs of lameness and 60% had no signs of arthrosis. A comparative study of 199
dogs and 174 cats with pelvic fractures that were treated conservatively revealed that 70 % had no signs of lameness but only 16 % were free of arthrosis.

**Conclusion:**
The advantages of osteosynthesis of pelvic fractures include better long-term results, easier patient aftercare and shorter convalescence. However, the results of internal fixation of pelvic fractures are better than conservative treatment only when optimal surgical technique is used.

References:
Fractures of the Femoral Head, Neck and Greater Trochanter

Thomas M. Turner DVM
Fractures of the Femoral Head, Neck and Greater Trochanter

Thomas M. Turner DVM

Learner Objectives:

- Define the fractures involving the proximal femur
- Identify the preferable fixation methods for the fracture types encountered
- Assess the fracture fixation options and the potential complications and outcomes
Fractures of the proximal femur are commonly encountered in the mature and immature animal. Proximal femoral fractures may occur singularly or in a combination of types. The degree of comminution will determine the extent to which the fracture can be anatomically reconstructed. Any remaining large defects may require supplementation with autogenous cancellous bone.

**Proximal Femoral Fracture Classification**
- Femoral head fractures
- Neck fractures
- Trochanteric fractures
- Pertrochanteric fractures
- Subtrochanteric fractures
- Metaphyseal fractures

Fractures of the femoral head and neck are preferably treated with smooth surface fixation pins in the immature skeleton and lag screw fixation in the more mature skeleton. The rare isolated femoral head fracture in the mature animal can be treated with small, 2.0 or 1.5 mm lag screw placed within the capital epiphysis and a smooth pin, avoiding penetration the articular surface with either screw or pin. Physeal fractures, Harris-Salter type I or II, are the more commonly encountered fracture classifications. These fractures are precisely aligned and fixed with 2-3 smooth Kirschner pins inserted diverging or parallel. The survival of the femoral head is dependent on the amount of fragment separation, length of time from fracture occurrence and the accuracy of the repair. All of which are a reflection of the degree of vascularity preserved. In general, the capital physeal repair will heal successfully in up to 80% of the cases.

Fractures involving the greater trochanteric region necessitate the use of a tension band. This may be accomplished using the standard two Kirschner pins and figure of eight wire or a bone plate contoured over the dorsal-lateral aspect of the greater trochanter. In the animal with a very immature skeleton two smooth Kirschner wires alone can be utilized. If a tension band wire is used in a very immature skeleton it should be removed within a few weeks otherwise trochanteric physeal growth arrest will occur.

Pertrochanteric and subtrochanteric fractures generally necessitate the use of a bone plate functioning as a buttress plate. The use of the bone plate although providing a very stable method of fixation does necessitate a minimum of two screws of purchase for fixation in
the proximal femur. This can generally be accomplished by directing the screws in a converging manner into the trochanter and femoral neck region, which can result in very secure fixation for the proximal end of the plate even with only two screws of purchase. Determination of the size, position and axis of the femoral head and neck for screw or pin purchase is imperative to obtain maximum secure purchase of the proximal femur. More commonly, multi-fragment subtrochanteric fractures consisting of small fragmentation are not anatomically reconstructed but are supported by a buttress plate in anatomic alignment to allow for biologic fixation.

Fractures involving a high degree of comminution in the proximal diaphysis and metaphyseal region should be treated by fragment alignment and stabilization with preferably lag screw fixation or cerclage wire. The reconstructed proximal femur is then supported with a buttress plate applied to the lateral surface. The sequence of reconstruction should initially be the proximal diaphysis followed by the proximal metaphysis, the trochanteric region, and finally the femoral neck and head. Reconstruction of the metaphyseal region is necessary in order to provide a buttress and base for support of the femoral head and neck.

Following reduction and fixation of the proximal femur fracture, the degree of hip stability must be assessed. Laxity of the hip can be addressed with a number of suture techniques such as direct capsule repair with primary or plication suture patterns. In addition, indirect stabilization techniques may be required such as internal suture splints external to the capsule such as heavy suture through the trochanter secured to a screw or suture anchor in the peri-acetabular bone. Hip stability must be assured prior to the surgical wound closure.

A prerequisite to achieving a successful fracture repair of the proximal femur is a well developed plan and the proper technical application of the fixation device. Stabilization of complex femoral fractures can frequently be accomplished with the judicious application of lag screws and a properly contoured plate. Other important determinants for the restoration of limb function are the gentle handling of tissues during the fracture repair process and treatment of soft tissue damage. Fractures of the proximal femur should not be supported postoperatively in a coaptation bandage in order to allow return of motion to the hip and stifle. If severe capsular damage has occurred or the capsular repair is questionable, the limb may be supported in a non-weight bearing sling for 10 days to allow capsular soft tissue healing.
Fractures of the Distal Femur, Proximal Tibia and Patella

Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS
Fractures of the Distal Femur, Proximal Tibia and Patella

Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS

Learner Objectives:

- Diagnose and classify common fracture adjacent to the stifle joint
- Compare advantages and disadvantages of appropriate fixation methods for fracture stabilization
- Review risk factors for development of complications after fracture stabilization
Periarticular Fractures of the Stifle
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Introduction
Fractures of the femur and tibia are common in dogs and most often affect the diaphysis. Fractures adjacent to the stifle can represent a treatment challenge, particularly if an intra-articular fracture line is present.

Fractures of the Distal Femur
Fractures of the distal femur represent about 20% of all femur fractures (Braden et al. 1995) and are particularly common in young dogs.

Supracondylar fractures. Supracondylar fractures are usually found in adult dogs and cats and are often comminuted. Given the cranial curvature of the distal femur, such fractures can represent a treatment challenge. Surgical treatment is typically provided through a lateral approach to the distal femur and a lateral parapatellar arthrotomy. However, other approaches, such as medial parapatellar arthrotomy or tibial crest osteotomy may be needed, depending on the specific fracture configuration. Simple fractures may be amenable to stabilization with cross-pins or Kirschner wires inserted as Rush pins (Whitney & Schrader 1987). However, fracture comminution often necessitates more rigid fixation with bone plating. Use of plates that can be contoured using out-of-plane bending is advantageous and will help to avoid impingement of the stifle joint and to obtain adequate distal fixation. Use of reconstruction plates is particularly useful in this regard (Lewis et al. 1993). Currently, several different other types of bone plates are available, such as the Advanced Locking Plate System or the String-of-Pearls plates that also permit this type of contouring.

Physeal fractures. Physeal fractures of the distal femur are common and usually have a Salter-Harris type I or II configuration. Type III or IV fractures are rare. As with all physeal fractures, the quality of the fracture reduction is an important factor affecting outcome (Hardie & Chambers 1984). The distal fragment is usually caudally displaced. It is easy to under reduce such fractures and risk patella impingement during flexion and extension of the stifle. Therefore, the surgical approach must permit sufficient access to the fracture site to remove bone debris and ensure appropriate reduction. It is a good idea to preserve the perichondrial margin of the epiphysis during reduction, as this will make it easier to ensure that fracture reduction is anatomic. Fracture stabilization is best achieved using cross-pins rather than convergent or Rush-type pins (Sukhiani & Holmberg 1997). The first pin should be started laterally just proximal to the tendon of origin of the long digital extensor. A medial cross should then be placed. Cross pins should be angled to ensure that they cross proximal to the physeal fracture line. Alternative fixation methods include Kirschner wires inserted as Rush pins, and intramedullary pin combined with a single cross pin, or pin fixation combined with a bone screw inserted for lag effect, if a sufficiently large metaphyseal spike is present. Use of a free-form biodegradable plate has also been evaluated for physeal fracture stabilization experimentally (Marcellin-Little et al. 2010).
Articular fractures. Articular fractures of the distal femur usually occur in adult dogs and are rare. Unicondylar fractures typically affect the medial condyle (Carmichael et al. 1989, Davis & Worth 2009) and may be associated with meniscal damage (Davis & Worth 2009). Stabilization of the fracture is typically achieved by a combination of bone screws inserted for lag effect and Kirschner wires. If necessary, exposure of the medial joint compartment can be improved by osteotomy of the medial epicondyle of the femur at the proximal attachment site of the collateral ligament (Daly & Tarvin 1981), or elevation of the tibial attachment of the collateral ligament for fractures of the medial condyle (Davis & Worth 2009) to facilitate perfect anatomic reduction, rigid fixation and treatment of meniscal damage.

Bicondylar Y or T fractures of the distal femur are also rare and again typically affect adult dogs and are often associated with ligament and tendon injury (Frydman et al. 2014). A lateral parapatellar approach to the stifle combined with a lateral approach to the distal femur is used for open reduction. The epiphyseal fragments are reduced and stabilized with bone screws inserted for lag effect. The remaining supracondylar fracture line is reduced and stabilized, most often with a bone plate, as discussed above.

Fractures of the Patella

Fractures of the patella are uncommon and represent a treatment challenge. Patella fractures are more frequently identified in cats, as opposed to dogs and are often bilateral. In cats, patella fractures often occur as a non-contact injury, and may be a stress fracture (Langley-Hobbs et al. 2009), although histological confirmation is lacking. Fractures most often have a transverse configuration from tensile loading, although comminuted fractures may also occur. Non-union of the fracture is likely without surgical treatment. Fracture non-union is associated with elongation of the quadriceps mechanism, decreased stifle extension, and possibly increased risk of proximal tibial fracture (Langley-Hobbs et al. 2009). Fractures of other bones have also been associated with diagnosis of non-contact patella fracture in cats (Langley-Hobbs et al. 2009).

For small fracture fragments, partial patellectomy is the treatment of choice (Langley-Hobbs et al. 2008, Bright & May 2011). Fracture fragments involving up to 50% of the patella can be removed with the expectation that a satisfactory clinical outcome is likely (White 1977). For displaced fractures, reconstruction is best achieved with Kirschner wires and tension-band wiring. Sesamoid bones typically consist of dense compact bone. Therefore, predrilling with a fine (1.5mm) drill bit is recommended before placement of the Kirschner wire to minimize thermal necrosis of bone. Surgical treatment should be considered carefully, as a high rate of implant failure is likely, particularly in cats (Salas & Popovitch 2011).

Fractures of the Proximal Tibia

Fractures of the proximal tibia are not as common as fractures of the distal femur. These fractures are generally more common in young dogs and often involve the proximal tibia physis. Articular fractures of the proximal tibia are rare.

Apophyseal avulsion fractures of the tibial crest. This injury usually affects animals 4-8 months of age, particularly Terrier breeds with well-muscled pelvic limbs. During growth, the apophysis eventually fuses with the proximal epiphysis and then the proximal metaphysis, as skeletal maturity is reached. Avulsions may also be associated with
epiphyseal physeal fracture (Gower et al. 2008). Avulsions usually arise from contraction of the quadriceps mechanism while the stifle is flexed and the foot is firmly placed on the ground, such as during jumping or running. A classification scheme for these fractures has been proposed graded from I to III. Grade I fractures - < 2mm displacement; Grade II fractures - ≥ 2mm displacement that reaches the junction of the apophysis with the epiphysis; Grade III fractures – wide displacement (von Pfeil et al. 2009). Partial minimally displaced (2-3mm) avulsions can be managed conservatively (von Pfeil et al. 2009). However, most fractures are best treated with open reduction and internal fixation using Kirschner wires and a tension band. If the dog is under 6 months of age, early removal of the fixation should be considered at 2-3 weeks to try and reduce the risk of premature closure of the apophysis. However, this risk is substantial, and may lead to growth deformity of the proximal tibia (Goldsmid & Johnson 1991). Consequently, prognosis for this fracture, particularly in young puppies is moderate. Distal translocation of the tibial attachment of the patella tendon may occur. In addition, partial closure of the tibial epiphyseal growth plate may lead to an altered tibial plateau angle and increased risk of cruciate rupture.

**Physeal fracture of the proximal tibial epiphysis.** These are usually Salter-Harris type I or II fractures and may also involve the tibial tuberosity. Displacement is typically caudolateral. Damage to the collateral ligaments of the stifle may be associated with the fracture. Open reduction and internal fixation is generally preferred. Cross-pinning fixation is most commonly used, although lag screw fixation could be considered, particularly if there is a large metaphyseal spike attached to the epiphysis.

**Fractures of the proximal tibial metaphysis.** Open reduction and internal fixation is again generally preferred. Depending on the pattern of fracture, plate fixation or use of an external skeletal fixator could be considered. Ilizarov or Ilizarov-hybrid fixation could also be considered because of the short proximal fragment.

**Articular fractures of the proximal tibia.** These fractures are uncommon. Articular fractures may involve either the lateral or medial compartment of the stifle. Open reduction is needed to enable anatomic reduction and rigid fixation. Use of a T plate is often advantageous with use of lag screws to create interfragmentary compression across the articular fracture line.

**Avulsion of the long digital extensor and popliteus**

Avulsion of the long digital extensor and the popliteus are uncommon conditions that typically affect young giant breed puppies. The mechanism for these avulsions is unclear.

**Cruciate ligament avulsion fracture**

Avulsion fracture of a cruciate ligament attachment site is uncommon and is typically associated with traumatic injury in young dogs, in contrast to the mid-substance rupture that is typically seen with non-contact cranial cruciate ligament rupture. Avulsion fractures can affect both the cranial and caudal cruciate ligaments and most commonly affect the tibia attachment (Reinke 1982, Huss & Lattimer 1994). Fracture fragments are usually visible radiographically, but it can be difficult to determine which attachment site is affected without cross-sectional imaging.
Fragment removal is typically performed for treatment, although fracture fixation with fine Kirschner wires or a bone screw inserted for lag effect could be considered if the fracture fragment is sufficiently large (Reinke 1982). Treatment of stifle instability may also be needed.

Aftercare
Periarticular fractures often occur in young animals and fracture healing is usually rapid. In general, external coaptation should be avoided after surgery. Physical therapy using cold and warm packs with a regimen of passive range-of-motion should be used to encourage early return to weight bearing and to minimize periarticular fibrosis as much as possible. Implants are generally left in place, unless implant loosening is sufficient to cause clinical signs.

Conclusion
Periarticular fractures of the stifle are often a treatment challenge. Careful patient evaluation, fracture planning, and postoperative patient care are important to minimizing risk of complications.

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Simple Fractures and Luxations of the Tarsus

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Learner Objectives:

- Distinguish the different patterns of tarsal fracture/luxation in cats and dogs
- Analyze the different treatment options and potential complications, according to the type of injury and the chosen method of repair
- Critically evaluate the results and associated prognostic factors
Introduction:
Fractures and dislocations of the hock occur predominantly in cats. Feline fractures of the tarsus most frequently involve the talus, followed by the medial and lateral malleolus. Calcaneal fractures are the fourth most common injury of the feline tarsus. The latter occur more often in the basal region than in the proximal parts of the bone. Other fractures, which are rarely seen in cats and often present in combination, involve the tibial trochlea and the central tarsal bone.

In contrast, ligament ruptures are the most common hock joint lesion in dogs with the medial collateral ligament most frequently affected. The calcaneus is more often fractured than the talus. This remarkable species-specific difference has two fundamental reasons:

1. The cause and nature of the accident and the behavior of the animal and
2. The differences in the anatomical structure of the canine and feline hind limb.

Traffic accidents, falls or jumps from a great height or a hind paw caught in some object are common causes of hock joint injuries. In dogs, motor vehicle accidents represent the primary cause of hock injuries followed by jumping over obstacles, whereas falls from great heights are the main reason for tarsal lesions in cats. It goes without saying that cats in urban areas are at a greater risk than cats living in rural regions. In contrast to dogs, cats possess a righting reflex. This postural reaction, which has developed over millions of years, allows the cat’s body to turn while airborne so that it lands on its feet. This reflex represents a protective mechanism provided that certain conditions prevail: the height of the fall does not exceed the height of an average tree, and the ground on which the cat lands is soft such as the soil of a forest or savannah. However, urban cats fall from multi-story buildings and hit hard pavement.

There are numerous subtle species-specific peculiarities of the musculoskeletal system that have developed through functional adaptation. These features make the cat a sprinter and the dog an endurance runner. It is therefore not surprising that excessive force loads acting on the bones of the hock joint have different consequences in the cat and dog. The lever structures are affected in dogs, whereas injuries in cats involve the load-bearing column.

There are also interesting differences between cats and dogs with regard to the muscles and ligaments of the hock region. It is important to remember that cats do not have the long collateral ligaments characteristic of the canine hock joint. Instead, the feline species has a particular mechanism, which has been overlooked for a long time: flanking end-tendons arranged in pairs, which act as contractile tension bands. The structures involved are the end-tendons of the caudal tibial muscle and the short peroneal muscle, both of which are bipenniform dynamic muscles with short fibres and a reduced mass. Nevertheless, their lifting force is strong enough to place the end-tendons under extreme tension. The highly
concentrated and tense posture of a cat just before jumping or sprinting allows one to understand how many large and small muscles are involved and the immense dynamic energy that is about to unfold in those moments.

Dogs do not possess such a mechanism. All the previously mentioned muscles are comparably weaker in the canine species. Thus, it can be concluded that the long collateral ligaments, which are most often affected in tarsal ligament ruptures in the dog, do not exist in the cat. The contractile tension bands, which have a similar function in the cat, however, are much less susceptible to ruptures.

From a clinical standpoint, this means that the end-tendons of the caudal tibial muscle and the short peroneal muscle must be protected and preserved whenever surgery is carried out in a fractured hock joint of a cat. This becomes very important if we take into account that the risk of recurring tarsocrural luxation is comparatively high in the cat.

As far as fracture repair is concerned, there are only very few species-specific differences that must be considered. Generally, all standard procedures established for the dog are also applicable to the cat. For example, fractures of the malleoli or the calcaneal tuber and shaft are fixed using one or two Kirschner wires and a figure eight tension band wire. Fractures of the base of the calcaneus with little dislocation and instability may be treated conservatively in patients with a good tolerance of bandages.

The greatest challenge for the surgeon is the repair of fractures of the talar trochlea, which are often comminuted. In smaller avulsions of the medial or lateral trochlear ridge, excision of the fragment may suffice to restore joint function. For larger avulsed fragments, fixation with thin wires that are countersunk in the cartilage is recommended. In the presence of multiple bone fragments, axial alignment and immobilization of the tarsus by external skeletal fixation should first be carried out. Once consolidation has been achieved, the possibility of surgical panarthrodesis may be considered. Primary arthrodesis is advocated in unfavorable cases, which fortunately are rare. If panarthrodesis is carried out, it is important to bear in mind that the fusion angle of the tarsocrural joint should be approximately 100° in cats and 130° to 140° in dogs.

Fractures of the talar neck can be difficult to diagnose radiographically at an early stage; however, because these fractures are prone to non-union, internal fixation is indicated as early as possible. This may be achieved by means of small screws, wires or plates, depending on the size of the patient. Fracture of the talar head, which is located distally, usually leads to spontaneous fusion of the talocalcaneocentral joint, even after precise surgical reconstruction.

A lesion that occurs almost exclusively in cats is luxation of the talus with rupture of the short ligaments of the talocalcaneal and talocalcaneocentral joints. This injury may be an isolated lesion but often occurs in combination with a distal fibular fracture and avulsion of a fragment from the lateral ridge of the talar trochlea. It is thought that this triad lesion is the result of valgus stress of the tarsus caused by the impact of landing. When reducing the talus, the surgeon will realize that the feline trochlea, which lies between the tibia and central tarsal bone, is highly moveable. To prevent reluxation, the talus must be surgically fixed in
most cases, even if this reduces its normal gliding movement. Our method of choice is the use of a small positional screw, which is introduced into the talar neck caudally, penetrating the calcaneus but leaving the talocalcaneocentral articulation intact.

**Fractures of the central tarsal** bone typically occur in racing dogs, rather than companion dogs or cats, and they also constitute an indication for osteosynthesis. Fractures complicated by luxation usually require that the central tarsal bone be fixed to the neighboring fourth tarsal bone. A similar approach is indicated for **fractures of the numbered tarsals**, although these fractures are very rare. If reconstruction is not feasible, partial arthrodesis may be considered. Partial arthrodesis is also the treatment of choice for **ruptures of the long plantar ligament**, which are characterized by hyperextension of the intertarsal and tarsometatarsal joints. In contrast, rupture of the dorsal ligaments can be treated conservatively, although internal fixation is preferred if there is concurrent instability of the intertarsal and tarsometatarsal joints. The most common lesion affecting ligaments of the tarsal joint involves the collateral ligaments, and the medial ligaments are more commonly affected than the lateral ligaments. Isolated **ruptures of a short and/or long collateral ligament** may be amenable to strict immobilization and bandage support. Avulsion fractures are fixed surgically provided that the bone fragment is large enough to accommodate an implant. So-called **shearing injuries are accompanied by loss of the collateral ligaments** and occur most commonly in dogs. They are usually caused by trauma and predominantly involve the medial aspect of the tarsus. These injuries require replacement of the long and short collateral ligaments using wire or slowly absorbable monofilament suture material in a fashion that simulates the normal anatomic relationship of the joint. In addition a transarticular external fixator may be required.

The long-term **prognosis of tarsal joint injuries** is guarded. The chances of restoring normal joint function are best for fractures of the malleoli and the calcaneus. The prognosis is poor for patients with a fractured talus, particularly if reconstruction of the trochlea is not possible. In our experience with 65 cats suffering from hock joint trauma, which were re-evaluated clinically and radiographically after a mean postoperative period of 18 (1.5 – 76) months, the risk of developing arthrosis secondary to lesions of the tarsocrural joint was as high as 73%, with lameness present in 30% of the cases. Almost identical percentages were obtained at a mean of 22 (3 - 86) months after surgery in 105 dogs treated for hock joint injuries.

**References:**
Pre-Operative Patient Evaluation and Management

Shantibhushan Jha BVSc, MS, DACVS-SA
Learner Objectives:

- Describe a methodical and systemic plan for evaluating the trauma patient
- Describe the initial stabilization of a seriously injured animal
- Describe importance of analgesia in the trauma patient
- Describe how to initially treat and coapt open and closed fractures
Pre-Operative Patient Evaluation and Management
Shantibhushan Jha BVSc, MS, DACVS-SA
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Pre-operative evaluation of a trauma patient is the first step towards a successful treatment of fractures. Some of these patients will have sustained severe trauma and life threatening injuries. A systemic evaluation of a trauma patient will help treat the injuries effectively and appropriately. Shock, brain injury, pneumothorax or hemoabdomen due to trauma can be life threatening if not treated.

TRIAGE:

Patient triage begins with a very short history and safe transportation of the critically ill, or a trauma patient in the treatment area. The team must be ready to move the animal from the transporting vehicle into the hospital. A backboard made of Plexiglass or plastic or a commercially available stretcher can be very useful, or patient can be transported from the reception area to the treatment area on a gurney. Initial questions can follow the “AMPLE” approach, which stands for:

- Allergies: To medications or blood products
- Medications: Current medications
- Past Medical History: Medical or surgical conditions
- Last: Meal, urination and defecation
- Events: Leading to trauma

Rapid assessment and triage should be completed within the first few minutes of arrival in all critically ill or injured animals.

EXAMINATION:

Every animal should be thoroughly examined post triage and after primary stabilization. Appendicular fractures are rarely life threatening. The examination of an injured patient is divided into primary and secondary survey. “ABC” approach followed by a detailed “A CRASH PLAN” approach is generally used for a systematic evaluation of a critically ill or seriously injured patient. The clinician should concentrate primarily on problems that pose an immediate risk to the patient’s life. A second survey, including a full physical examination, can be completed once life threatening conditions have been stabilized.

ABC Approach: Primary survey

Airway: The initial assessment should determine if the patient has a patent airway and is attempting to breathe by itself. The airway should be cleared or suctioned, if required and
then intubated. The patient should then be ventilated with 100% oxygen, with eight to twelve breaths per minute by an Ambu bag. In many cases an emergency tracheostomy should be performed to keep the airway patent. A careful evaluation of respiratory rate, rhythm, and character is important, as well as evaluation of the presence and quality of lung sounds on thoracic auscultation.

**Breathing:** Respiratory compromise are indicated by an elevated respiratory rate, abnormal breathing patterns, and cyanosis of mucous membranes. Once a patent airway has been confirmed, the patient showing signs of respiratory distress should be placed on oxygen supplementation. A face mask provides an effective way of increasing levels of inspired oxygen rapidly, however, another option would be to place nasal catheters for flow-by oxygen supplementation. Pneumothorax is seen in about 15% of trauma patients and 40% of dogs and 60% of and cats fallen from a height. A therapeutic thoracocentesis should be performed in these cases.

**Circulation/Cardiovascular:** Once the airway and breathing assessment has been completed, assessment of the patient’s heart rate, rhythm, pulse rate and quality, mucous membrane color and capillary refill time (CRT) needs to be completed to assess the animal’s circulation. Cardiac arrhythmias and clinical signs of hypovolemic shock are very common after traumatic events. Tachyarrhythmias with heart rate more than 160bpm to 180bpm in dogs, and more than 200bpm in cats are indicative of hypovolaemia, pain, hypoxaemia, hypercapnia. Careful assessment of patients pulse rate and quality gives an indication of blood pressure, as a palpable femoral pulse means a mean blood pressure of at least 50mmHg and a palpable dorsal metatarsal pulse indicates a systolic blood pressure of at least 80mmHg.

“A CRASH PLAN” approach: Secondary survey

A= Airway
C= Cardiovascular/circulatory
R= Respiratory
A= Abdomen
S= Spine
H= Head (including eyes, ears and neck)
P= Pelvis (including rectal examination)
L= Limbs (including tail)
A= Arteries
N= Nerves (including cranial nerves, reflexes and pain sensation)
This can be performed once the analgesics have been administered and patient has been stabilized and deemed less critical. A, C and R from this approach have been discussed above.

**Abdomen:** Palpation of the abdomen, followed by radiographic and ultrasonographic assessment will rule out a defect in the abdominal wall and peritoneal effusion (uroabdomen or hemoabdomen). Recent reports indicate that approximately 40% of animals with pelvic fracture develop some degree of urinary tract trauma. Abdominocentesis can be performed to differentiate uroabdomen and hemoabdomen. The advantage of a belly bandage in cases of hemoabdomen in trauma patients is debated. A urinary catheter can be very beneficial in non-ambulatory patients.

**Spine and Head:** A complete neurological examination, including the cranial nerves will help localize the lesion in an injured patient with neurological deficiency. Animal with suspected spinal injury should not be moved or manipulated. Initial examination is conducted with the animal taped to the plexiglass board and radiographs should be taken without moving the dog from the board. In patients with head injuries a thorough cranial nerve examination will lead to the localization of lesion in the brain. Recent reports indicate doing a CT scan if multiple jaw fracture is suspected, apart from survey skull radiographs.

**Pelvis and Limbs:** Animals with multiple pelvic bone fracture and SI luxation may not be ambulatory. The examination is performed after a dose of analgesics, which include observation of the tail and anal tone, asymmetry of the pelvis, rectal examination, and gentle palpation for detecting any crepitus. All the limbs should be palpated thoroughly which not only includes palpation of long bones but also range of motion test of major joints. An animal who is presented with one fractured limb should be (almost all cases) ambulatory in other three legs.

**Arteries and Nerves:** Finally, the status of blood supply is assessed along with an examination of central and peripheral nerves (previously covered in spinal examination). The neurological assessment is aimed to identify serious neurologic abnormalities of the brain. Evaluation of the neurological system includes evidence of head trauma, assessment of the level of consciousness to assess for changes in the patients mentation and immediate treatment of seizures if occurring. Examination of arteries and nerves can give useful information which can determine the prognosis of the treatment and further care in seriously injured patients.

**BLOOD-WORK:**

Blood-work is as important as a thorough physical examination and is useful in planning a proper treatment in critically ill or seriously injured patients. A complete blood count, biochemical profile, acid-base status and urinalysis should be done. Blood is sampled at the time of catheter placement. The response to therapy can be serially monitored with multiple blood draws during the hospitalization.
INITIAL TREATMENT AND STABILIZATION:

Shock:

Hypovolemia due to blood loss is one of the most common causes for an animal to go into shock. Animals with signs of poor perfusion, the blood volume must be restored as soon as possible. Clinical signs of poor perfusion includes, poor pulse quality, tachycardia in dogs and bradycardia in cats, prolonged CRT, pale mucus membrane color and hypothermia. Isotonic crystalloid, colloids and blood products are generally used to restore the volume deficit. The shock dosage for an isotonic crystalloid solution is One Blood Volume of the patient generally given in one hour. This dose should be quartered and essential vital parameters much be reevaluated for an effective response.

<table>
<thead>
<tr>
<th></th>
<th>Dog (Shock dosage)</th>
<th>Cat (Shock dosage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalloid (LRS, Plasmalyte, Normosol)</td>
<td>80-90mls/Kg/hr</td>
<td>45-60mls/Kg/hr</td>
</tr>
<tr>
<td>Colloids (Hetastarch)</td>
<td>10-20mls/kg</td>
<td>10mls/kg</td>
</tr>
<tr>
<td>Blood, pRBC</td>
<td>10-30mls/kg</td>
<td>10-30mls/kg</td>
</tr>
<tr>
<td>Plasma</td>
<td>10-30mls/kg</td>
<td>10-30mls/kg</td>
</tr>
</tbody>
</table>

Analgesia:

Opioids are the mainstay of analgesia in critically ill and seriously injured patients. Opioids cause minimal cardiovascular and respiratory depression and they can also be reversed readily. NSAIDs should be avoided in the preliminary duration as hypovolemia and shock can increase the risk of adverse side effects, most notably GI and renal complications. The table below shows the types and dosage of opioids, which can be used in this group of patients.

<table>
<thead>
<tr>
<th></th>
<th>Dog</th>
<th>Cat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fentanyl</td>
<td>5ug/kg initial bolus IV followed by a CRI of 2-5ug/kg/hr</td>
<td>2-3ug/kg initial bolus IV followed by a CRI of 2-5ug/kg/hr</td>
</tr>
<tr>
<td>Hydromorphone</td>
<td>0.05-0.1mg/kg IV or IM every 4-6 hours</td>
<td>0.02-0.05mg/kg IV or IM every 4-6 hours</td>
</tr>
<tr>
<td>Buprenorphine</td>
<td>0.005-0.02mg/kg IV or IM every 6-8 hours</td>
<td>0.005-0.02mg/kg IV or IM every 6-8 hours</td>
</tr>
<tr>
<td>Butorphanol</td>
<td>0.2-0.4mg/kg IV or IM every 4 hours</td>
<td>0.2-0.4mg/kg IV or IM every 4 hours</td>
</tr>
</tbody>
</table>
Wound management:

A seriously injured animal may be presented with an open or closed fracture with or without skin wounds. Under heavy sedation the management of fracture and wound should be initiated. Aseptic technique should be practiced with gloved hand to avoid transfer of nosocomial infection. Trauma patients with open fracture with either small or large soft tissue loss needs prompt and aggressive debridement of the contaminated material for successful management. The area is irrigated profusely, removal of gross contamination and devitalized tissue is performed, any arterial bleeding is addressed with ligation and bandaging. Antimicrobials should be administered especially in open fractures at this time. Collection of samples at the time of wound management for antibiotic culture and sensitivity is debatable.

Temporary stabilization of fracture:

Once the initial treatment of a wound has been performed, a temporary bandage should be applied and radiographs should be taken. Post radiography a full bandaging should be done. Bandages promotes healing and protects the wound from the environment. In patients with fractured limbs, the bandage provides temporary stabilization, which helps in reduction of pain in pre-operative period. The basic principle of bandage application is to immobilize the joint above and below the fracture. Fractures of scapula, humerus, and femur are generally not bandaged. Fractures of lower extremities (tibia and radius) are bandaged with a splint.

SUMMARY:

The trauma patient should be first triaged, stabilized and put on supportive care before initiating any fracture repair. In summary, the timing of fracture repair depends as soon as a patient vital parameters are deemed fit for anesthesia.

REFERENCES:


Soft Tissue Handling and Fracture Reduction

Kei Hayashi
DVM, PhD, Diplomate ACVS
Learner Objectives:

- Define the concept of biological approach to fracture treatment
- List different techniques for fracture reduction
- Construct an appropriate fracture reduction strategy
Soft Tissue Handling and the Fracture Reduction
Kei Hayashi
DVM, PhD, Diplomate ACVS

Concept of “Biological Fracture Fixation”
Goal of fracture treatment is a) early ambulation and complete return of function, b) pain free recovery, and c) prevention of fracture disease. To achieve this goal, AO principles emphasize preservation of the blood supply to soft tissues and bone by careful handling and gentle reduction techniques.

Reconstructable Fracture? Closed or Open Approach?
In planning fracture management, the surgeon must first determine a) whether full reconstruction of the bone column is possible, and b) whether open or closed reduction is preferred. Fracture healing is initially dependent on extraosseous blood supply from surrounding soft tissues. In any fractures, soft tissue attachment should be preserved as much as possible. Fracture hematoma is generally believed to improve fracture healing.

Completely closed reduction would be ideal for preservation of soft tissue, blood supply and hematoma, and minimization of surgical trauma and risk of infection. This approach can be attempted with external coaptation (full cast) or external skeletal fixators. However, difficulty in gaining adequate reduction and unavailability of advanced imaging techniques such as fluoroscopy may limit its application in veterinary medicine.

Limited open approach, or Open-But-Do-Not-Touch approach, is currently recommended for many fractures to practice the concept of biological fracture fixation. In this approach, the major bone segments are manipulated but the fracture fragments are not disturbed, and the bone is distracted to length where the major segments are realigned with an intramedullary pin (in plate rod combination, PRC) or interlocking (ILN), or minimally invasive plate osteosynthesis (MIPO). Autogenous cancellous bone graft can be applied.

Open approach is chosen for internal fixation (e.g. bone plate). Most bones can be approached by muscle/fascia separation techniques, with occasional tenotomy or osteotomy (see Surgical Approaches to the Bone and Joints of the Dog and Cat, Piermattei and Johnson). While minimizing surgical trauma, surgical incision should be sufficient to allow adequate exposure for fracture reduction and implant placement.

Soft Tissue Handling in Fracture Repair
The surgeon must abide by Halsted’s principles of surgery: preservation of all soft-tissue attachments to bone fragments, sharp and accurate tissue dissection, avoidance of excessive trauma, and careful and gentle handling of soft tissues, nerves, and vessels. Minimization of finger use will decrease contamination, minimize tissue devitalization, and result in improved tissue handling. During dissection, large blood vessels and major nerve trunks must be preserved at all cost. The anatomy of the area should be kept firmly in mind, particularly around radial and sciatic nerves. Whenever possible, the nerve is retracted.
with an adjoining muscle. If isolation of the nerve is necessary, Penrose drain can be passed around and is then used to maintain traction.

Fracture Reduction
The goal of fracture fixation is to restore functional limb alignment (reduction) and to stabilize the fracture (stabilization). Fracture reduction is important for fracture stability during healing and for limb mechanics. Reduction is the process of either reconstructing the fractured bone to its normal anatomical configuration, or restoring the normal alignment of the limb. Normal limb alignment is achieved by
1. restoring normal limb length,
2. maintaining normal spatial orientation of the limb, and
3. restoring the alignment of the joints adjacent to the fractured bone.

Preoperative Planning for Fracture Reduction
Type of fracture and choice of fixation method dictate method of fracture reduction. Methods of fracture reduction include closed reduction, open but do not touch approach, limited open reduction, and open reduction.

Indications for closed reduction include
- Non-displaced or incomplete fractures
- Comminuted fractures treated with minimally invasive fixation methods

Indications for open reduction include
- Articular fracture
- Simple displaced fracture
- Comminuted fractures treated by major segment alignment + cancellous bone graft

Closed Reduction
Closed reduction involves reducing fractures or aligning limbs without surgically exposing the fractured bones. This approach has several advantages as it preserves the surrounding soft tissues and blood supply to the bone, and decreases the possibility of iatrogenic contamination associated with surgery. The end result is shorter overall operating time, improved healing potential, and a lower rate of infection. The main disadvantage is that cortical apposition of the fracture fragments can be hindered.

Open reduction
Open reduction uses a surgical approach to expose fractured bone segments and fragments, so they can be anatomically reconstructed and held in position with implants. The fracture fragments may be seen and reconstructed and a cancellous bone graft can be used. The major benefit of a fully reconstructed bone column is that it can share the load during fracture healing. Therefore, open fracture fixation is reserved for fractures that can be anatomically reconstructed. The potential disadvantages include iatrogenic contamination, additional soft-tissue damage, and impairment of blood supply.
**Muscle Relaxation**
The major difficulty in achieving reduction is often caused by counteracting muscle contraction. Chemical methods (general anesthesia) should be used to achieve adequate muscle relaxation. Muscle relaxant agents can also be added. Local and regional anesthetics and analgesics may also facilitate most fracture reduction as they decrease the intraoperative pain response and provide good muscle relaxation.

**Reduction Techniques**
Methods of fracture reduction are multi-modal and are often combined. The steps can include limb hanging during surgical preparation, anesthesia and neuromuscular blocking, open approach, and use of a special device fracture distractor. Reduction is often the most difficult part of fracture repair and is mastered by practice.

**Distraction:**
Aligning fragments can be achieved by simply distracting the bone. Distraction may be achieved by traction and counter-traction applied to the limb as used in the hanging limb technique. Traction is applied by suspending the limb from a stand or ceiling and using the animal’s own weight to distract fractured bone and eventually fatigue the muscles.

**Intramedullary Pin:**
An intramedullary pin may be used to push the distal segment away from the proximal segment prior to stabilizing the fracture with an external fixator (as in a “tie-in configuration”), buttress plate (as in a plate-rod construct), or interlocking nail (ILN).

**Toggling:**
Transverse fractures may be reduced by elevating the fracture ends to a certain angle and bringing them into contact with each other. Pressure is slowly applied to place the bones in a normal (straighter) position.

**Levering:**
A slim instrument, such as an osteotome or spay hook, placed between bone segments may be used to lever the bone segments into alignment.

**Instruments:**
Bone-holding forceps can be placed on fracture segments to facilitate manual distraction and reduction. Long oblique fractures can be reduced by securing the bone segments with bone-holding forceps and distracting the segments as far as possible and self-retaining reduction forceps may be positioned obliquely to the fracture line and used to slowly force distraction of the segments until anatomical reduction is achieved.

**Plate:**
Eccentrically placed fractures such as transverse distal radial fractures may be better reduced and maintained in reduction by securing a contoured plate to the short distal segment and reducing the proximal segment to the plate. The reduction is maintained by securing the plate to the proximal segment with plate holding forceps.
**Fracture Distractor:**
The fracture distractor is an instrument designed to distract fracture fragments. This device is attached to pins in the proximal and distal fracture segments, and axial traction is applied to the segments by the pin-distractor unit. The mechanical advantages of this device allow easy distraction of fragments.
Post-Operative Assessment of Fracture Fixation

Jonathon Dyce, MA, VetMB, DSAO, MRCVS, Diplomate ACVS
Post-Operative Assessment of Fracture Fixation
Jonathon Dyce, MA, VetMB, DSAO, MRCVS, Diplomate ACVS

Learner Objectives:
- Apply the AAAA method of postoperative fracture assessment to clinical cases
- Differentiate appropriate from inappropriate radiographic progress after fracture repair
- Identify predictors of probable success or failure of orthopedic fixation from interpretation of immediate postoperative radiographs
POSTOPERATIVE ASSESSMENT OF FRACTURE FIXATION

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THE OHIO STATE UNIVERSITY, COLUMBUS, OHIO

Radiographic evidence of fracture healing does not necessarily correlate with clinical outcome. A thorough clinical examination should be the primary means of evaluating fracture repair. The following features should be assessed:

1. Limb alignment. Compare to the contralateral (normal) limb. Progressive malalignment suggests implant failure or, in the growing dog, physeal disturbance.
2. Stability of the fracture plane.
3. Muscle atrophy. Can be obvious within days if immobilization used. Atrophy is generally reversible. Recovery of muscle bulk is a sensitive indicator of restoration of limb function.
4. Soft tissue adhesions or contracture causing decreased range of motion. Conversely joint laxity syndrome associated with fracture disease, e.g. carpal hyperextension secondary to prolonged casting in the immature dog.
5. Adjacent joints for range of movement, crepitus, pain and effusion. Consider joint penetration with implant, intraarticular fracture malalignment, osteoarthritis, juxtaarticular implant.
6. Palpate implants for pain, loosening, migration.
7. Complications of surgical wound healing, eg. dehiscence. Sinus formation may be associated with loose or infected implants, foreign bodies, sequestra.
8. Signs of systemic illness, possibly related to infection.
10. Neurologic function, particularly if neurapraxia was present at the time of fracture repair. Deteriorating sciatic function may be associated with eg. migration of femoral I/M pin, or entrapment associated with ischial callus formation.

Be alert to unusually poor progress. This may suggest complications of fracture repair or problems which were overlooked at initial examination. Ensure owners understand instructions for postoperative care and necessity for postoperative follow-up examination. Schedule follow-ups at discharge and establish criteria for unscheduled check appointments, eg. deteriorating limb function etc.

Postoperative radiography is essential to assess the quality of fracture repair, identify complications, and monitor progress to clinical union. Objective appraisal of the postoperative radiograph is mandatory for the surgeon seeking to improve orthopaedic technique.
Alignment. Orthogonal radiographs must include the joint proximal and distal to the repair. Assess angular and axial alignment. Ignore the region of the fracture and assess whether the outline of the remaining bone could be superimposed upon its normal template. Note that craniocaudal malalignment is tolerated better than a similar degree of valgus or varus deformity. Be familiar with normal anatomy e.g femoral neck anteversion. Alignment primarily determines postoperative function.

Apposition. The quality of reduction at the fracture site. Anatomic reduction implies obliteration of fracture planes and is the goal of interfragmentary compression. Greater degrees of displacement are acceptable with more biological osteosynthesis. Apposition primarily influences the mode of fracture healing.

Apparatus. Is the fixation device appropriate and applied correctly? The determination of acceptability requires comprehensive knowledge of the principles of application of the fixation system employed in that specific case (see other lectures). The type of apparatus determines both function and fracture healing. Implants that are found to be intraarticular on postoperative radiography should be removed as soon as possible. Simply backing pins out is not recommended as these may migrate back into the joint. Similarly, inadvertent physeal compromise must be addressed.

Activity. The radiographic assessment of activity is routinely undertaken 6 weeks postoperatively in the adult. Attention is directed to bone, joints (osteoarthritis), soft tissues and implants. Additional radiographs are required to monitor inappropriate progress, and prior to and after any implant removal.

Appropriate activity
Factors including fracture configuration, fixation strategy, degree of soft tissue compromise, general health and age have a profound influence on fracture healing. Consequently the progression toward clinical union is not uniform between patients. Clinical union has occurred in the period in the recovery process when healing has progressed to allow safe removal of the fixation. The radiographic appearance of primary bone union with contact healing (minimal radiographic change) is predictably very different from secondary bone union in a situation of moderate fracture instability (massive callus formation and remodeling).

Broad guidelines are that fracture margins are initially sharp (1 week) and then become less distinct with slight widening of the fracture gap associated with osteolysis (2 weeks). The fracture plane remains visible with patchy mineralization of periosteal callus at 4-6 weeks. Bridging callus develops a more homogeneous density with smooth borders at 6-9 weeks. The density of callus increases and its size decreases (8-12 weeks) as corticomedullary remodeling removes endosteal callus. Obliteration of the fracture plane, ongoing condensation of callus and distinct corticomedullary separation are seen after 10 weeks.

Consider also the influence of any cancellous autograft on fracture healing, and compare this to the behaviour of an intercalary full cylinder cortical allograft with rigid stabilization.
**Inappropriate activity**

**Delayed union.** Failure to heal in the usual time, which may vary from days to weeks, dependent upon fracture type, fixation etc. Delayed union can obviously be a precursor of nonunion.

**Ischaemia.** With interruption of the normal intraosseous and periosteal blood supply following fracture, the fracture site is vascularised initially by the transient extraosseous supply derived from the surrounding soft tissues. The presence of excessive quantities of implants either within the medullary canal, or about the cortex may also impede blood supply. Soft tissue compromise is most likely to occur during open reduction, and at specific sites with little surrounding soft tissue bulk eg. distal radius / tibia, or tenuous blood supply eg. femoral capital physis. Compare this to the negligible incidence of ischaemic complications of pelvic fracture repair.

**Synostosis.** Fusion of adjacent bones associated with exuberant callus. Significant risk of elbow incongruity in radius/ulna fractures in the immature dog. Loss of pronation/supination is less significant. Metapodal synostosis can affect function.

**Viable nonunion** fractures have a good blood supply and are capable of biological reaction. Interposed material is fibrocartilaginous. In theory, axial compression of such fractures, without debridement, will result in union. Such nonunions show a tendency to hypertrophy. The radiographic appearance of the fracture site is described by the Weber-Cech classification; hypertrophic (elephant’s foot callus), slightly hypertrophic (horse’s hoof callus), or oligotrophic (minimal callus).

**Non-viable nonunion** fractures have a restricted blood supply and interposed material is fibrous. Such fractures will not heal without surgical interference and are typified by distal radius / ulna fractures in toy breed dogs. Weber-Cech; dystrophic, necrotic, defect, and atrophic. Atrophic nonunion represents an end stage of non-viable nonunion and is most commonly seen in distal radius / ulna nonunion in toy breeds.

**Pseudarthrosis.** An articulated nonunion in which bone ends are joined by a fibrous capsular structure containing synovial-type fluid. Pseudarthrosis occurs rarely, with the femur being the most affected bone.

**Radiology of nonunion**
- Persistent gap at the fracture plane.
- Rounded, well defined or sclerotic fracture ends.
- Obliteration of the medullary cavity by endosteal callus.
- Osteopaenia of neighbouring bone, through disuse.
- Callus, if present, does not bridge the fracture.
- Displacement of the bone ends.
- In cases of pseudarthrosis, hypertrophy of the 'periarticular' tissues may be apparent.
- Soft tissue swelling.
- Irregular (pallisading) or smooth periosteal reaction. There is a lag of circa 2 weeks before radiographic signs appear in bone.
- Cortical lysis.
- Increased medullary density.
- Sequestrum: radiodense cortical fragment surrounded by radiolucency. No change in fragment outline with time. Ring sequestra about ESF fixation.
- Involucrum: sclerosis about a sequestrum
- Delayed union or nonunion.
- Gas shadows in soft tissue, if gas-forming bacteria present.

Malunion describes a fracture which has healed in a non-anatomic position. The resultant deformity may comprise rotation, angulation, and shortening. A functional malunion permits normal limb function, whereas a non-functional malunion precludes normal function. Disability may result from the deformity itself, relate to subluxation or DJD of adjacent joints, or be due to soft tissue compromise.

**Stress protection.**
Fixation which is too stiff will fail to load bone in a manner appropriate to fracture healing and remodelling. This is generally seen following application of oversized plates, however this degree of rigidity can also be achieved with some ESF configurations. Radiographic signs include reduction in cortical density and thickness and gap formation between plate and bone.

**Implant Failure**
Failure may occur at the implant-bone interface or within the implant itself. Prevent by using correct insertion techniques and adequate implants. Beware of narrow pins, thin cerclage, negative profile threaded pins, short plates, defects in the trans cortex of plated fractures, screws near fracture planes, and empty plate holes at the fracture plane. Implant failure is more likely in circumstances of fracture instability and poor reduction.

**Acute material failure.** The massive energy required to cause sudden and catastrophic crack propagation in an implant is rarely experienced in small animals, unless a grossly inadequate implant is used.

**Fatigue failure.** Stresses well below those required to fracture an implant can permanently deform the implant. Cyclic loading stresses, in excess of a fatigue limit, are responsible for implant failure, which generally occurs weeks after repair, in regions of stress concentration eg through plate holes.

**Electrolysis.** Use of dissimilar metals can establish a galvanic charge and dissolve bone locally. Rare, but check implant compatibility.

**Fracture related sarcoma**
Fracture related sarcoma describes the occurrence of (osteosarcoma at the site of a previous fracture repair. The pathogenesis of fracture related sarcoma remains controversial. Proposed aetiological factors include metal implants, corrosion, excessive tissue damage, and altered cellular activity. Presenting history is of lameness or progressively enlarging mass. Sudden deterioration in lameness may be associated with
pathological fracture. The tumors are usually diaphysal and exhibit aggressive local and metastatic malignant behavior. Typically, the patient is a large breed dog that had a femoral fracture fixation several years previously, at 1-3yo, complicated by eg. infection and implant loosening.
Bandages and Splints after Fracture Surgery

Amy S. Kapatkin DVM, MS, Dip ACVS
Bandages and Splints after Fracture Surgery
Amy S. Kapatkin DVM, MS, Dip ACVS

Learner Objectives:
- Identify the factors that influence the decision to use a bandage/splint
- Describe some pros and cons of bandages/splints after fracture surgery
- Recognize the complications that can occur using a bandage/splint after fracture surgery
Bandages and Splints after Fracture Surgery - Do We Need Them?

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The question of whether or not we need bandages and splints after fracture fixation is not a simple yes or no answer. There are numerous factors that have to be considered that may influence any given situation. To date, there are virtually no scientific studies studying the pros or cons of external coaptation after internal fixation; therefore, an individual’s decision, although based on some sound ideas and principles, is anecdotal.

The four functions of a bandage are protection, absorption of draining material, compression of soft tissue and stabilization. Bandages and splints may add to patient comfort, decrease post surgical swelling and protect wounds associated with the fracture or the surgical incision. Yet bandages can also prevent or inhibit early limb weight bearing, joint motion, and rehabilitation methods that are commonly employed after fracture fixation. In general, bandages and splints placed after internal fixation are considered only for fractures below the elbow and stifle.

The factors that influence whether or not we use a bandage or splint post surgery are mechanical, biological, patient, client and surgeon related. These factors have to be considered together for each individual situation to help to answer whether or not a bandage or splint may be needed.

Mechanical factors- (fracture type & fracture repair)
In this course, you have learned that reconstructable fractures can be repaired with the implant and bone sharing the load. This is inherently a more stable situation then a non-reconstructable fracture repaired in buttress/bridging fashion. No implant is indestructible. There are situations when the implant itself cannot be placed on the tension side of the bone. The implant that fits on a bone may not be stiff enough to counteract the forces that the patient may put on it. For example, a small dog that had a distal radial fracture repaired with a 2.0 mm bone plate on the dorsal surface. The plate size may be correct as far as width and screw size relative to bone diameter, yet the plate is not stiff and there is room for only 4 cortices in the distal fragment. The radius cannot have a pin added to the repair to help counteract bending and the ulna fracture is too distal and too small for a pin. The bone is not large enough to be plated in the medial-lateral as well as the cranio-caudal planes. This patient may benefit from a bandage and splint applied for 2-4 weeks post operatively.

Biological factors
Fracture repair and healing are influenced by biological factors such as surrounding soft tissue and blood supply. High-energy fractures will have longer healing times than simple, low impact fractures. Distal limb fractures fundamentally have less soft tissue coverage and probably a longer healing time than those in areas with abundant
soft tissue coverage. Although the fracture fixation method chosen for the repair may be mechanically correct for a fracture with good biological factors, it may be insufficient in one with tenuous biological factors. A bandage or a splint post operatively may help protect the apparatus used in situations where revascularization of the fracture may be prolonged.

Internal fixation is used even in open fractures. Wound care may be necessary and a bandage with or without a splint may be needed to help in keeping bacteria out of the wound, absorption of exudates and to help wound healing.

**Patient factors**

Young patients heal more rapidly than older patients. Young patients are growing quickly and a bandage or splint could adversely affect the growth plates or joint mobility. Therefore a postoperative bandage or splint in the exact same fracture but in a 6-month-old patient versus a 12-year-old patient may have different pros and cons.

The patient’s size and weight may play a role in whether or not a bandage/splint is used. A small patient that has internal fixation and a bandage or splint may not allow the patient to weight bear at all, which can delay fracture healing. An overweight patient may put a lot of stress on the fixation method, yet a large patient may be served better if additional internal fixation devices are used.

Poly trauma fracture patients must use at least one of the limbs that had a fracture repair. A bandage/splint may be indicated because of the forces on all the repairs. Yet a poly trauma patient may be incapacitated with multiple or even 1 bandage.

Some patients will not tolerate a bandage or a splint well. They may be unwilling to eat, drink or ambulate.

**Client factors**

Postoperative owner compliance after internal fixation of fractures is essential. Despite detailed instructions, clients do not always comply and this may affect whether or not a bandage or splint is used after internal fixation. A bandage or splint may be used to help prevent catastrophic implant failures or even to “slow” the patient down. Since a bandage must be changed and monitored closely, the patient will need weekly check ups that may be advantageous in a non-compliant patient-owner situation. Yet keep in mind that a poorly maintained bandage/splint by a noncompliant client may be more detrimental than no bandage/splint.

**Surgeon factors:**

Every surgeon approaches each fracture by balancing the biological and mechanical factors in choosing a repair method. There are instances when the original plan must be revised due to complications intra-operatively, miscalculation of the biological factors of the injury or iatrogenic trauma. The surgeon has to evaluate all of the above factors as well as their own postoperative repair and make a decision if they think a bandage or splint will help assure a successful outcome.

If a bandage or splint is used postoperatively, it must be monitored closely to avoid complications. Devastating complications, such as limb loss, can occur if they are
placed improperly or from poor patient/owner compliance. They should be changed and monitored on a weekly basis when used.

Rehabilitation, after orthopedic surgery, is showing positive outcomes in observational studies. The benefits include stimulation of tissue healing, pain relief, decrease of postoperative inflammation, and decrease of musculoskeletal disabilities that occur from immobilization. The techniques employed are local hypothermia for the first 72 hours, local hyperthermia only when the inflammation and swelling as subsided, massage, range of motion exercises, therapeutic ultrasound and neuromuscular stimulation. Using a bandage and splint will prevent these techniques from being used.

**Summary:**

The surgeon must synthesize all of the above factors into a reasonable decision whether or not a bandage or a splint is appropriate after fracture fixation. In general, good internal fracture fixation techniques should not need extended use of bandage and/or splints.

**References:**

Prophylactic Antibiotics in Orthopedic Surgery

Steven C. Budsberg DVM, MS, Diplomate ACVS
Prophylactic Antibiotics in Orthopedic Surgery
Steven C. Budsberg DVM, MS, Diplomate ACVS

Learner Objectives:
- Explain the common misuses of antimicrobial prophylaxis in surgery
- Provide a logical plan for the use of antimicrobial prophylaxis in specific cases
- Explain the potential benefits and risks for using antimicrobial prophylaxis
Antimicrobial Prophylaxis in Orthopedic Surgery

Steven C. Budsberg DVM, MS, Diplomate ACVS

Definition and History: A working definition of antimicrobial prophylaxis in surgery is the administration of an antimicrobial drug to a patient, in the absence of infection, prior to surgery. The history of the use of these agents during surgery is interesting and reveals many of the problems which occur with their use. When antimicrobial agents became available to surgeons, they did not provide the panacea for prevention of all surgical infections. In fact, a twenty-year analysis done in the mid-seventies indicated that no significant alteration of infection rates had occurred since the advent of prophylactic antimicrobial usage in human surgery. The study went on to identify the following misuses:

1. Excessive use in clean surgical procedures
2. Faulty timing of administration of the antimicrobial agent
3. Continued use beyond the time necessary for benefit.

Today, unfortunately, some of these misuses are still occurring in veterinary surgery.

The reason that misuses still occur in our profession is partly due to the limited amount of data based on clinical studies in veterinary medicine. Most of the studies available do not justify the use of prophylactic antibiotics in the study populations examined. Despite this fact, it is safe to say that a majority of surgeries done in veterinary practices are performed with antimicrobials given to the patient.

Wound Infections: In the evolution of wound infections, there are three main components. These are bacterial inoculum, bacterial nutrition, and impaired host resistance. The mere presence of bacteria is less important than the level of bacterial growth. Therefore, the goal of the surgeon is to maintain a favorable balance between patient and bacteria. It is important to remember that proper surgical technique and proper patient preparation, strict adherence to aseptic technique and application of atraumatic surgical technique are far more important in the prevention of infection than the use of antibiotics.

Patient Profile for Antimicrobial Prophylaxis: The next question to ask is "In which patients should I use antimicrobial prophylaxis?" There are no hard and fast rules to follow but the following examples can be used for some general guidelines. Most orthopedic procedures are defined as clean surgical wounds, and, in general, the use of prophylaxis is not recommended. Important factors to consider when giving antibiotics prior to surgery include: anticipated duration of the operation (degree of contamination), local wound factors favoring infection (e.g., extensive tissue trauma, placement of large implants) and systemic factors favoring infection (e.g., concurrent infections, diseases suppressing immunity).

Procedures in which it is difficult to justify giving antibiotics include:
1. Patellar repair
2. Arthrotomies including removal of endochondral ossification defects or open joint reductions
3. Arthroscopy
4. Many closed fracture repairs

Procedures which can be more easily justified for the use of prophylaxis are:
1. Total hip replacement
2. Complex multiple fractures
3. Open fractures
4. Systemically comprised patients

**Timing of administration:** Maximal therapeutic concentrations of the antibiotic must be present in the tissue at the time of contamination (i.e. beginning of surgery)!!!
Experimental work has demonstrated a short, early period in which "decisive biochemical interactions" between the microorganisms and the host tissue occur. During this time the development of the primary bacterial lesion is susceptible to the action of parenterally administered antibiotics. The major effect is in the first minutes of the contamination and no effect is seen if antibiotics are given 3 hours after contamination has begun. Thus, if given intramuscularly, administer 30 minutes prior to your incision. If given intravenously, administer 15 minutes prior to the incision. Repetitive dosing during surgery should occur depending on the antimicrobial given. As an example with a first generation cephalosporin (Cefazolin) every 2 to 2.5 hours is adequate according to published data. Serum half-life has been used as a guideline for this dosing, but it is not consistent with concentrations in the tissue (i.e., the drug is given at every half-life).

**Choice of Antibiotics:** No single antibiotic agent or combination can be relied on for effective prophylaxis in all the various settings found in surgery. Antibiotics used in surgery should be aimed toward the expected contaminating bacteria. The antimicrobial agent should also be bactericidal, have a low side-effect profile, be cost effective and be parenterally administered. In orthopedics, the expected contaminating organism is a staphylococcus from the skin of the patient, which usually produces beta-lactamases. Thus first generation cephalosporins, semi-synthetic beta-lactamases, resistant penicillins, and clindamycin are acceptable choices.

**Duration of Antimicrobial Prophylaxis:** The use of antibiotics beyond the immediate postoperative period is unnecessary. *6 HOURS POSTOPERATIVE* Use beyond this time will not prevent, nor will it decrease the severity of, a subsequent infection. There is strong evidence that use of antibiotics for days after surgery is not only unnecessary but can actually be detrimental to the patient.

**Potential Advantages:** The most obvious advantage is the prevention of infections. This, in turn, will decrease morbidity and mortality from surgery and decrease hospital stay and cost. Ultimately, this pulse form of usage can actually reduce total antibiotic use in surgical patients.
Potential Disadvantages: In veterinary medicine, we do not look critically at the potential disadvantages of antibiotic use. The most clinically important and seldom considered disadvantages are:
1) The development of resistant organisms.
2) Allergic reactions also are not considered, unless it entails a life threatening situation.
3) Non-allergic toxic reactions such as nephrotoxicity of aminoglycosides.
4) Costs, remember the cost of each dose given to a patient in which antibiotics are not necessary should not be overlooked.

Case Example
A simple example I always use that will hopefully help you make your decision on antibiotic use is this:

You have an infection rate of 4% for a given procedure. You are attempting to decrease that rate to 2%.
To institute your plan, you perform 100 of the aforementioned surgical procedures. All animals receive a prophylactic antimicrobial drug. After evaluating all the patients, you discover that you have decreased your infection rate to 2%. Thus you have accomplished your goal. Now the question arises, was it worth it? (ie. Are you willing to give 96 dogs antimicrobial agents which are not benefitting them to prevent an infection in 2 animals)?
Prevention and Management of Postoperative Pain

Phillip Lerche, PhD, BVSc
Learner Objectives:

- Describe a methodical and systematic plan for evaluating the trauma patient
- Explain the importance of appropriate analgesia in the trauma patient
- Describe how to initially treat and coapt both open and closed fractures until definitive treatment can be safely performed
- Describe the AAAA method of post-operative fracture assessment
- Acquire appropriate orthopedic terminology for assessment of fracture fixation
- Distinguish positive and negative attributes of the AAAA method in assessment of fracture fixation
Treatment of Postoperative Pain

Phillip Lerche, PhD, BVSc

Analgesia is perhaps the most important aspect of anesthetizing a patient with an orthopedic injury, and should begin in the pre-operative period. The use of intra-operative analgesic techniques such as constant rate infusions and/or epidural administration of drugs can be extremely useful as part of a multi-modal strategy to combat pain.

Assessment of post-operative pain and the appropriate treatment thereof should be an extension of the pre- and intra-operative analgesia plan.

Pain assessment after anesthesia can be complicated by emergence from anesthesia as well as post-operative sedation; however, pain medication should not be withheld just because a patient appears to be sedate. Sedatives may be used to enhance the effects of analgesic drugs, as well as to counteract emergence delirium.

Multimodal therapy designed to target several different nociceptors (e.g. sodium channel blockers, opioid receptor agonists, NMDA receptor antagonists, alpha$_2$ receptor agonists, NSAIDs) is most useful in the immediate post-operative period. The ability to provide analgesia by targeting several different mechanisms of action is also useful in decreasing doses required, which also decreases the potential for side effects to occur.

This lecture will look at the use of opioids, alpha$_2$ agonists, ketamine, and local anesthetics, as well as combinations of these drugs to treat post-operative pain in small animals.

The use of local anesthetic techniques, such as epidural injection, and ultrasound- and electro-stimulator guided nerve blocks will also be covered.

________________________________________________

Morphine, lidocaine, ketamine (MLK) infusion protocol

Add morphine 24 mg*, lidocaine 300mg, ketamine 60 mg to a 500mL bag of crystalloid fluids (LRS, Plasmalyte etc). [*morphine can be replaced with hydromorphone 2 mg]

Administer fluids at 5 mL/kg/hr, infusion rates will then be:

M: 0.24 mg/kg/hr [or H: 0.02mg/kg/hr]
L: 3 mg/kg/hr
K: 0.6 mg/kg/hr
AOVET North America

Principles in Small Animal Fracture Management

SUNDAY LECTURE ABSTRACTS
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Sunday, April 19, 2015

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Open Fractures

Marc Wosar, DVM, MSpVM, DACVS
Learner Objectives:

- Identify and describe the different degrees and prognoses of various types of open fractures
- Apply the principles of treatment to the soft tissues and bones involved in an open fracture
- Recognize which surgical fixation techniques are appropriate to repair open fractures
Open Fractures
Marc Wosar, DVM, MSpVM, DACVS
Miami Veterinary Specialists

An open fracture is defined as a bone fracture exposed to environmental contamination as a result of soft tissue disruption. The treatment of open fractures differs from the treatment of closed fractures mostly in the emphasis on the management of the soft tissue envelope. With open fractures, the injury to the soft tissues is more severe, with the added complication of contamination from the outside world.

The approach to an open fracture is similar to the approach for any patient presented for polytrauma. First, the life of the patient takes precedence over any orthopedic injury. The ABCs of resuscitation cannot be ignored simply due to a dramatic visual presentation of a mangled limb with exposed bone. The patient must be resuscitated appropriately, with support of blood pressure, IV fluids, etc. If possible, the limb can be treated by one team at the same time as the patient’s systemic needs are addressed by another team. If not possible, the limb is simply covered in a sterile drape until the patient is stable enough for damage control measures to be applied to the limb.

Once the patient’s stability allows, the open fracture can be addressed. First, arterial bleeding must be located and stopped. The neurovascular integrity of the limb must be assessed, so that the appropriate prognosis can be given and appropriate damage control measures applied. Institute broad spectrum intravenous antibiotics early. Studies have shown that the infection rate of open fractures is much lower when IV antibiotics are started within 3 hours of injury compared to after 4 hours (4.7% vs 7.4%). The next step is damage control. The wound is coated with a copious amount of sterile water-soluble lubricant (to capture hair and loose debris) and the hair around the wound is clipped and the wound lavaged. At this early stage, the composition of the lavage solution is not critical. Sterile saline, 0.05% chlorhexidine or dilute iodine are all appropriate. In severely contaminated wounds with large amounts of dirt and debris, even tap water is acceptable so long as it is rinsed away with sterile saline once the gross contamination has been removed. Lavage fluid pressure is limited to 8 psi. Too high a pressure (for example pressures developed by dental cleaning devices like Waterpiks) can actually drive debris deep into previously intact tissue planes. Obtain a deep swab for bacterial culture and sensitivity.

Devitalized tissue and bone can be removed at this early stage, but there is controversy over how aggressive this early stage debridement should be. Some advocate for early removal of all questionable tissue, as leaving necrotic tissue in the wound will later lead to higher infection rates. On the other hand, some argue that severely contused skin and muscle may initially appear nonviable to the naked eye, but may still survive and provide much-needed soft tissue coverage for reconstruction. At this stage the wound can be classified in order to help plan treatment and prognosticate on future limb function or need for amputation. The wound can then be covered with a hydrocolloid or wet-to-dry debridement bandage and splinted until definitive repair can be performed. Alternatively,
a simple four-pin external fixator can be applied temporarily, to be replaced by a more definitive fixation at a later procedure.

Open fractures can be classified using several classification schemes, which are helpful in fracture repair planning and prognostication. The most common classification scheme is the Gustilo-Anderson scheme, which ranks fractures on three point scale.

Grade I: opening less than one cm, no tissue loss.

Grade II: opening more than one cm, without soft tissue flaps, avulsions or loss.

Grade III: open fracture with extensive soft tissue damage. Grade III fractures are further subdivided:

- Grade IIIA: extensive soft tissue laceration or flap, but with adequate soft tissue coverage
- Grade IIIB: extensive soft tissue loss preventing adequate primary coverage of the fracture, periosteum stripped from bone
- Grade IIIC: open fracture with arterial injury requiring repair to save the limb

This grading scheme is helpful in planning surgical repair, but has low interobserver agreement.

The Orthopedic Trauma Association (OTA) has developed a scheme similar to the oncologic TNM scheme. The scheme ranks five factors on a 1-3 scale. The five factors are skin defect (S), muscle injury (M), arterial injury (A), bone loss (B), and contamination (C) so that a score would be communicated as, for example: S3 M2 A1 B1 C3.

Another grading scheme that has been modified from the human trauma field is the Mangled Extremity Severity Score (MESS). Similar to the OTA scheme, it ranks four factors (skin-soft tissue injury, limb ischemia, shock and age). The system is intended to rapidly provide the clinician with a prediction of whether the limb will need to be amputated; scores above 7 expected to have a high likelihood of requiring an amputation. While a low MESS score has been found to be sensitive in predicting that the limb can be saved, unfortunately the converse has not been proven to be true. High MESS scores may or may not be predictive of the need for eventual amputation.

Traditionally, open fractures have been considered emergencies requiring surgical debridement and stabilization within 4 to 6 hours of injury. Several recent studies have not supported this strict time schedule, and infection rates have not differed significantly in those fractures debrided before or after 6 hours from the time of injury. However, surgical stabilization should occur as soon after presentation as the health and stability of the patient allows. Stabilization of an open fracture should not be delayed while waiting for the open wound to heal, rather the wound should be treated concurrently with fracture stabilization. This raises the question of which stabilization method should be used for the treatment of open fractures. External coaptation alone is never recommended for open fractures.
fractures as the tenuous nature of the soft tissue envelope requires rigid fixation for predictable healing.

Gustilo Grade I and II fractures can be treated with either external fixation or internal fixation (including IM pins, plates and interlocking nails). There is no compelling evidence that contraindicates internal fixation in contaminated open fractures. On the contrary, the stability afforded by rigid fixation is more valuable than avoiding metal implants, if internal fixation is deemed necessary. Grade III fractures usually require an external fixator. External fixation has the benefit of allowing for removal of implants after bone healing, which may be especially important in the face of active infection (beyond contamination). However, external fixators can make soft tissue treatment more challenging, especially if the pin tracts tether the skin, preventing skin closure and movement of skin flaps. In cases where bone graft is desirable, cancellous bone graft can be used safely, but cortical allografts are at high risk of infection and sequestrum formation. When the injury includes a joint, stabilization may require reconstruction of the ligamentous structures of that joint. Stabilization can take the form of an external fixator incorporating a hinge to allow protected early motion of the injured limb and joint.

The soft tissue envelope must be restored for bone healing to occur. In most Gustilo Grade I and II fractures the wound can be closed primarily, given adequate debridement and decontamination. In most Grade III fractures, there is loss of substantial volumes of the soft tissue envelope, so the wound must be allowed to close by second intention, or skin flaps or musculocutaneous grafts must be used. Vacuum-assisted closure can be very helpful in eliminating dead space, reducing edema and accelerating the formation of granulation tissue.

The most challenging fractures to treat are those where there is bone loss. Often bone can be regenerated using distraction osteogenesis using the Ilizarov Method. Bone substitutes like cancellous bone graft, cortical allografts, or titanium meshes can be used. A new technique uses a two-stage procedure, where a temporary antibiotic-impregnated polymethyl methacrylate plug is used to induce the formation of a cylindrical membrane around the defect. At a later surgery, the PMMA plug is removed, and the cylindrical membrane is filled with cancellous graft. Results have been promising in the human field, but clinical data are lacking in veterinary patients. Unfortunately, bone loss often leads to amputation, especially when a joint surface is lost.
Delayed Union and Nonunion

Kei Hayashi, DVM, PhD, Diplomate ACVS
Delayed Union and Nonunion
Kei Hayashi, DVM, PhD, Diplomate ACVS

Learner Objectives:
• List common causes of delayed unions and non-unions
• Assess clinical and radiographic signs of delayed unions and non-unions
• Determine a treatment strategy for delayed unions and non-unions
Delayed Union and Nonunions
Kei Hayashi
DVM, PhD, Diplomate ACVS

Delayed union refers to “a fracture that has not healed in the usual time for that particular fracture” and nonunion refers to “a fracture in which all evidence of osteogenic activity at the fracture site has ceased, movement is present at the fracture site, and union is no longer possible without surgical intervention” (Brinker, Piermattei, Flo, and DeCamp).

Delayed Union
A delayed union is a fracture that takes longer to heal than anticipated.

Table 1. Expected healing time of uncomplicated diaphyseal fractures

<table>
<thead>
<tr>
<th>Age of Animal</th>
<th>ESF (type I, some II)</th>
<th>IM pin</th>
<th>Plate</th>
<th>ESF (type III, some II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3 months</td>
<td>2-3 weeks</td>
<td>4 weeks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-6 months</td>
<td>4-6 weeks</td>
<td>6-12 weeks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-12 months</td>
<td>5-8 weeks</td>
<td>12-16 weeks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;1 year</td>
<td>7-12 weeks</td>
<td>16-30 weeks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In general, the biological and mechanical environments determine the rate and extent of fracture healing. Biologically, adequate vascularity is essential for fracture healing. Soft tissue trauma is the most usual cause of an inadequate vascular supply. Stability is the most important mechanical factor for fracture healing. Inadequate fracture fixation results in instability and subsequent motion at fracture site that creates interfragmentary strain. If high interfragmentary strain persists, bone cannot form. Inadequate size and inappropriate application of implants are the common causes of instability. Systemic disease, drugs, and post-operative care also influence fracture healing.

Nonunions
As in delayed union, inadequate blood supply and fracture stability are the common causes of nonunions. Nonunions are largely classified as viable and non-viable nonunions. Biologically viable nonunions have a variable amount of callus but this callus fails to bridge the fracture gap. These are further classified as follows:

**Viable nonunion (biologically active)**
- Hypertrophic: abundant callus “elephant foot”.
- Moderately hypertrophic: moderate callus “horse hoof”
- Oligotrophic: little callus

**Nonviable nonunions (biologically inactive)**
- Dystrophic: poorly vascularity, callus formation only at one fracture end
- Necrotic: avascular and necrotic fragments within a comminuted fracture
- Defect: large bone defect at the fracture site
- Atrophic: defect at the fracture site with resorption of the adjacent bone ends
For convenience, it is simpler to classify nonunions into **those with callus formation (the hypertrophic and moderately hypertrophic viable nonunions)** and **those without callus formation (the viable oligotrophic and nonviable nonunions)**, since the distinction between the latter types is somewhat academic and their treatment is identical.

### Table 2. Factors associated with delayed union and nonunion

- Soft tissue trauma: loss of blood supply due to initial trauma
- Soft tissue trauma: loss of blood supply due to surgical trauma
- Instability: inadequate fixation, implant failure
- Malposition: inadequate reduction
- Large fracture gap: bone loss, soft tissue interposition, postop fracture distraction
- Systemic disease, malnutrition, age, drug
- Contamination, infection

### Diagnosis

Clinically, the patient is often lame, and the limb is more painful or is used less than anticipated. Muscle atrophy and joint stiffness are common clinical findings secondary to limb disuse. Movement of the fracture may be present although in many cases instability is not clinically obvious.

Radiographically, delayed union may present as the same as normal healing except that the changes occur at different time points. Nonunions show no evidence of progression of fracture healing over a period of several months. Radiographic features include a persistent gap at the fracture plane, rounded, well defined or sclerotic fracture ends, and obliteration of the medullary cavity by endosteal callus. Callus does not bridge the fracture and there may be displacement of the bone ends. Sequestra may be evident. There may be osteopenia of neighboring bones through disuse.

### Treatment: Delayed Union

If fracture stability and vascularity are thought to be satisfactory, the animal may be confined for a further period and reoperation unnecessary.

If implants are intact and stable, improvement of the biological environment may be considered with the addition of an autogenous bone graft.

If implants are loose or broken, they should be removed and the fracture should be stabilized appropriately. The addition of an autogenous bone graft is strongly recommended in this situation. If it is thought that the original implants were too weak, they should be augmented.

Where patients are treated with external fixators, destabilizing the construct may stimulate bone healing. Staged removal of implants may also be considered with other fixation devices, such as serially removing screws from a plate or removing the intramedullary pin from a plate-rod construct.
Treatment: Nonunion
Surgical intervention is necessary to create an improved environment for fracture healing. As a first step, it is important to determine the cause of the nonunion, by assessing both biological and mechanical factors. Infection may also be present. In addition, there may be an underlying metabolic disease present. Serial radiographic examination of the fracture area will provide the information necessary to determine the appropriate direction of management.

Standard surgical approaches should be used with a special caution to preserve existing blood supply to the fracture site. Loose or broken implants must be removed. Ischemic or necrotic bone fragments, which may be radiographically apparent as sequestra, must also be removed. The sclerotic or atrophic bone ends of biologically inactive nonunions must be osteotomized to expose their medullary cavities and thereby improve vascularity. Osteotomy facilitates apposition of the bone fragments but will inevitably result in limb shortening. Multiple holes can be drilled through their sclerotic ends to open medullary cavities.

Copious lavage is indicated, particularly if bacterial contamination or infection is suspected. Deep wound swabs should be taken routinely for bacterial culture and sensitivity.

The use of bone grafts should always be considered. Advantages include the ability to fill defects, improvement of osteogenesis at the fracture site, and a reduction in the time to clinical union. The proximal humerus is the preferred donor site due to the large amount of readily accessible bone and reduced postoperative morbidity. Other sites include the proximal tibia and the ilial wing. Corticocancellous grafts harvested from the ilial wing may be effective in cases with a large bony defect. Banked bone may also be used, either to supplement an autogenous cancellous graft or by itself. Recombinant human bone morphogenetic protein (rhBMP-2) has recently been shown to be effective in treating nonunions in animals, but is very expensive and is not readily available.

Rigid fixation is essential. Plates have the advantage of the stability, the patient has little discomfort postoperatively, and the postoperative care is simple. Plate-rod fixation and interlocking nails are alternatives. Both linear and circular external skeletal fixators may also be used. They have the advantage that frames are connected to the bone away from a potentially infected area, and allow postoperative adjustments. Both systems have the advantage that staged implant removal is possible. Some linear and circular external fixator systems have the capability to induce “distraction osteogenesis”. The disadvantages of osteogenic distraction techniques are that the constructs are cumbersome, and require a much higher level of owner compliance in the postoperative care of the frame.

Post-operative care
Appropriate physical therapy is indicated. The prognosis for bone healing is generally good, an exception being the atrophic nonunion of the distal radius in toy breed dogs.
Prevention and Management of Infections of Bone and Implants

Simon C. Roe, BVSc, PhD, Diplomate ACVS
Learner Objectives:

- Apply effective prevention strategies to reduce the incidence of post-operative infection in clean orthopaedic surgeries
- Evaluate a potential post-operative infection and institute an effective management plan
- Apply the principles associated with management of established osteomyelitis
Prevention and Management of Infections of Bone and Implants
Simon C. Roe, BVSc, PhD, Diplomate ACVS
North Carolina State University

While infection is always a possibility in orthopaedic surgery, it is always disheartening to get one in a clean surgery. There are many factors that determine whether this will happen, and it is the surgeons’ responsibility to eliminate as many as possible. “The dog licked the wound” or “He got it from his dermatitis” are not viable excuses – these are still your responsibility.

**Prevention is better than Cure** – this is an important adage to live by. It takes a process and a team that is very focused on this goal. Its outcome is hard to celebrate.

Pre-Operative – Patient factors, such as concurrent infections (teeth, ears, skin, urine, etc) and immunodeficiency should be considered and potentially managed before elective surgery. Environmental factors in the hospital should be optimized in all areas where surgical patients will be handled and housed. Regular, rigorous cleaning of surfaces, cages and equipment is needed and assessment of effectiveness of cleaning will reinforce its importance. Protocols for management of patients with known infections and keeping them, and the equipment and space they contaminate, separate from clean patients will reduce the chances of nosocomial transmission.

Peri- and Intra-operative – Establish robust protocols for clipping, scrubbing and skin sterilization and reward adherence to these processes. Develop a culture during surgery that focusses on maintaining sterility, and reporting any possible breaches. Include barrier drapes to cover the patient. Adhesive drapes will reduce contact between the surgeons’ gloves and skin, but they have not been shown to reduce infection rates. This may be because the hair follicles that are exposed during incision of the skin are not covered, and, in many cases, the adhesion fails before the end of the procedure. A stockinette that is sewn or stapled to the subcutaneous tissue will exclude this cut surface.

Basic surgical principles are extremely important but often are compromised as the day gets busy and rushed - Gentle handling of tissue, Meticulous hemostasis, Preservation of blood supply, Strict aseptic technique, Minimum tension on tissues, Accurate tissue apposition, Obliteration of deadspace. When implants are close to the skin (e.g. TPLO, carpal and tarsal arthrodesis), these principles are particularly important. Failure to close deep tissues over the implants places them close to the surface. Leaving a large deadspace will allow accumulation of fluid around the implant. A rushed subcutaneous and skin closure will not provide the seal needed to protect the deeper regions from infection. An interesting study of surgical site infections (SSIs) with TPLO’s and extra-capsular sutures suggested that skin staples were related to higher infection rates. This may reflect the hurried closure process rather than the device itself.

Peri-Operative Antibiotics – helpful in reducing SSI’s, but should not be relied upon. Usual approach – cefazolin 22 mg/kg Q 90 minutes, started at induction.
Post-Operative – protect the wound during the first 24 – 48 hrs – soft padded bandage or adhesive wound covering. Prevent licking and self-trauma. Don’t blame the dog for the infection – maybe the dog needed to lick the wound because it was not healing well or was already infected?

**Managing acute wound infections**

Educate owners regarding the early signs – redness, swelling, discharge, more lameness, wanting to lick the wound. With camera phones and electronic communication, have them send you a picture. If there is significant concern, but no obvious discharge, institute broad spectrum antibiotics for a 7 – 10 days course. Given that the most common organism is Staph, use either Clavamox (15 – 25 mg/kg, Q12) or Simplicef (5 – 10 mg/kg, Q24). Antibiograms of Staph pseudointermedius infections at NCSU show that only 56% are sensitive to Clavamox, but most of these cultures are from patients that have been treated unsuccessfully before presentation.

Strict activity limitation, hot packing, and gentle massage can help promote resolution. Educate the client regarding the expected response to treatment and what to do if there are still issues after 4 -5 days. If discharge begins, or persists, this suggests that more aggressive therapy will be needed. Culture and sensitivity become very important for ensuring appropriate antibiotic choices. Because this can take 3 – 4 days, a broad spectrum choice should be started/continued until results are known.

**Principles of Management of Bone and Implant Infection**

- Open, drain and eliminate deadspace
- Remove dead bone and tissue
- Remove loose implants and provide stability
- Choose antibiotic therapy based on culture and sensitivity – long course of treatment
- Consider local as well as systemic therapy
- Consider bone graft

Assess if there are local factors contributing to the infection or slow resolution. Fluid accumulation in deadspace, questionable tissue viability, instability and implant movement will all potentiate infection and reduce the effectiveness of antibiotic therapy. If these are considered significant factors, it will be necessary to address these surgically. Opening deadspace and debriding dead tissue or bone will improve the wound environment. It may be beneficial to leave the wound open until all tissue is healthy. A VAC (vacuum assisted closure) device can be very helpful to keep the wound clean and promote healthy tissue development. Bone fragments that are without blood supply and are contaminated need to be removed.

Once implants become contaminated, it can be difficult to fully resolve the infection. Many bacteria can adhere to the inert metal surface, form a glycocalx, and protect themselves from antibiotics and the host response. The aim is to keep the infection
controlled while the bone heals and, if draining tracks develop later, remove the implant. This is acceptable as long as the implant is stable. If the implant becomes unstable before healing is complete, more extensive steps are needed.

Culture and sensitivity is essential once infection has become established. Most antibiotics will have good penetration into bone with a good vascular supply. Once bacterial sensitivity is known, the choice of which to use is dictated by ease of administration and cost. The generic form of ciprofloxacin (25 mg/kg Q24) may be a reasonable choice if high doses of a fluoroquinolone are indicated. Its absorption may be variable in dogs. If the patient has good liver function, Rifampin (5 mg/kg, Q12) may be added to the treatment regimen – do NOT use by itself – resistance develops rapidly. It may reduce the ability of Staph organisms to adhere and form colonies. Long term use in combination with the primary antibiotic may be successful in achieving complete resolution of the infection and preservation of the implant.

Local antibiotic therapy may help in the acute phase but add complexity to the management process. The classic approach is using antibiotic-impregnated beads that are removed after a few weeks. Pluronic gel may also be used as a carrier. It is a polymer that is liquid when cool, and forms a gel at body temperature. It is resorbed over approximately 8 days. It must be sterilized and compounded.

If implants loosen and bone healing is delayed by instability or infection, removal of the implants and placement of new fixation is needed. In many instances, an external fixator is usually considered as they reduce the amount of metal in the infected area. Also, once healing is complete, the pins will be removed and issues of persistent contamination will not need to be addressed.

If healing appears delayed, or there is a defect, bone grafting may be used. My preference is to stage this if possible. Begin with opening and debriding all diseased tissue, removing loose implants and providing stability, getting a C&S and starting local and systemic appropriate antibiotics. Once the tissue around the bone is healthy and well vascularized, and the active infection is controlled, then place a bone graft. Autogenous cancellous bone is preferred, though be careful to not contaminate the donor site.

Managing Established and Resistant Infections

The same basic principles apply but must be followed very rigorously. Anything that might potentiate the infection (bone, soft tissue, implants) must be removed. Sequestra buried deep in effusive callus must be dug out. Sclerotic bone with poor vascular supply should be debrided or perforated. Local antibiotic delivery may be more valuable. Systemic antibiotics will need to be administered for a prolonged period.

Resistant infections that are established in bone are very difficult to resolve. The antibiotics that are available are often more toxic to the patient (Gentamicin or Vancomycin), need to be administered by injectable route (Vancomycin) or are very expensive (Linezolid). The best that may be achieved is suppression therapy with a less
expensive oral antibiotic. While bacteria may not be sensitive on their antibiotic profile, their virulence may be reduced by the antibiotic. Ciprofloxacin and clindamycin (11 mg/kg Q12), used in combination with Rifampin, may be used this way. Trimethaprim sulfa’s (15 – 30 mg/kg Q12 or Q24) may also be used in patients with normal renal function. Adverse reactions (KCS, hepatopathy, arthropathy, skin eruptions, etc) are somewhat common in dogs, so monitor carefully.

References:

Technical Errors

Prof Bruno Peirone
Technical Errors
Prof Bruno Peirone

Learner Objectives:

- Identify the three ways in which a bone-implant composite can fail
- List the common implant application errors that occur with each type of commonly used implant
- Construct a rational and complete plan for approaching a fixation failure
Technical failure in orthopaedic surgery is problematic because it can compromise the entire treatment and limb function of the patient. Almost always a second and more difficult surgical treatment is necessary. During a second intervention, the surgeon must handle previously traumatized tissue that has formed scar tissue and callus, implants have to be removed and the bony tissue may have sustained further fractures. Bone loss may be present due to the motion at the bone-implants interface. Following the rules and guidelines for orthopaedic surgery and applying the AO principles will help the beginners to avoid mistakes and in most cases will lead to a successful outcome.

Although inadequate restriction of the patient activity may play a role, most failures are surgeon induced. The surgeon must understand the strength and weakness of the implant system he is using. Understanding the failure mechanism of an implant system is critical to be able to avoid technical failure leading to non-union of the fracture.

The failure mechanism of the bone-implant construct can be divided in two areas: structural failure of the implant and implant loosening. Structural failure of the implant occurs when the allowable stress applied to the implant exceed elastic deformation. In a load deformation curve the elastic region is followed by the plastic region which terminates in a fracture of the implant. In the elastic region the implant can return in its original state. During the plastic deformation the implant is permanently deformed. Finally the implant can break, if the applied load exceeds the region of plastic deformation.

There are three different types of structural failures:
• Plastic deformation: occurs when the implant absorbs part of the energy but does not break.
• Catastrophic breakage: occurs when a large amount of load is applied suddenly.
• Fatigue breakage: occurs after multiple smaller loads that weaken the mechanical properties of the implant.

In most cases structural failure of the implant is due to improper selection of the implant size (to small) or technical errors, which lead to stress riser in the implant system (empty screw holes) or to stress concentration.

The second failure mechanism is implant loosening. This occurs most commonly with intra-medullary pinning or external skeletal fixation and less commonly with screws. Bone plates are compressed to the bone by the screws. This compression creates friction between the plate and the bone. Once inserted in to the bone, screws are placed under tension while bending and shear forces are minimal. Conversely all these forces act on intramedullary pin and pins inserted into the bone used for external fixation. If the mechanical stress applied to the implant is high, it can result in high motion area. In this situation the pin/bone interface becomes unstable. Pin/bone interface The surgeon should have access to adequate
instrumentation for fracture reduction and fixation and have multiple types and size of implants to choose from. Occasionally the implants are not the weakest link in the construct. In some cases poor bone quality will lead to failure of the implants. This is sometimes the case when pathologic changes such as neoplasia is infiltrating the bone. When changes are suspected a biopsy for histopathologic examination and bacterial culture should be taken.

**Iconography**

Fig 1: Mild diaphyseal tibia fx treated by medial plating. Plate breakage occurred 15 days after comminuted surgery (arrow). Note small gap at the fracture site and screws close to the fx site increasing stress concentration on the plate.

Fig 2. a: pin loosening, note the radiolucency around the pin. b) screws loosening in a oblique femoral fracture. The screws have been inserted in a fissure line.
Implant Removal

Ulrike Matis, Dr. med. vet. PhD, Professor of Surgery, Dipl. ECVS
Implant Removal
Ulrike Matis, Dr. med. vet. PhD, Professor of Surgery, Dipl. ECVS

Learner Objectives:
- Debate the need of implant removal after fracture healing
- Evaluate the optimal time of implant removal
- Utilize the proper technique to remove an implant and be aware of difficulties associated with implant removal
IMPLANT REMOVAL

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The decision of implant removal is based on:

1. Age of the animal
2. Location and type of fracture
3. Type of fixation - rigid or semi-rigid, interrupted or inadequate
4. Progress of fracture healing - normal, delayed, single or multiple surgeries, impaired circulation, infection
5. Radiographic appearance in two or more views - clinical union

<table>
<thead>
<tr>
<th>Age of the patient in month</th>
<th>Expected healing times in month</th>
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<tr>
<td>&lt; 3</td>
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<td>3 – 6</td>
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<td>6 – 10</td>
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<td>&gt; 10</td>
<td>5 – 14</td>
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Implants should be removed under the following conditions:

1. When they become nonfunctional (e.g. loose, bent or broken), impede healing or cause discomfort
2. When interference with bone growth may occur in young animals.
3. When causing lameness under cold conditions, due to thermal conduction. This phenomenon is most frequently noted with plate fixation of the radius and tibia.
4. When lick granulomas develop because of soft tissue irritation.
5. When infection is present and the implant is loose. If the implant is not loose, it is left in place until clinical union takes place.
6. When stress protection and/or vascular impairment by the implant lead to local bone atrophy. Oversized plates encourage demineralization and thinning of cortices in the underlying bone as they reduce periosteal perfusion and prevent the bone from responding to normal physiological stimuli. In order to prevent the bone from refracturing, broad rigid plates should be replaced by more flexible narrow ones which are secured to the bone only by the end screws. Cancellous bone grafting may also be necessary.

Implants are usually left in place:

1. In older animals (over 8 years) except under the conditions listed above.
2. In the pelvis, scapula and skull because they don't alter the bone architecture and density.
3. When they don't cause any discomfort and where excessive surgical trauma would be caused by removal (e.g. countersunk Kirschner wires or screws covered by bone).
The time for implant removal depends on the age of the animal, the location and type of fracture as well as the type of fixation. Most epiphyseal and metaphyseal fractures heal within 6 to 9 weeks. Shaft fractures of long bones in kittens and puppies are usually united in one month. Plates stabilizing long bone fractures in adults should not be removed within the first 6 months, more so when primary bone healing has taken place.

The surgery should be as minimal invasive as possible. The same surgical approach is used as for the initial repair. If the implant has little soft tissue covering (radius, ulna, metabones), surgical trauma can be minimized if only step incisions are made directly over the screws. Exposure of implants may require sharp debridement of fibrous tissue or removal of reactive bone. A scalpel blade or periosteal elevator can be used to remove or elevate fibrous tissue. Bone removal is accomplished using an osteotome, chisel, rongeur or burr. Bone plate removal requires removal of the screws first. The cavity of the screw head should be cleaned of debris prior to inserting the screwdriver and attempting removal. If the screwdriver is not completely seated in the cavity of the screw head, stripping of the screw head is much more likely. Removal of a stripped screw can become quite difficult. In such a case a slit may be cut in the screw head with a diamond saw. With a normal sterile screw driver the screw can now be loosened. Grasping the screw head with pliers or vise grips, followed by careful turning, can lead to successful removal. If the screw head is broken off, the screw threads are either left in place or a special hollow drill is used to remove the remaining screw shaft. Removal of the broken portion should only be attempted if absolutely necessary to treat infection, chronic pain or to allow placement of another needed implant. Pins are removed using a hand chuck, pin driver, pliers, wirepuller or old needle holder. The pin should be grasped tightly, oscillated back and forth while applying traction. Removal of orthopedic wire is done with wire cutters pliers or old needle holders. Active hemorrhage is controlled and the wound closed by layers, avoiding dead space. The wound bed is drained, if there is a large dead space left.

Postoperative radiographs in two planes should always be taken. They reveal osteoporotic changes that have been covered by the implants. Thus the chance of refracture can be detected in time. If osteoporosis is present, the owner should be told to restrict their dog to a leash or not to let their cat out for 6 weeks. Occasionally a splint is used to protect the area. In most cases, sufficient bone strength is regained within 6 weeks after implant removal.
Radiographic Assessment of Fracture Healing

Noël M.M. Moens, DVM, MSc., Dipl. ACVS/ECVS
Radiographic Assessment of Fracture Healing
Noël M. M. Moens, DVM, MSc., Dipl. ACVS/ECVS

Learner Objectives:
- Define different fracture healing patterns under various conditions
- Describe radiographic signs of fracture complications
- Construct a systematic method of radiographic assessment of fracture healing
Post-operative assessment of fracture fixation is an integral part of fracture fixation. It is often best (and less costly) to correct surgical errors immediately rather than correcting them later or after failure. Critically evaluating each repair is also an essential part of the learning process and each fracture repair, as perfect as it may seem at first glance, must be evaluated critically in order to detect areas of improvement.

Although one of the obvious goals of post-operative radiographic examinations is to document when the bone is healed, the detection or the anticipation of any impending problem is a major reason to perform regular follow ups. Generally post-operative radiographs are taken every 4-6 weeks until healing is confirmed and all complications have been ruled out. This timeline can be adapted depending on the situation. For tenuous repairs or if complications are highly probable radiographs after 2 weeks may be advised. A young animal will often heal quickly and radiographs every three weeks can be advocated. For older animals or at a later stage of healing, the timeline can be extended (6-8 weeks) as long as complications have been ruled out. Radiographs are continued until healing is confirmed and all complications have been ruled out or resolved.

The radiographic appearance will greatly vary depending on the animal, the fracture, and fixation method. They should always be interpreted in light of the clinical and physical examination of the patient. Historical radiographs should also be available for comparison. It is important to use the same radiographic technique and the same positioning of the patient for the follow up radiographs. Consistency in the technique will make it easier to appreciate implant migration, changes in bone density and to appreciate the changes in callus development.

**Primary bone healing:** The fracture lines will gradually disappear without evidence of callus formation. Resorption will not be observed, although because of the progression of cutting cones across the fracture line, the fracture will initially lose radio-opacity.

**Secondary bone healing:** This type of healing is the one most often observed and will generally start by limited resorption of the fragment ends and “rounding” of the sharp fragment ends. Within 5-7 days of surgery, the edges of the fracture will become less defined and the fracture gap will slightly widen. Although callus starts forming soon after fracture repair, it only becomes visible when mineralized. Evidence of callus formation often is visible at the periphery of the bone after 10-12 days. The fracture line(s) will progressively disappear and bony bridging is expected around 10-25 weeks however, can vary between 5 and 37 weeks. Remodeling may take several months.

The amount of callus is often inversely proportional to fracture stability. Young animals will also demonstrated larger callus than their adult counterparts. Bridging callus is generally smooth and regular.
The development of an irregular callus, with irregular margins and variable radiographic optical density is suggestive of osteomyelitis. Early bone resorption at the fracture ends in absence of infection is often suggestive of relative instability (low stiffness fixation). This resorption is usually temporary and followed by the formation of a bridging callus. Resorption that is not followed by the deposition of a bridging callus or a lack of significant healing progression between several visits are suggestive of delayed union or non-union. Implant migration or the development of a radiolucent line surrounding the implant usually indicated implant loosening and instability.

A fracture is considered healed if:
- There is continuity of the cortex
- There is presence of mineralized and ossified bridging callus (complete or spanning at least three out of 4 cortices)
- No remaining visible fracture lines

**Signs of complications are variable and may include:**
- Absence or lack of callus formation
  - Primary bone healing (if applicable)
  - Devascularization of fragments
  - Severe instability
  - Large gap
- Exuberant callus / periosteal reaction
  - Periosteal stripping or very young animal
  - Mild-moderate instability
  - Infection
  - Neoplasia
- Bone lysis / resorption / osteopenia
  - Motion at the fracture site (normal or pathologic)
  - Interposition of soft tissue between fractures (large gaps)
  - Infections
- Radiolucency around implants
  - Motion, intermittent contact
  - Infection
- Soft tissue changes (swelling)
- Loss of reduction or implant integrity
- Growth deformities, closure of growth plates

**References:**

Radiographic interpretation for the small Animal Clinician, 2\textsuperscript{nd} ed, JM Owens and DN Biery eds. Williams and Wilkins 1999; Chapter 4, Extremities, p 27-58.
