Lecture Abstract Manual

AOVET North America Course – Principles in Small Animal Fracture Management

April 7-10, 2016

Hilton Columbus at Easton Hotel
Columbus, Ohio
AOVET North America

Principles in Small Animal Fracture Management Course

LECTURE ABSTRACTS

Columbus, OH

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AOVET North America

Principles in Small Animal Fracture Management

THURSDAY LECTURE ABSTRACTS

April 7, 2016
# Table of Contents

**Thursday, April 7, 2016**

- Bone Structure, Vascularity and Function .......................................................... Johnson
- Fracture Classification and Biomechanics ......................................................... Guerrero
- Bone Healing Under Stable and Unstable Conditions .................................... Kapatkin
- Principles and Clinical Application of Cerclage Wiring .............................. Roe
- Principles and Clinical Application of Tension Band Wiring ...................... Kim
- Principles of Bone Screw Function: Plate Screw, Position Screw and Lag Screw .......................................................... Blake
- Principles of Treatment of Diaphyseal Fractures ........................................ Guerrero
- Principles and Clinical Application of Dynamic Compression Plate \( \text{(DCP)} \) \( \text{and Limited Contact-Dynamic Compression Plate (LC-DCP)} \) Stabilization .......................................................... Johnson
- Principles and Clinical Application of Neutralization Plate Stabilization .... Muir
- Principles and Clinical Application of Buttress/Bridge Plate and Plate/Rod Stabilization ....................................................... Bergh
- Orthopaedic Implant Design and Performance .......................................... Roe
Bone Structure, Vascularity and Function

Kenneth A Johnson, MVSc PhD FACVS Diplomate ACVS Diplomate ECVS
Bone Structure, Vascularity and Function
Kenneth A Johnson, MVSc PhD FACVS 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 fulcru ms 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 inter-fibrillar 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.

**Vascular Organization of Long Bones**

**Medullary and Periosteal Supply**

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.

![Images of bone sections](image)

**References:**
Fracture Classification and Biomechanics

Noël M.M. Moens DVM, MSC, Dipl ACVS/ECVS
Learner Objectives:

- Describe the forces acting in a bone and that need to be neutralized to achieve fracture healing
- Identify how different forces cause different fracture patterns
- Classify a fracture
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,
   - Metaphyseal,
   - Diaphyseal
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:

<table>
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<th>Traction</th>
<th>Compression/Collapse</th>
<th>Rotation</th>
<th>Bending</th>
<th>Shearing</th>
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Reference:
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:

1. Define the different types of bone healing
2. Discuss how rigid internal fixation versus biological fixation affects bone healing and describe other factors that may lead to complications
3. Apply direct and indirect bone healing to clinical case examples and case outcomes
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 or no callus) and unstable (indirect bone healing or callus) conditions but the biology is different.

**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 last 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.
Once injury occurs, the natural process of bone healing begins with the creation of soft callus—a cascade of cellular differentiation occurs.

**Phase 1:**
- New blood vessels invade the organizing hematoma
- Decrease of pain and swelling

**Phase 2:**
- Fibroblasts, derived from periosteum, invade and colonize the hematoma.

**Phase 3:**
- Fibroblasts produce collagen fibers (granulation tissue).

**Phase 4:**
- Collagen fibers are loosely linked to the bone fragments.

**Phase 5:**
- The cells of the granulation tissue gradually differentiate to form fibrous tissue and subsequently fibrocartilage (replacing hematoma).

Endochondral ossification converts the soft callus to woven bone starting at the periphery and moving towards the center, further stiffening the healing tissue. This continues until there is no more interfragmentary movement.
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.

![Remodeling stage: conversion of woven bone into lamellar bone through surface erosion and osteonal remodeling once interfragmentary movement ceases.](image)

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.

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 (> 200\(\mu\)m but < 1mm) bone healing:

In areas with small gaps (>200\(\mu\)m & < 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.
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:


Images: All images are from AOTRAUMA
Principles and Clinical Application of Cerclage Wiring

Simon C. Roe, BVSc, PhD, Diplomate ACVS
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 wire 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.\textsuperscript{1}

Cerclage wire cause 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.²
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:


2. Roe SC. Evaluation of tension obtained by use of three knots for tying cerclage wires by surgeons of various abilities and experience, JAVMA, 220(3):334-336, 2002
Principles and Clinical Application of Tension Band Wiring

Sun Young Kim, DVM, MS, Diplomate ACVS
Principles and Clinical Application of Tension Band Wiring
Sun Young Kim, DVM, MS, Diplomate ACVS

Learner Objectives:

- Explain biomechanical concepts of tension band principle
- Identify indications (fracture or osteotomy) of tension band wire
- Plan and execute repair of an avulsion fracture using pins and tension band wiring
Principles and Clinical Application of Tension Band Wiring
Sun Young Kim, DVM, MS, Diplomate ACVS – Small Animal
Michigan State University, East Lansing, Michigan

Principles
When a bone is eccentrically loaded, there are always a tension side and a compression side. The tension band principle is used to achieve the absolute stability at the fracture site by converting a tensile force into a compressive force. Tension band wiring is applied to the tension side of bone segments which, following osteotomy or fracture, are distracted because of the pull of attached muscle, tendon or ligament. Tension band wiring in the proper orientation not only neutralizes a tensile force but ideally convert it into a compressive force. The premise of the tension band wiring is intact cortical bone contact on the compression or bending side. Also, a fracture pattern or bone should be able to withstand a compressive force, and tension band wire should resist a tensile force.

Tension band wire is placed in a figure-of-eight fashion to maintain the longest lever arm between the bending point and the wire. Supplementary fixation with two K-wires is often necessary to neutralize shear forces at the fracture plane. The K-wires are inserted as parallel to each other as possible and serve as anchors for the tension band wire. Tension band wiring should provide the absolute stability and lead primary (direct) bone healing.

Technique
1. Two parallel K-wires are driven across the fracture plane to align the fragment. It is recommended that the wires be driven into the trans-cortex to reduce the risk of implant migration. The K-wires should be directed to avoid joint penetration and soft tissue interference.
2. A transverse hole is drilled through the tension aspect of the metaphysis or diaphysis and a wire is placed. This step can precede the K-wire insertion to prevent drill or wire impingement on the K-wires. The hole is positioned to locate the crossing point to the figure-of-eight wire near the fracture line.
3. The figure-of-eight is constructed by passing the wire over the tension surface, anchored around the K-wires. In some situations, it may be necessary to pass the wire under or through the ligament or tendon to keep it in contact with the bone and the K-wires. Wires should be of appropriate strength to withstand a tensile force. Wire diameter ranges from 22 gauge (0.64mm) to 16 gauge (1.25mm). Double or single twist knots are tied on both arms of the figure-of-eight to tighten the wire. Overtightening of the wire should be avoided while there should not be slack in the arms of the figure-of-eight.
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 three turns on the knots, and fold them toward bone.
6. Bend down the K-wires away from the bone and cut them with 2-3 mm of bent arm. Then, rotate them in the direction of the muscle pull on the fragment.

Application
Tension band wiring is applicable to fix avulsion fractures or of tendon and ligaments or osteotomy at the tendon and ligament insertion such as the greater trochanter of the femur, tibial tuberosity, medial tibial malleolus, tuber calcanei, acromion process, supraglenoid tubercle, greater tubercle of the humerus, olecranon of the ulna, and patella. The technique should also be considered for other collateral avulsion injuries.
When tension band wiring is used to fix avulsion fractures of the apophyses, e.g. tibial tuberosity, in young growing animals, early removal of the implants is recommended (3-4 weeks after the fixation) to avoid premature closure of physis.

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

Cara A. Blake, DVM, DACVS, CCRT
Principles of Bone Screw Function: Plate Screw, Position Screw and Lag Screw
Cara A. Blake, DVM, DACVS, CCRT

Learner Objectives:

- Recognize and explain the differences between cancellous and cortical bone screws
- Describe the indications and technique for inserting a plate screw, position screw and lag screw
- Identify instrumentation required for insertion of each type of screw
Bone Screws

Various types of bone screws are available for use in orthopedic procedures. They are manufactured from the same metal as bone plates to prevent corrosion (most commonly 316L stainless steel and titanium). Bone screw diameters range from 1.5mm-6.5mm. The two basic kinds of bone screws are cortical and cancellous. Cortical screws are designed to achieve maximum purchase in cortical bone. Cortical screw threads have a smaller pitch and a decreased thread depth as compared to cancellous screws. Cancellous screws are designed to achieve maximum purchase in cancellous bone. Cancellous screws have a larger outer diameter, larger pitch threads and deeper thread depth. Cancellous screws may be fully threaded or only contain threads on one end of the screw (partially threaded). Bone screws are also manufactured as self-tapping. Self-tapping screws are designed with a cutting flute on the tip to speed screw insertion.

Bone screw placement and insertion requires a hole drilled into the bone using an appropriately sized drill bit. The hole depth is then measured to determine the screw length. A “Tap” is then used to cut threads into the bone prior to placing the screw. If using self-tapping screws, the screw hole does not need threads cut into the bone with the tap. As the cutting flute on the self-tapping screw decreases the surface area of the bone-screw interface, the cutting flute must pass completely through the far cortex (2mm beyond).¹ The diameter of the screw should be ≤40% of the bone diameter.

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¹ The diameter of the screw should be ≤40% of the bone diameter.
Bone Screw Function

A bone screw is applied in such a way as to achieve a specific function based on the fracture configuration. Screws can be placed to hold bone fragments in place (positional screws), secure a plate to a bone and to compress fracture fragments (lag screw). The screw can serve more than one function, depending on how the screw was inserted.

Positional Screws

A position screw is indicated when the fragments will collapse if compression is applied. The bone fragments are reduced and held in position using bone forceps. A pilot hole is drilled, depth measured and tapped (if non-self-tapping screws are being used). The screw is placed and tightened with threads engaging both the near and far cortex, fixing the bone fragments in position.

Plate Screws

Plate screws are used to secure a plate to the bone. The size of the screw diameter is dictated by the size of the plate. The screw is placed through the hole in the plate, engages the bone, compressing the plate to the bone. Screws can be placed in a neutral or load position. Cortical screws are most commonly used. A minimum of three screws on either side of the fracture is recommended for adequate fixation. Stability and rigidity of the repair relies upon the frictional forces between the plate and bone and the number of cortices engaged by the screw threads.
Lag Screws

Screws are placed in lag fashion when compression of the fragments is required such as with articular fractures or in fractures containing a butterfly fragment. A lag screw can be placed directly though the bone or through a plate. Both cortical and cancellous (full or partially threaded) screws may be placed in lag fashion. The compression of a lag screw is created when the screw threads engage only the far cortex (opposite the screw head) of the bone. As the screw is tightened, the screw head contacts the near cortex, causing the fracture fragments to be compressed. A fully threaded screw can be placed in lag fashion by overdrilling the near cortex. This creates a “glide hole” in the bone, which the screw threads do not engage. The far cortex is drilled using the appropriate size drill bit to create a “thread hole”. This allows the threads of the screw to engage the bone of the far cortex. A drill sleeve must be placed into the glide hole while drilling the thread hole to ensure it is centered. Lag screws should be placed perpendicular to the fracture line. When a lag screw is placed alone, and not in combination with a plate, countersinking the near cortex maximizes contact with the bone and minimizes stress concentration. Avulsion fractures and apophyseal fractures may also be stabilized using a lag screw.

References:

Principles of Treatment of Diaphyseal Fractures

Mark Glyde BVSc MAMCVS MVS HDipUTL Diplomate ECVS
Principles of Treatment of Diaphyseal Fractures
Mark Glyde BVSc MACVS MVS HDipUTL DiplomateECVS

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
- Describe the relative pros and cons of different stabilization techniques
Principles of Treatment of Diaphyseal Fractures
Mark Glyde BVSc MACVSc MVS HDipUTL DiplomateECVS
Associate Professor, Small Animal Surgery
Murdoch University

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 recognize 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 (e.g. 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 extrasosseous 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 extrasosseous 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 devascularized 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 stabilize 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. Minimizing 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 (e.g. 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 stabilized 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 pluripotent 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 stabilization**

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 postoperatively.

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 won’t “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 neutralize these fracture forces.

- **Bone plates, interlocking nails** and **external skeletal fixators** (ESF) are able to neutralize 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 neutralizing 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 neutralizing bending and torsional forces of low magnitude. Casts rely on immobilization 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 immobilization 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.
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.

DCP
- 2.0
- 2.4
- 2.7
- 3.5
- 3.5 broad
- 4.5
- 4.5 broad

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.
Table top bending press  Hand held bending press

Flexible template to facilitate contouring  Bending and twisting with irons.

**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 remodeling 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.
3. **Pre-stressing 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.
Eccentric loading of femur Tension side opens  Plate loaded in tension Plate in bending

**Limited Contact – DCP (LC-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 Plates

Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS, ECVS
Principles and Clinical Application of Neutralization Plates
Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS, ECVS

Learner Objectives:

- List the techniques for creating interfragmentary compression with application of a neutralization plate
- Describe the step-wise procedure for application of a neutralization plate
- List the advantages and disadvantages of using a neutralization plate for stabilization of a long bone fracture
Introduction

The dynamic compression plate (DCP), limited contact dynamic compression plate (LC-DCP) and locking compression plate (LCP) can be used to stabilize shaft fractures in small animals. Depending on how the plate is applied to the fracture construct, the plate can have different functions including: (1) Static and dynamic compression, (2) Neutralization, and (3) Buttress or bridging.

Definition: A neutralization plate is a bone plate applied to neutralize the forces acting at a fracture site to produce displacement.

Neutralization plates act as an internal splint to counteract bending, rotational, and shearing forces at the fracture. Neutralization plates are applied after primary fixation has been used to reconstruct the bone column. Most types of bone plate function as a neutralization plate in a fracture construct. In addition to the DCP, LC-DCP, and the LCP, the Veterinary Cuttable plate, the String-Of-Pearls plate, and the Advanced Locking Plate System plates are examples of other types of plate that can be used for this application.

Indications

The most common pattern of long bone fracture in dogs and cats is comminuted. However, the majority of comminuted long bone fractures arise from low energy trauma and can be reconstructed during surgical treatment. Consequently, neutralization plate constructs are common in small animal long bone fracture repair. Neutralization plates are only used for fractures that can be reconstructed with interfragmentary compression. In plated fracture constructs in which the bone column is not reconstructed, the plate will have a bridging/buttress function. Open reduction and internal fixation (ORIF) generally yields good outcomes with a low complication rate if performed correctly.

Surgical technique

Fracture reduction. Open reduction is generally chosen for neutralization plate application. Initially fracture fragments are anatomically reduced and temporarily stabilized. This is usually accomplished with bone-holding forceps. Primary fixation is then used to generate interfragmentary compression. Interfragmentary compression will increase friction between the fracture fragments and augment stability of the overall construct. Primary fixation is typically achieved using cerclage wiring or bone screws inserted for lag effect.

During fracture reduction and stabilization, disruption of soft tissue attachments should be minimized. With a stable repair, revascularization of the fracture site will occur rapidly after surgery. Although minimally invasive plate osteosynthesis (MIPO) is a consideration for some fracture repairs in small animals, there is little evidence that clinical outcomes are superior to ORIF for fractures that are amenable to neutralization plate application (e.g. Boero Baroncelli et al. 2012). Anatomic reduction and interfragmentary compression for neutralization plate application is technically challenging with percutaneous implant application.

Cerclage wire fixation. Multiple wires are placed. Cerclage fixation is more versatile than lag screw fixation for comminuted fractures in dogs and cats and is generally easier to apply.
The principle reason for this is that wire location is not critical to plate position. If a cerclage wire ends up under a plate hole, it is usually possible to move it slightly to allow placement of a bone screw in that plate hole. Loop cerclage is preferred because greater interfragmentary compression is generated after application. Cerclage wires are typically applied first and are located under the plate. It is possible to place cerclage wiring over a neutralization plate, but this is rarely used, as the construct is less rigid. Skewer pin cerclage and hemi-cerclage (interfragmentary wiring) should be avoided.

**Lag screw fixation.** Fracture compression can also be achieved by interfragmentary compression using a lag screw. For optimal lag effect, the bone screw should be placed perpendicular to the fracture line. Screw placement close to a fracture line should be avoided to minimize the risk that a secondary fracture is created. Screws may be placed independently or through the plate.

**Independent lag screw.** During placement of an independent lag screw, consideration must be given to the final position of the plate on the bone. Although the drill hole in the cis cortex is typically countersunk to improve the lag effect, the cortical thickness in dogs and cats is not sufficient to avoid the head of the screw interfering with the plate, in contrast to large animals, such as horses, where cortical thickness is much greater.

**Lag screw fixation through the plate.** In situations when optimal screw location interferes with the position of the plate on the bone, the lag screw(s) may be placed through a plate hole. The plate must be contoured well to avoid loss of fracture reduction as the lag screw is tightened. When a LCP is used for neutralization plate fixation, a combi- or non-locking hole must be used for the lag screw. A locking screw cannot be used. In addition, the LCP must also be contoured correctly.

**Placement of the neutralization plate.** The width of the neutralization plate should generally be 50 to 75% of bone width. The length of the bone plate should be sufficient to span the fracture, such that at least three screws or six bone cortices can be engaged with positional screws in each of the bone fragments either side of the fracture. Longer plates may be needed in patients with soft bone or in larger more active animals, where greater construct loading is anticipated. Radiographs of the contralateral bone are often helpful for plate contouring. If a DCP or LC-DCP is applied, the plate screws should be placed in the neutral position to avoid stresses on the fracture construct. In general, the plate should be placed on the tension surface of the bone. This will facilitate creation of dynamic compression of the fracture during weight-bearing.

**Bone grafting.** In addition to rigid stabilization of the fracture, use of cancellous bone graft to stimulate fracture healing is recommended in skeletally mature patients. In very small patients, cortico-cancellous graft material can be collected from the wing of the ilium, if a larger volume of bone graft is needed. Autogenous graft material is typically used.

**Aftercare**

With rigid neutralization plate fixation, fracture healing is usually rapid. Secondary fracture healing is typical with a neutralization plate construct, particularly if cerclage wire fixation is used for reconstruction of the bone column, as more micromotion will be present at the fracture line(s) with this type of repair. 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 fracture disease and tissue...

fibrosis as much as possible. Patient activity should be carefully managed until the fracture has healed. Follow-up radiographs should be made to document fracture healing. These radiographic views are usually made after sufficient time has elapsed for callus formation to develop, a time period that will vary with patient age.

**Implant removal.** Implants are generally left in place, unless implant loosening is sufficient to cause clinical signs. Construct instability and infection are the most common reasons for planned implant removal (Emmerson & Muir 1999). Bone pain from cold-intolerance is occasionally seen in cold climates and may necessitate plate removal. Elective bone plate removal in dogs is not typically performed, since the risk of re-fracture is high, particularly in toy breeds (Bernard et al. 2008).

**Conclusion**

Neutralization plate application with ORIF is a versatile technique that is commonly indicated for long bone fractures in small animals. For many fractures, it is the treatment of choice. However, careful patient evaluation, meticulous fracture planning, atraumatic surgical technique, and excellent postoperative patient care are important to minimizing risk of complications.

**References:**


Principles and Clinical Application of Buttress/Bridge Plate and Plate/Rod Stabilization

Mary Sarah Bergh DVM, MS, Diplomate, ACVS, Diplomate ACVSMR
Learner Objectives:

- Recognize fracture types repairable using buttress plate and plate/rod stabilization
- Explain the important mechanical principles involved in buttress plate stabilization
- Describe the surgical techniques of applying buttress plates and plate/rod fixation
- Recognize common complications of buttress plate fixation and plate/rod fixation
Buttress or bridge plating and plate/rod constructs are both used in situations where the fracture cannot be or is elected not to be reconstructed in favor of a more biological approach or because reconstruction would be too time consuming or would significantly disrupt the blood supply to the fracture site. As such, the implants carry the entire load applied across the fracture site. They are commonly used in comminuted fractures or in corrections of malunions or angular limb deformities, where interfragmentary compression cannot be achieved. While older surgical literature frequently used buttress and bridge plating interchangeably, there are in fact important differences between the two terms.

**Buttress plates** are typically applied to the metaphyseal region, where they support the alignment of the articular surfaces that would otherwise collapse under weight bearing loads. (Figure 1) In these situations, the articular component would be reconstructed and interfragmentary compression may be achieved with lag screws. The lag screw is not sufficient to support loading forces, and thus the buttress plate should be applied to support the repair across the non-reconstructed metaphyseal portion. Nearly any plate type may be used in buttress fashion.

**Bridging plates** are typically used in diaphyseal fractures of long bones. (Figure 2) In these cases, screws are applied to the proximal and distal segments, without direct reduction of the fracture fragments. As such, bridging plates act as an internal splint to maintain bone length and spatial alignment of the bone by resisting shear and bending forces. The soft tissue envelope is best left intact so that it may exert concentric pressure on the fracture fragments and pull them into alignment as the envelope undergoes tensile forces during spatial realignment of the fractured bone. In addition, preservation of the blood supply will result in more rapid secondary bone healing and thus decrease implant failure. Autogenous cancellous bone graft or allograft may also be placed at the fracture site to promote bone healing. When using standard screws, a minimum of six cortices should be engaged on either end of the bridging plate construct. Pre-operative planning can be greatly enhanced by radiographing the contralateral normal limb and evaluating normal bone length and shape.
Many different plate types may be used for bridge plating techniques, however the most common are the dynamic compression plates (DCP) and limited-contact dynamic compression plate (LC-DCP). When using DCP plates, the screws must be placed in the “buttress position” by using a drill sleeve (rather than the DCP drill guide) to position the screw hole near the steep wall of the plate hole (as opposed to the neutral or compression position). Placing the screw in this fashion will prevent collapse of the fracture gap. When using LC-DCP plates, the LC-DCP drill guide is used with the arrow pointing away from the fracture line. For all plates used in bridging fashion, screw holes positioned over the fracture gap must be left empty. Failure of bridge plating may occur due to plate bending or breaking at these open screw holes, or by breaking or loosening of the screws.

Plate-rod fracture fixation utilizes a bone plate and screws, in bridging fashion, in combination with an intramedullary pin. Much like the bridging plate, it is most commonly used to treat comminuted fractures of long bones, whereby the bony column cannot be restored or the bone column is elected not to be restored in favor of a more biologic approach to fracture healing. (Figure 3) In these cases, the bone plate functions to protect the fracture from axial compression and rotational forces. The plate is highly susceptible to fatigue failure from bending forces and may therefore fail via plastic deformation or plate breakage. The addition of the intramedullary pin to the construct reduces the internal plate stress and increases the fatigue life of the plate. The pin also decreases the strain present at open screw holes – biomechanically making it effectively as if the bone plate was a solid piece of metal in the central region. Experimental models have shown that the a plate-rod combination is a significantly less compliant fixation method in torsion and compression, compared with an interlocking nail, and may therefore be superior in providing rigidity in non-reconstructed fractures.

Figure 2: Examples of fractures that could be treated with a bridging plate or a plate-rod construct. All of the fractures shown are comminuted and non-reconstructable.
The plate-rod construct is a biological fixation method and may be used with a standard open approach, an open-look-but-do-not-touch approach, or a minimally invasive approach. During application of this construct on the clinical patient, the intramedullary pin is selected and inserted first, in a normograde fashion. The optimal pin size is 35-40% of the diameter of the medullary canal at the isthmus of the bone. Once the length of the bone is restored, rotational alignment must be assessed by palpation or direct visualization of anatomic landmarks. When good angular and rotational alignment is achieved, the bone plate is applied allowing for 3-4 screws in each bone segment. Ideally, the plate should span at least 75% of the bone length. Screw holes should be directed to avoid interference with the intramedullary pin. If the drill bit hits the pin, a monocortical screw may be used. Six cortices should be engaged with screws on both the proximal and distal fracture segments. The extra-osseous portion of the intramedullary pin should be cut short to avoid interference with adjacent joints and soft tissue. Due to the inability to safely insert an intramedullary pin into the radius without damaging articular surfaces, plate-rod fixation cannot be used in this bone.

**Further reading:**


Orthopaedic Implant Design and Performance

Simon C. Roe, BVSc, PhD, Diplomate ACVS
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
Implant Design and Performance
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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/mm². 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 structures 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 4\textsuperscript{th} power for cylinders, and 3\textsuperscript{rd} 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 (i.e. bone plates), the direction of bending relative to the implant becomes important. $\text{AMI} \approx \text{width} \times \text{height}^3$ 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\textsuperscript{4} for the solid portion to 14.8 mm\textsuperscript{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.
AOVET North America

Principles in Small Animal Fracture Management

FRIDAY LECTURE ABSTRACTS

April 8, 2016
# Table of Contents

**Friday, April 8, 2016**

Principles and Clinical Application of Intramedullary Pins and Wires ................................................................. Moens

Principles and Clinical Application of Interlocking Nailing ............... Guiot

Introduction to Locking Plates................................................................. Johnson

Fracture Planning and Basic Instrumentation Needs ......................... Wosar

Principles and Clinical Application of Cancellous Bone Grafting and Bone Graft Substitutes ........................................ Muir
Principles and Clinical Application of Intramedullary Pins and Wires

Noël MM Moens, DVM, MSc, Dipl. ACVS/ECVS
Learner Objectives:

- Recognize the different fracture types amenable to IM pin and cerclage fixation
- Be familiar with the biomechanical properties and limitations of the IM pin and cerclage wire constructs
- List, in the appropriate order, the different steps taken to perform the fixation with IM pin and wires
- Recognize the different pin insertion methods and be able to choose the appropriate insertion method for each bone
Principles and Clinical Application of Intramedullary Pins and Wires
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University of Guelph

The use of intramedullary pins for fracture fixation started in the late 40’s. Because of its widespread availability, intramedullary pins quickly became a popular method of fixation and, despite its limitations is still used today. The key for successful application of pins and cerclage wire is an acute awareness of their shortcomings in stabilizing fractures. Once recognized and dealt with, IM pin and wires can be a very successful method of fixation that can be used with minimal complications.

Pin and wire fixation is much less expensive than bone plate. Their application requires only minimal equipment. Most pin and wire placement requires a smaller surgical approach than plating, resulting in less vascular damage and soft tissue trauma. Although, initial placement of the pin will interfere with the medullary vascularization, good intramedullary vascularization is generally restored within a week or two following implantation as long as the implants are stable. It must be noted, however that a loose, unstable pin or a pin filling the entire medullary cavity will seriously impair bone vascularization and may cause delayed and non-unions.

Intramedullary pins provide some alignment and provide excellent resistance against bending forces. They, however cannot act as a buttress nor provide rotational stability. As they generally do not fill the entire medullary cavity, their ability to counteract shearing forces is also poor. For these reasons pins are almost never used alone and are always used with some additional method of fixation (such as cerclage wires, external fixator or bone plate etc.). They should also only be used for fractures that are inherently stable and that can be adequately stabilized with cerclage wires. Today, IM Pins are also frequently used in complex and highly unstable fractures as adjunct fixation, in combination with an external fixators (Tie-in external fixator) or bone plates (Plate-rod). These uses are beyond the scope of this lecture and will be discussed elsewhere.

**Pin types:**
Pins are arbitrarily divided, based on their size into 2 main types: Kirschner wires and Steinmann pins
- Kirschner wires (a.k.a. K-Wires) are smaller and their diameter in inches are often expressed as a decimal number (0.028 to 0.062”) The most frequently used sizes are 0.035, 0.045, 0.054 and 0.062 inches (0.9 to 1.6mm).
- Steinmann pins sizes are usually identified by a fraction of an inch from1/16 to ¼ inch (1.5mm to 6.5mm).
The tip of the pin is designed to penetrate the bone to allow insertion. The two most common tips are trocar and chisel. The 3-sided trocar tip is usually easier to get started because of its sharp point and symmetrical design. The chisel point is harder to start, particularly at a shallow angle, however, its design allows better cutting of the bone and therefore generates less heat during introduction.
Pins can be smooth or have a threaded end. Although threaded pins are essential when used trans-cortically for external fixator, in IM pinning,
the thread offers no biomechanical advantage. In some cases, the thread creates a weak spot where the thread meets the shank and failure can be observed at the interface if this area of junction falls near the fracture site.


**Pin Diameter:**
Although filling the entire medullary cavity appears to offer some advantages as far as stability is concerned, it presents some major drawbacks. The pin would completely obliterate the medullary cavity causing widespread devascularization of the bone, leading to delay union. The curvature of most long bones in the dog also does not allow the use of a large diameter pin. For this reason, it is recommended that the pin fills 70 to 80% of the medullary cavity at its smallest diameter. Because of the cranial entry point in the proximal tibia, the pin will generally be required to bend along the caudal cortex during insertion. A large pin would not allow this bending to occur therefore a smaller pin (50%-60% of the medullary cavity) is often selected.

The stiffness of the pin is a function of its diameter at the 4th power. Therefore, a small increase in diameter significantly increase the stiffness of the pin. Inversely, small diameter K-wires often provide minimal stability.

**Stack pinning**
This is an outdated method of fixation that consisted of using several smaller pins rather than a single large pin. This method of fixation was used, because it was thought to provide better rotational stability or was recommended in large dogs in which a ¼ inch pin would be considered too small. Improved rotational stability has not been demonstrated clinically or experimentally and better methods of fixations are available for large breed dogs. Stacked pins often migrate out because some of the pins cannot be properly seated into the distal fragment. The pins were frequently left long because multiple pins were difficult to cut short, increasing soft tissue morbidity. Stacked pins cannot be recommended.

**Seating of the pin**
To be properly seated, the pin should span the entire medullary cavity and the extremities should be seated into the cancellous bone of the epiphysis. Driving the pin too far results in penetration of the distal cortex and, in most cases, penetration of the joint. When this happens, the pin must be **removed and redirected** into the distal fragment. Simply retracting the pin without re-orienting it will result in late migration of the pin back into the joint.

**Cutting the pin**
Often a sterilized bolt cutter is used to cut the pin. It is important to cut the pin as short as possible (5mm from the bone end or less, for the femur, the tip of the pin should be level with or below the level of the trochanter. In some locations it may be necessary to countersink the pin below the level of the cortex to avoid interference with tendons. Leaving the pin too long often results in severe soft tissue morbidity, pain, seroma formation or may result in severe and irreversible nerve damage by entrapment or transection.
Cutting the pin short may often be a challenge because of interference between the soft tissues and the large tip of the bolt cutters. One way to circumvent this difficulty is to properly seat the pin and determine the location where the pin should be cut. The pin is carefully retracted from the bone by a known distance, exposing the location of the cut (~ 2 or 3 cm). The pin is cut at the predetermined location then gently impacted back into its final position using a mallet and a pin punch. For small and medium diameter pins, the pin can be partially cut with the bolt cutter (notched). The pin is then advanced into its final position with a hand chuck. Bending the pin at the notch will result in the pin breaking at that level.

**Pin insertion.**

Pins can be inserted in long bones by either NORMOGRADING or RETROGRADING. The choice is dictated by the bone, location of the fracture and in some cases personal preference.

- **Normograding:** The pin is started at one end of the bone and driven through the bone. Once the pin reaches the level of the fracture, the fracture is reduced and cerclage wires are applied. The pin is then pushed past the fracture and into the opposite segment. More intimidating at first, this approach often allows better orientation of the pin and decreases surgical trauma.

- **Retrograding:** The pin is inserted from the fracture side in either end of the bone. The pin is driven through the fragment and retracted up to the level of the fracture. The fracture is reduced and cerclage wires are applied. The pin is then driven back through the fracture line, into the other bone segment. Although retrograding is often initially considered easier, it does limits the ability to fine tune the pin direction. It also requires a more aggressive exposure of the fracture to fully expose the bone ends.

Regardless of insertion direction, it is essential to fully reduce and stabilize the fragments before inserting the pin through the opposite fragment. Inserting the pin in the second fragment before reducing and stabilizing the fracture will invariably result in the impossibility to properly reduce the fracture once the pin is seated.
The femur and the humerus can be pinned using both methods. In these bones, the proximal articular surfaces are offset relative to the axis of the medullary cavity and therefore joint penetration by the pin is rarely a problem. Pinning of the tibia is almost always performed NORMOGRADE because the medullary cavity is in direct alignment with the articular structures. Insertion of a pin from the medullary cavity, into the proximal segment would likely result in the pin being directed straight into these structures. Instead, a smaller pin is chosen and inserted normograde, starting cranial to the articulation. If properly inserted, the pin will bend along the caudal cortex and follow the medullary cavity of the distal segment. The same technique is also used for IM fixation of metacarpal/tarsal fractures to avoid the distal metacarpo-phalangeal articular surfaces.

There is no good way to pin radii because of the size and shape of the bone but also because both articular extremities are “in line” with the medullary cavity and would inevitably be damaged during pin insertion.

The ulna can be pinned in many dogs. Both normograde and retrograde pinning can be performed. Because of the small medullary cavity and irregular shape of the proximal ulna, normograde pinning can be challenging.

**Pin removal**
Pins do not necessarily need to be removed unless they are causing a problem or are migrating out. Pins that are migrating out often create a small seroma and cause mild lameness. They have the potential however to cause severe and sometimes irreversible damage (particularly to the sciatic nerve) on their way out if they are left to migrate further. Loose pins no longer provide stability and must be promptly removed. Migrating pins are usually “easy” to retrieve under short general anesthesia or sedation.

**IM pins and cerclage wires:**
Combination of IM pins and cerclage wires is often the most successful combination of implant for diaphyseal fracture fixation using IM pins. The pin provide alignment and bending resistance while the cerclages, for an appropriate fracture configuration, are effective at resisting shearing, collapse and rotation. Although very successful, this method can only be applied to very specific types of fractures such as closed, simple (2-piece) long oblique and long spiral fractures. Slightly comminuted fractures (3 large pieces) may also, in some situations be considered for this fixation as long as all the different fragments have a “long oblique” configuration and are effectively reduced with cerclage wires. A more stable fixation method should be considered for very large and giant breed dogs or for any other fracture configuration not meeting the strict description above.
The fracture is approached and trial reduction is performed to ensure that the fracture can be perfectly reduced. Once confirmed, the pin may be introduced into the first fragment. The fracture is reduced and cerclage wires are applied, following all the rules of cerclage wire application. Cerclage wires should be evenly distributed and placed at least $\frac{1}{2}$ bone diameter away from the fracture ends and $\frac{1}{2}$ to 1 bone diameter from each other. Following these rules, AT LEAST 3 cerclages should easily fit the fractured area. If 3 or more cerclages cannot easily be fitted, fracture configuration should be reviewed and other methods of fixation considered. Once fully repaired, the pin is advanced to its final position and cut flush. Often the bone reduction forceps are kept on the bone until the pin is fully seated.

Great care must be taken to avoid cortical/joint penetration during final seating. Preoperative measuring, manual insertion and estimation of penetration depth with a pin of similar length are often used to minimize the risk. Palpation of the joint is also always performed to detect any grinding of the articular cartilage. Penetration of a joint presents a significant challenge to correct and is best avoided. Simple retraction of the pin will invariably result in the pin migrating back into the joint. In some cases, re-orientation of the pin may resolve the problem. If penetration was only partial, a larger pin (larger than the hole in the cortex) can sometimes be used. Alternately, the pin can be replaced by a much longer pin and “tied-in” to a simple frame external fixator to prevent migration.

Complications:
Complications are unfortunately frequently observed following IM pinning, however, the vast majority of the complications are the results of inappropriate fracture selection or incorrect application. When done properly, complications are actually quite rare. Premature pin migration can be a significant and potentially dangerous problem. Pin migration is in most cases the result of instability as opposed to its cause. A migrating pin must in most cases be promptly removed before it causes more troubles. Because pin migration is often caused by instability, it is very likely that the fixation will require some form of revision to provide additional stability until healing is observed. Pins that migrate after healing of the fracture, are often easily removed. Because the integrity and stability of the cerclage wires are essential to this fixation, IM pins and cerclage wires should not be used on infected or potentially infected fractures. Bone resorption that occur during infection would destabilize the cerclage wires and cause the fracture to fail catastrophically.
Principles and Clinical Application of Interlocking Nails

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 Application 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 instruments](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 intra-operative 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 Steinman 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 of 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.
Figure 4: Open (left) and closed (right) reduction techniques can be used with ILN fracture repair. Most often, a jig is used to identify the location of locking holes in the nail (middle and right top). Alternatively, intraoperative fluoroscopy (right bottom) may be used for this purpose.

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 Locking Plates

Kenneth A. Johnson, MVSc, PhD, FACVS, Diplomate ACVS and ECVS
Principles and Clinical Application of 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
- List potential advantages of choosing a locking compression plate instead of a DCP or LC-DCP
- Name some potential complications or limitations of the LCP
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 1980s 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 sometimes 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, String of Pearls, ALPS, 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).

Application of the LCP with entirely locking screws results in fixed angle construct. Used 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).

**Figure 3:** Accurate plate contouring unnecessary

**Figure 4:** Locking screw maintain reduction

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).

**Figure 5:** Blood supply under LCP

**Figure 6:** Locking screws (green) and standard screws (blue) in the DCU producing interfragmentary compression.
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 could fail (Figure 7).

![Figure 7: Axial malalignment of the plate may result in inadequate screw purchase.]

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, and the tibial plateau levelling osteotomy plate for dogs that is anatomically contoured to the proximal end of the tibia.

![Figure 8: Cross threading of locking screws]
References:


Fracture Planning and Basic Instrumentation Needs

Marc Wosar, DVM, MSpVM, DACVS
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
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 cranio-caudal 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 foramina, 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
Principles and Clinical Application of Cancellous Bone Grafting and Bone Graft Substitutes
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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 ingrowth, 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.
(2) 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.

(3) **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.

(4) **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).

(5) **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.

(6) **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.

(7) **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 principally 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 (Hoffer et al. 2008). 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:**


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Principles in Small Animal Fracture Management

SATURDAY LECTURE ABSTRACTS

April 9, 2016
Table of Contents

Saturday, April 9, 2016

Principles of Joint Fracture Treatment.......................................................Budsberg
Growth Plate Fractures .............................................................................Marcellin-Little
Fractures of the Elbow Joint .....................................................................Dyce
Sacroiliac Luxation ....................................................................................Kapatkin
Fractures of the Pelvis and Acetabulum .....................................................Matis
Fractures of the Femoral Head, Neck and Trochanter ...............................Turner
Fractures of the Distal Femur, Proximal Tibia and Patella .........................Guerrero
Simple Fractures and Luxations of the Tarsus ..........................................Matis
Preoperative Patient Evaluation and Management ...................................Bergh
Soft Tissue Handling and Fracture Reduction .........................................Hayashi
Postoperative Assessment of Fracture Fixation .......................................Dyce
Bandages and Splints after Fracture Surgery – Do We Need Them? ........Marcellin-Little
Prophylactic Antibiotics in Orthopedic Surgery ......................................Budsberg
Implant Removal ......................................................................................Matis
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
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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

Denis J. Marcellin-Little, DEDV, Diplomate ACVS, ECVS, ACVSMR
Growth Plate Fractures
Denis J. Marcellin-Little, DEDV, Diplomate ACVS, ECVS, ACVSMR

Learner Objectives:

- Identify the types of growth plate fractures and their consequences
- Explain how to select a management option for various types of growth plate fractures
- Describe the surgical principles of management of growth plate fractures
Growth Plate Fractures
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Anatomy and physiology
The process ensuring the longitudinal growth of long bones is named endochondral ossification. That process relies on the growth plate or physis (plural physes, adjective form physeal). The physis was once named the epiphyseal plate. The physis is the zone that separates the epiphysis and the metaphyses, at end of long bones. Most long bones have two physes, one at each end. Metacarpal and metatarsal bones have a single physis located at their distal aspect. Histologically, the physis is cartilaginous, with a basal layer where chondrocytes multiply, become linearly organized, and migrate toward the metaphysis as chondrocyte multiplication occurs. Chondrocyte hypertrophy, become surrounded by blood vessels, die, and are replaced by osteoblasts and osteocytes. Physes are weaker than the bone surrounding them and are therefore vulnerable to fractures.

Physeal fractures occur in skeletally immature animals. Physeal fractures are generally low-energy fractures with a single fracture line. That fracture line often runs along the physis or across the physis. It can also run along part of the physis and across it. The conventional classification of physeal fracture includes 5 fracture types described in Roman (I to V) or Arabic (1 to 5) numerals by Salter and Harris. A Salter-Harris type 1 fracture runs along the physis; type 2 runs along part of the physis and across the metaphysis, away from the articular surface; type 3 runs along part of the physis and across the epiphysis and articular surface; type 4, runs across the metaphysis, epiphysis, and articular surface. Type 5 Salter-Harris fractures are disturbances of physeal growth resulting from physeal injuries. Some authors have described type 6 and 7 physeal abnormalities as partial physeal closures or bone bridges around an open physis, but these descriptions are not universally accepted. Physeal fractures are always near or in joints, even if they are type 1 or 2 fractures, because the physes are always close to joints. For example, a fracture across the femoral head is located within the hip joint. Physes general close after 6-10 months of age. Physes close earlier in small dogs compared to large dogs. Some physes (away from long bones) remain open for several years. For example, the physis of the wing of the ilium always remains open for years and, in some dogs, it remains open. Physeal closure is influences by hormones. For example, estrogen promotes physeal closure. Dogs and cat that undergo an ovariohysterectomy (or ovariectomy) see a delay in physeal closure and, as a result, have longer bones. Some physeal fractures in long bones can occur at a late date (e.g., 2 years of age) because of a delay in physeal closure in patients that underwent early neutering.

Incidence of physeal fractures
The actual incidence of growth plate fractures is not known because large epidemiologic studies describing fractures in dogs are lacking. However, physeal fractures appear to be quite common, possibly because the physis is a weak point along bones that acts as a stress riser (ie a location where stress is concentrated) when bending or torsion are applied to a long bone. In one retrospective study that included approximately 500 fractures of all types, 20% of all fractures were physeal fractures. In another retrospective study that included approximately 250 humeral fractures, physeal fractures also represented 20% of fractures. A recent survey of fractures
managed in VCA animal hospitals in 2014 indicated that dogs less than 1 year of age had a fracture rate (2,685 fractures; 534,765 visits; fracture rate of 50 per 10,000 visits) that was 5 times higher than dogs over 1 year of age (2,024 fractures; 2,039,289 visits; fracture rate of 10 per 10,000). In dogs under 1 year of age, 2,685 long bone fractures were reported. They included 11 ilial fractures, 551 femoral fractures (22%), 786 tibial fractures (31%), 16 scapular fractures, 214 humeral fractures (8%), and 979 radial/ulnar fractures (38%). The number and type of physeal fractures was not reported. That survey indicated that cats less than 1 year of age had a fracture rate (439 fractures; 114,850 visits; fracture rate of 38 per 10,000 visits) that was 3 times higher than cats over 1 year of age (492 fractures; 393,418 visits; fracture rate of 13 per 10,000). In cats under 1 year of age, 401 long bone fractures were reported. They included 11 ilial fractures, 190 femoral fractures (47%), 101 tibial fractures (25%), 2 scapular fractures, 39 humeral fractures (10%), and 57 radial/ulnar fractures (14%). The number and type of physeal fractures was not reported.

**Stabilization of physeal fractures**

Owners of cats and dogs sometimes have difficulties justifying the surgical management of physeal fractures. This is potentially linked to the fact that the bond between pets and owners may not be as strong in recently acquired pets compared to adult pets. Also, owners may think that young dogs and cats are particularly healthy and therefore do not need surgery after a fracture. They may recall fractures that occurred in children and were managed without surgery. This may complicate discussions and management decisions in skeletally immature dogs and cats.

The stabilization of physeal fractures is challenging because the fracture fragments are small and somewhat friable and because the reduction of these fractures should be precise, particularly when fractures involve the articular surface, but also when a clinically significant growth potential remains (i.e., in very young dogs) and growth is an important part of the success of fracture repair.

Fixations methods include longitudinally placed pins (also named Kirschner wires or Rush pins) that do not rigidly prevent physeal growth. Rush pins have been shown to limit bone growth, unless they are removed after 1 month. In patients with physeal fractures that are close to full size, bridging surgical procedures (pins and tension bands or bone plates are selected.

**Factors predicting the likelihood of premature physeal closure**

Reevaluations of physeal fractures should be aimed at confirming the absence of failure of fixation, the absence of loss of fracture reduction, the absence of loss of joint motion, the return of limb use, and the absence of premature physeal closure.

Historically, the clinical impression was that Salter I and II fractures were associated with a low risk of premature physeal closure and that Salter III and IV were associated with a higher risk of physeal closure because the Salter III/IV fractures crossed the physis. This myth has been debunked, in part because histologically, all salter fractures cross the physis. In human tibiae, 12% of distal tibial fractures lead to abnormal tibial growth. The mode of injury and initial displacement influence the likelihood of growth disturbance.
References:

Footnotes:
Fractures of the Elbow Joint

Jonathan Dyce, MA VetMB DSAO MRCVS Diplomate ACVS
Learner Objectives:

- Identify fractures of the humeral condyle with an emphasis on distinguishing unicondylar from discondylar fractures
- Recognize the relationship between incomplete ossification of the humeral condyle and fracture of the humeral condyle
- Describe how to plan and execute repair of a fracture of the lateral portion of the humeral condyle using a transcondylar lag screw and pin inserted into the lateral epicondylar crest
**Articular fractures of the humerus**

Fractures of the humeral condyle are common in the dog. Unicondylar fractures of the lateral portion are ten times more frequent than fractures of the medial portion. This is the result of anatomical and biomechanical differences between the two regions. Certain breeds e.g. Yorkshire terrier, pit bull terrier, are overrepresented as immature dogs, whereas working breeds e.g. cocker spaniel, springer spaniel are overrepresented as mature patients. Intercondylar (Y- or T-fractures) account for approximately 25% of condylar fractures and present a significantly greater challenge for orthopedic repair. The principles of articular fracture repair should be applied, including anatomic reconstruction, rigid internal fixation, and early return to weight bearing function.

**Fracture of the lateral portion of the humeral condyle**

This is commonly the result of low energy trauma e.g. jumping down. Such fractures are Typically Salter-Harris type IV fractures in the immature dog. If the fracture is displaced, the medial epicondyle will be palpated distal to the lateral epicondyle. Radiography confirms the diagnosis and should rule out dicondylar fracture. Open reduction via a caudolateral or craniolateral surgical approach to the elbow is the norm although the technique for minimally invasive fluoroscopically guided osteosynthesis is also reported. Accurate articular reconstruction is required and the sagittal fracture configuration is amenable to lag screw fixation. Drilling the gliding hole from the center of the fracture surface outward facilitates placement of a transcondylar lag screw. The screw is inserted from a point just distal and cranial to the lateral epicondyle to a similar exit point with respect to the medial epicondyle. Drill aiming guides are helpful, particularly if using orthograde drilling. Ideally the screw should be located entirely within the epiphysis but there appears to be little effect on humeral growth if the screw crosses the growth plate. Reduction of the articular margin of the condyle should be confirmed by direct inspection. The metaphyseal epicondylar fracture plane should also be exposed to confirm alignment. Consider use of a metal washer to distribute load to the lateral cortex, but this should not impinge on the radial head. 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. Note that fragmentation of the medial portion of the coronoid process can occur as a result of displacement of the medial portion of the condyle. Malunion is the most frequent result of conservative treatment, whereas nonunion commonly follows surgical failure. In juvenile dogs that are presented with chronic fractures of the lateral portion of the humeral condyle, if the condyle has an established malunion, given the likely degree of remodeling of all surfaces of the joint, it is unlikely that revision involving corrective osteotomy will be beneficial. I would recommend repair prior the development of spontaneous union but would consider plate augmentation of the transcondylar screw, and offer a worse prognosis for restoration of range of motion.
Fracture of the medial portion of the humeral condyle

The technique for repair is similar to that for fractures of the lateral portion of the humeral condyle. The fragment is often larger than that seen laterally and may be amenable to placement of multiple lag screws. Note that in some older dogs fissures may extend proximally through the lateral cortex and can propagate after repair. Consider computed tomography to identify these fissures and if found, supplement the lag screw with a medial plate to stabilize the fissured portion.

Intercondylar (T-Y) fracture of the humeral condyle

These are generally three-piece fractures but may have supracondylar comminution. A number of surgical approaches has been described including a bilateral approach, osteotomy of the olecranon, proximal ulnar diaphyseal osteotomy, and triceps tenotomy. There is a high complication rate of ulnar osteotomy (nonunion) and triceps tenotomy (avulsion) and while these techniques do remove soft tissue tension that opposes reduction, I would recommend the bilateral approach.

In general the articular fracture plane is reduced first, and stabilized using a transcondylar lag screw, because of the priority of anatomical articular reconstruction. The repaired condyle is then attached to the diaphysis. In some cases restoration of the medial humerus is performed first and this can facilitate reduction of the lateral portion of the condyle. I do not recommend insertion of the lag screw through a plate hole, as the optimal positions for the screw and the distal plate hole are different. In small dogs the supracondylar fracture is adequately stabilized by a medial intramedullary pin and a lateral epicondylar crossed pin. In larger dogs medial plate fixation is the principle stabilization. The distal end of the plate is located level with the distal humerus and the plate should be twisted to direct the screws into the condyle and away from the olecranon fossa. A lateral epicondylar pin, or more commonly a lateral plate (recommended with increasing bodyweight) should supplement this plate. While the medial surface of the humerus is amenable to use of standard plates (DCP, LC-DCP, LCP) the lateral aspect has a more complex contour and the use of reconstruction plates or SOP plates should be considered. Often the challenge of fixation is to achieve an adequate number of screws that engage the condyle.

Complications of dicondylar fracture repair are more common than after unicondylar fracture.

Incomplete ossification of the humeral condyle (IOHC)

Union of the separate centers of ossification of the medial and lateral portions of the humeral condyle should occur by 3 months of age. Failure of fusion allows persistence of a weak plane of fibrous tissue and this can predispose to condylar fracture. IOHC has a prevalence of 14% in springer spaniels, and 43-86% of dogs with humeral condylar fracture have been reported to have contralateral IOHC.

Radiographic features include identification of the radiolucent intercondylar plane; best projected by a 15° CrMed-CaudLat oblique, and periosteal proliferation on the lateral epicondylar crest; representing adaptive remodeling. Computed tomography is a more sensitive imaging modality and will readily illustrate IOHC, often with adjacent trabecular sclerosis. Note that intercondylar fissure fractures can occur without pre-existent IOHC and can also predispose to condylar fracture.

In cases of IOHC that has progressed to displaced lateral condylar fracture, consider a stronger repair than in the routine case e.g. augment the transcondylar screw with a lateral plate and pack autogenous cancellous autograft into the fracture plane and around the epicondylar crest. Fatigue fracture of the transcondylar screw at the fracture plane is a common failure mechanism if intercondylar bone union is not achieved. Note that trabecular sclerosis is prohibitive of normal progression to union. If IOHC is identified prior to fracture there is consensus that prophylactic
stabilization is indicated, but the ideal implant choice e.g. lag or positional screw or other fixation is unresolved. Forage and bone grafting are probably helpful in stimulating union.

Avoidance of osteoarthritis is rare with humeral condylar fractures and complicating factors include traumatic cartilage injury, morbidity of surgical approach, delay to repair, BCS, age and technical challenges at surgery. Beyond surgery the recovery of function should be facilitated by use of NSAIDs, DMOADs, and physical rehabilitation modalities including passive range of motion exercise. Restrictive periarticular fibrosis is a particular complication of elbow fracture repair and therefore promotion of early return to weight bearing function and mobilization should be a priority.

**Intra-articular fractures of the ulna**
Fractures of the semilunar notch are commonly simple two fragment fractures with an oblique orientation, but may be comminuted. The pull of the triceps brachii will distract the olecranon fragment proximally, and the choice of fixation is directed by the requirement for articular reconstruction and neutralizing this distraction. Stabilization can be achieved using pins and caudal figure of eight tension band wire anchored proximally around the exposed pin ends. Note that because of the density of cortical bone in the olecranon predrilling may be required to minimize thermal necrosis. Although pins and figure of eight tension band wire can achieve successful fixation, a plate should provide a more secure fixation, and is definitely recommended in larger patients. While a caudally applied plate will act as a mechanically appropriate tension band, there can be irritation as the dog lies sternal and I would generally favor a lateral plate. Lag screw fixation may be used initially in suitable fracture configurations and the plate is then applied with neutralization effect.

**Monteggia fracture**
The Monteggia fracture is a fracture of the proximal ulna with concurrent luxation of the radial head. This may be further classified by the direction the radial head displaces i.e. cranial (the most common: Type I), caudal, medial or lateral. These are treated by anatomical reduction of the radial head and ulna fracture stabilization with either a pin or plate fixation. The proximal radius can be stabilized to the ulna with a temporary transfixation pin or screw if the ulnar fracture is distal enough. 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 implant will result in loosening or breakage due to antebrachial pronation and supination.

**Radial head fracture**
Radial head fractures occur rarely. They are usually treated with cross pin or T-plate fixation. The surgical approach is lateral and the radial nerve should be identified and protected.

**Reference:**
Sacroiliac Luxations

Amy S. Kapatkin, DVM, MS, Dip ACVS
Learner Objectives:

- Cite the incidence and presentation of dogs and cats with SI luxations
- Explain the advantages of doing surgical fixation for SI luxations
- Describe the open surgical approach and the minimally invasive technique for placement of a SI lag screw
- Diagram the anatomical sites in the dog and cat for ideal lag screw placement for SI fractures
- List SI luxation surgical options other than a lag screw fixation
Sacroiliac Luxations
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Sacroiliac luxation (SI) can be called SI fracture-luxation and SI fracture- separation. It is distinctly different than a sacral fracture. Sacral fractures are less common and clinically more painful with increased chance of the patient having neurological deficits (69%). The actual number of SI luxations in dogs and cats after trauma is difficult to pin point in the published studies. Some facts that are published include: In dogs, 77% are unilateral and 23 % bilateral SI luxations. 85% of the dogs with SI luxations have disabilities of both pelvic limbs and 93% of the dogs will have some other major injury. In cats with pelvic fractures, 27% of them will be SI luxations and 85% of cats have bilateral SI luxations.

Dogs and cats with SI luxations usually present non-weight bearing on the affected side(s). The ilial wing is usually displaced cranial and dorsal to the sacrum. Instability can often be felt on examination; the patients are painful and sedation is recommended. Neurological status must always be assessed because sacral nerve roots or lumbosacral trunk can be damaged. In one study, with partial nerve injuries from SI luxations, 81% had a full recovery in 16 weeks. High quality lateral and VD pelvic radiographs are needed for a correct diagnosis. A tilted ventrodorsal pelvic radiograph can lead to false positive diagnosis of an SI luxation. A step between the ilium and caudal sacral wing indicates a SI luxation is present. A gap in the SI joint with no step may be normal and should be further evaluated.

Surgery for a SI luxation is indicated when the patient has severe pain, if the pelvic canal is narrowed, the patient is unable to ambulate or if there is neurogenic dysfunction due to the SI luxation. Surgery enhances early weight bearing and avoids malalignment of the coxofemoral joint and pelvis. Cats with pelvic narrowing greater than 45% are at high risk for constipation and obstipation. Conservative management of SI luxations is indicated when the patient is already ambulating well, there is only a partial subluxation of the SI, or repair of other pelvic fractures, keeps the SI reduced. If an SI luxation is greater than 7-10 days old and feels stable on palpation, conservative management at that point is probably indicated even if the patient is not yet ambulating on the limb. Reduction after it starts to stabilize can be difficult and can cause stretching of the sciatic nerve leading to pain or dysfunction.

Both an open and minimally invasive surgical approach is well described in the literature for placement of a lag screw as the repair for SI luxations. This is the most common method of repair. For the open approach, the patient is usually placed in lateral recumbency with the pelvis perpendicular to the operating table. A dorsal surgical approach with a gluteal roll down is used. This allows direct visualization of the lateral sacral wing to ensure proper placing of the screw in lag fashion. The patient can be placed in ventral recumbency with the same gluteal roll down approach. Care must be taken to ensure the angle of the screw placement is correct if this position is used. Both positions allow placement of a bone forceps on the ilial wing to retract it away from the sacrum to identify the sacral landmarks and later to reduce it to the sacrum. A ventral approach using the gluteal roll up is also described with the patient in lateral recumbency. The surgeon will not visualize the sacral wing during the repair during a ventral approach; instead it is done by palpation of the ventral aspect of the sacrum. The minimally invasive approach should be done with the patient in lateral recumbency. A C arm is used to ensure that the pelvis is completely lateral. A small incision is made either over the ilial wing to grab it with
a reduction forceps or pin in a Jacobs chuck or at the ischial tuberosity to grab it there for reduction. Only a stab incision for placement of the pins and lag screw will be used after this. One or both these techniques will identify the anatomical site for the sacral drill thread hole in the dog:

1. Find the dorsocranial and ventral aspect of sacral wing (A & B) and make an imaginary line. The drill hole should be placed about 60% from point A and just behind the imaginary line of A-B. The hole should be perpendicular to the sacral body and drilled to about 60% of the width of the sacrum (measured from the radiographs before surgery).
2. Find the sacral notch (open circle) and the drill hole should be caudal to that notch.

The ilial wing hole site is found by palpating the joint surface on the medial side, feeling for a “bump” or prominence and then the glide hole is drilled just caudal to the prominence or bump.

The anatomical site for the sacral drill thread hole in the cat is identified by: Measure the sacral length and height. The drill hole should be 51% (+/- 6%) length from the cranial aspect and 47% (+/- 4%) sacral height from the dorsal aspect. The sacral drilling is almost in the middle of the sacral body in the cat.
Measure the sacral tuber length on the ilium and then measure 70% caudal from the cranial point. Then measure 51% down from the point to place the glide hole.

In both the dog and the cat, mechanical studies show that the lag screw should be at least 60% of the sacral length and the largest screw possible for maximum repair strength. This can be determined on preoperative radiographs with a measuring device. In the dog, a second short positional screw placed into the dorsocranial sacral wing (not into the spinal canal) may help to increase strength of the repair. In cats, there is rarely enough room for a second screw.

Other methods to repair SI luxations include:

- Trans-iliosacral rod
- Transilial pinning
- Pin and tension band wiring

References:


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
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
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 Femoral Head, Neck and Trochanter
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Fractures involving the proximal femur are some of the more commonly encountered fractures in the mature and immature animal. These fractures may occur singularly or as a combination of types. The degree of comminution will determine the extent to which the fracture can be anatomically reconstructed. Fractures of the extreme proximal aspect of the femur can pose challenges to achieve bone purchase in the small proximal fragments. Any remaining non-reconstructable defects may require supplementation with autogenous cancellous bone. The following classification is used to describe fractures of the proximal femur.

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 the screw or pin. Physeal fractures, Salter-Harris 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 these factors are a reflection of the degree of the vascularity preserved to the head and neck. In general, the capital physeal repair will heal successfully in up to 80% of the cases without severe remodeling changes limiting hip function. Although infrequent, if extreme avascular necrosis of the head and neck does develop a femoral head and neck resection or a total hip replacement may be required at a later date if functional hip impairment or pain occurs.

Fractures involving the greater trochanteric region necessitate the use of a tension band principle. The tension band fixation 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 premature 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 the distal femur to allow for biologic fixation.

Multi-fragment proximal femoral fractures involving the proximal diaphysis and metaphysis regions should be treated by fragment alignment and stabilization with preferably lag screw fixation providing fragments of sufficient size are present then supplemented with a bone plate to further support the reconstructed femur. 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. In fractures with a high degree of comminution, the remaining proximal femur is supported with a buttress plate applied to the greater trochanter and lateral femoral surface with the fragments left undisturbed but anatomic alignment is achieved.

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 only 10 days to allow capsular soft tissue healing.
Fractures of the Distal Femur, Proximal Tibia and Patella

Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS
Learner Objectives:

- Recognize the different fractures occurring in the stifle of the dog and cat
- Explain the principles of treatment of these fractures
- Identify the challenges associated with the treatment of fractures of the stifle
Fractures of the Distal Femur, Proximal Tibia and Patella
Peter Muir BVSc, MVetClinStud, PhD, Diplomate ACVS, ECVS
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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 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). Several other 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. In larger animals, additional pins can also be placed. Alternative fixation methods include Kirschner wires inserted as Rush pins, and intramedullary pin combined with a single cross pin, or an intramedullary 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. For fractures of the medial condyle, 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 (Davis & Worth 2009) to facilitate perfect anatomic reduction, rigid fixation and treatment of meniscal damage.

Bicondylar Y or T fractures of the distal femur 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 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). Minimally displaced (2-3mm) partial 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-pin 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 if there is a 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. Patient activity should be carefully managed until the fracture has healed. Follow-up radiographs should be
made to document fracture healing. The timing of follow-up radiographs should reflect that age of the patient, with earlier follow-up in immature patients.

*Implant removal.* 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.

**References:**


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Simple Fractures and Luxations of the Tarsus

Ulrike Matis, Dr. med. vet. PhD, Professor of Surgery, Dipl. ECVS
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
Simple Fractures and Luxations of the Tarsus
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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:
Preoperative Patient Evaluation and Management

Mary Sarah Bergh DVM, MS, Diplomate, ACVS, Diplomate ACVSMR
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 bandage both open and closed fractures until definitive treatment can safely be performed
Many patients that present for evaluation of fractures will have sustained severe trauma and may have life threatening injuries. It is important to evaluate the patient in a systematic way so that all potential problems can be identified and treated appropriately. Rarely is an appendicular fracture life threatening, however shock, or an untreated pneumothorax or hemoabdomen, could cause acute deterioration and death of the patient. An initial and sometimes abbreviated history from the owner is helpful until a more complete history can be obtained.

Every animal should be thoroughly evaluated. Examination of the critically ill patient should initially focus on the life-threatening issues, and once the patient is stabilized, a more complete examination must be performed. There are a number of proposed mnemonics that have become popular to help one remember the important facets of the examination. In any animal, the ABC’s must be assessed first. This stands for Airway, Breathing, and Cardiovascular status. Another pneumonic is: “A CRASH PLAN”

A. = Airway  
C. = Cardiovascular  
R. = Respiratory  
A. = Abdomen  
S. = Spine  
H. = Head  
P. = Pelvis  
L. = Limbs  
A. = Arteries  
N. = Nerves

Regardless of the system that you use, your examination should be thorough and methodical and your findings must be prioritized. The most life-threatening conditions must be addressed first.

Respiratory system:
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. Elevated respiratory rate, abnormal breathing patterns, and cyanosis of mucous membranes indicate respiratory compromise. Cyanosis corresponds with a PaO\(_2\) of less than 40 mmHg and is a sign of severe hypoxemia. Pulse oximetry and arterial blood gas analysis may be very helpful in evaluating respiratory function in trauma patients. Between 30-60% of dogs with traumatic fractures and approximately 50% of cats that have been hit by a car, suffer from chest trauma.
Once the patient has been stabilized, ventrodorsal and both right and left lateral thoracic radiographs should be taken of the patient to evaluate for thoracic injuries including pneumothorax, pulmonary contusions, diaphragmatic hernia, pleural effusion, and rib fractures. Pulmonary contusions may take 12-24 hours to become radiographically evident, therefore radiographs should be repeated 12-24 hours after presentation if you are suspicious of thoracic trauma. Pneumothorax is present in 11-18% of animals that have been hit by a car and in 36% of dogs and 63% of cats that have fallen from a height. If pneumothorax or hemothorax is suspected, diagnostic and/or therapeutic thoracocentesis should be performed. Diaphragmatic hernias should generally be repaired before definitive repair of the fracture is attempted. Surgical repair of diaphragmatic hernia is generally not considered a surgical emergency unless the stomach is entrapped in the thoracic cavity or the patient is not able to be stabilized.

**Cardiovascular system**

The heart rate, rhythm, pulse quality and character, as well as mucus membrane color and capillary refill time should be evaluated. Placing an EKG and measuring blood pressure non-invasively is helpful. Cardiac arrhythmias and clinical signs of hypovolemic shock are very common after traumatic events. Hypovolemic shock is treated with rapid administration of crystalloid or colloid fluids, or a combination of both. Shock doses of intravenous fluids are listed below. For isotonic fluids, the shock dose is given in 25% increments while the patient is carefully assessed. Isotonic crystalloid fluid rates should be reduced to 20-40 ml/kg/h in dogs, and to 5-10 ml/kg/h in cats after the first hour. Generally, the volume of the crystalloid is more important than the type of crystalloid. The effectiveness of the fluid therapy must be evaluated every 10-15 minutes and therapy adjusted as necessary.

<table>
<thead>
<tr>
<th>FLUID TYPE</th>
<th>SHOCK DOSE</th>
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</thead>
<tbody>
<tr>
<td>Crystalloids (LRS, Plasmalyte, Normosol-R)</td>
<td>50-100 ml/kg/hr (dog)</td>
</tr>
<tr>
<td></td>
<td>40-60 ml/kg/hr (cat)</td>
</tr>
<tr>
<td>Hypertonic Saline (7.5%)</td>
<td>3-5 ml/kg</td>
</tr>
<tr>
<td>Colloids (Hetastarch, Dextran 70)</td>
<td>10-20 ml/kg (dog)</td>
</tr>
<tr>
<td></td>
<td>10 ml/Kg (cat)</td>
</tr>
<tr>
<td>Blood</td>
<td>10-30 ml/kg</td>
</tr>
<tr>
<td>Packed RBCs</td>
<td>10 ml/kg</td>
</tr>
<tr>
<td>Plasma</td>
<td>10-30 ml/kg</td>
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</tbody>
</table>

Ventricular Premature Complexes (VPCs) are present in 97% of dogs that have sustained vehicular trauma. The cause of VPCs should be carefully investigated; altered electrolyte levels, hypovolemia, or inadequate pain management could be affecting the patient. Symptomatic treatment of VPCs is generally performed if the VPCs are multiform, if ‘R on T’ is present, if the patient develops ventricular tachycardia (HR > 160-200), or if there is evidence of impaired cardiac output. Most VPCs resolve within 96 hours of injury.

<table>
<thead>
<tr>
<th>Lidocaine dose to treat VPCs</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Dogs</td>
<td>2 mg/kg (toxic dose is 8mg/kg)</td>
</tr>
<tr>
<td>Cats</td>
<td>0.25-1 mg/kg</td>
</tr>
</tbody>
</table>
Abdomen

Abdominal palpation, radiographs and/or ultrasound performed to assess for abdominal wall defects, uroabdomen and hemoabdomen. If uroabdomen or hemoabdomen are suspected, a diagnostic abdominocentesis should be performed. Approximately 40% of animals with pelvic fractures develop some degree of urinary tract trauma. Once stabilized, consider placing a urinary catheter if the patient is non-ambulatory or has significant pelvic or lumbar injuries.

Neurologic and Orthopedic Examination

A complete neurologic and orthopedic examination must be performed in every trauma patient. Pay particular attention to animals who are non-ambulatory or those that are suspected to have multiple injuries. If a spinal fracture is suspected, avoid manipulation of the patient, preferably by taping the animal to a board, to minimize additional spinal cord trauma during initial patient resuscitation. Radiographs should be taken of the spine without moving the dog from the board.

Bloodwork:

A complete blood count, biochemistry profile and urinalysis are helpful to obtain from the patient. The best time to get the blood samples is at the time of catheter placement. Electrolytes, lactate, and blood pH can be monitored with venous blood gas analyzers. The response to therapy can then be serially monitored.

The importance of analgesia

Appropriate analgesia should be initiated as soon as possible and continued throughout the recovery process. Pain initiates a tremendous cascade of catecholamine release and physiologic change that can result in respiratory and cardiac depression, shock, and even death. Opioids are generally preferred because they are often effective, cause minimal cardiovascular and respiratory depression, and they can be reversed readily. Non-steroidal anti-inflammatory drugs should be used cautiously in the trauma patient, as hypovolemia and shock can substantially increase the risk of adverse side effects, especially in the renal and gastrointestinal systems.

Preoperative wound management:

Once the patient has been stabilized, and the examinations complete, attention to open wounds and temporary fracture stabilization can be performed. If the patient has an open fracture, the area should be clipped, scrubbed, and lavaged with an isotonic solution. It is helpful to obtain a swab for bacterial culture and sensitivity at this time, after which broad-spectrum antibiotics may be initiated. Based on the degree of gross contamination, either a wet-to-dry bandage or a sterile non-adherent covering should be applied. Gloves and aseptic technique should be used to avoid nosocomial bacterial contamination. Radiographs of the fractured limb may be taken at this time, however heavy sedation is often necessary to achieve good quality images, and therefore additional radiographs or advanced imaging with CT may be performed under general anesthesia prior to surgery.

After the wound is addressed, the fracture should be immobilized to improve patient comfort and reduce the risk for further fragment displacement and additional soft tissue trauma. To obtain adequate stabilization of the fracture site, the joint above and the joint below the fracture must be immobilized with the wrap. Thus, fractures of the scapula, humerus, and femur
are not routinely bandaged. Either a traditional Robert-Jones bandage may be applied, or a lighter modified Robert-Jones bandage in combination with a splint may be used. It is essential that the bandage be properly placed and the toenails of the two central digits visible, so that the foot can be assessed for swelling. If there is an open wound under the wrap, the bandage should be changed as often as the wound dictates – typically at least daily – until surgery is performed. The patient should be kept in a clean, dry, and well-padded environment.

**Timing of Surgery**

Surgery may be performed as soon as the patient is stabilized. This will help decrease the morbidity and risk of general anesthesia and surgery. Stabilized patients typically have a mean arterial blood pressure > 80 mmHg, PCV 25-35%, urinary output > 1ml/kg/day, SpO₂ > 92% or PaO₂ > 80 mmHg.

**Suggested reading:**

Soft Tissue Handling and Fracture Reduction

Kei Hayashi, DVM, PhD, Diplomate ACVS
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
Cornell University

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.
Postoperative Assessment of Fracture Fixation

Jonathon Dyce, MA, VetMB, DSAO, MRCVS, Diplomate ACVS
Postoperative 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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Clinical assessment of orthopaedic repair
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.

Radiological assessment of orthopaedic repair
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.

AAAA Scheme
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 eg 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.

**Nonunion**

**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.

**Radiology of osteomyelitis**

- 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
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 (osteos)arcoma 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 tumours are usually diaphyseal and exhibit aggressive local and metastatic malignant behaviour. 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 or Physiotherapy after Fracture Surgery
Do We Need Them?

Denis J. Marcellin-Little, DEDV, Diplomate ACVS, ECVS, ACVSMR
Bandages and Splints or Physiotherapy After Fracture Surgery – Do We Need Them?
Denis J. Marcellin-Little, DEDV, Diplomate ACVS, ECVS, ACVSMR

Learner Objectives:

- Identify the types of coaptation available after fracture stabilization
- Explain the risks and benefits of coaptation after fracture stabilization
- Describe the rationale for physiotherapy after fracture repair
- Explain the algorithms for optimal postoperative management of fractures
The purpose of this lecture is to discuss whether or not bandages, splints, and physiotherapy are needed after the surgical stabilization of fractures in companion animals. These questions are best answered separately and by describing patients and situations that warrant or do not warrant these supportive therapies. The text is a combination of scientific evidence from the human and veterinary medical literature and a combination of clinical experience from the author, who has been practicing and teaching orthopedic surgery and physical rehabilitation for approximately 20 years.

The need for bandaging after fracture stabilization

Bandaging after surgery generally refers to the placement of a compressive bandage (soft, padded bandage, also known as modified Robert Jones bandage, MRJB). Modified Robert Jones bandages are bandages placed around the lower portions of thoracic and pelvic limbs that are made of cast padding secured in place with gauze and an outer layer of self-adhesive tape or other tape (eg, woven cotton tape). Other bandages are sometimes placed on the limbs of companion animals after surgery, particularly limb suspension bandages (e.g., Ehmer sling, 90-90 bandage, Robinson sling, Velpeau sling). The Ehmer sling is used to maintain pelvic limbs in a flexed, non-weight bearing position while promoting internal rotation of the crus in relation to the thigh and decreasing the likelihood of external rotation of the thigh in relation to the body wall. It includes a wrap that surrounds the thigh, crus, and metatarsal region in a figure-of-eight pattern. It is usually made with cast padding covered with rolled gauze and self-adhesive tape. The 90-90 bandage, named after the fact that its goal is to maintain the stifle and tarsal joints at 90° angles, is similar to the Ehmer sling (with regard to its size and materials) but does not apply internal torque to across the stifle joint. The Robinson sling is a bandage that holds a pelvic limb in a flexed, non-weight bearing position. Suspension is maintained by wrapping the metatarsal region and the chest/abdomen and connecting these wrapped areas with longitudinal bands starting on the medial and the lateral aspect of the metatarsals and ending on the left and right side of the chest/abdomen. The Velpeau sling is a bandage that is designed to avoid weight bearing of the forelimb. It maintains the carpus and elbow in a flexed position, tucked under the chest.

Compressive bandage are used after surgery to compress limbs. In humans, compression bandages are used most often as part of the management of vascular and lymphatic conditions (prevention of deep venous thrombosis, edema control, venous ulcer management, etc.). Several aspects of bandaging have been scientifically evaluated, including the effect of various bandage materials, loss of compression over time, and teaching methods for bandaging. The rationale for using a MRJB includes to decrease edema or prevent the formation of edema, to protect the wound from bacterial contamination or self-mutilation, to decrease the pain induce by joint motion in the early postoperative period, and to decrease the (axial, torsional, and bending) loads applied to musculoskeletal soft tissues. In companion animals, the MRJB does not appear effective at decreasing edema after internal fixation. It provides an effective barrier against contamination and self-mutilation. However, that barrier can be provided using a thin adhesive
bandage over the surgical skin incision. The mechanical impact of a MRJB has not been evaluated but bandaging can reduce the forces traveling through toes.\(^9\)

Suspension bandages and slings are used when protected weight bearing is considered to be an absolute contraindication after the stabilization of a fracture with internal fixation. Even if some fracture repairs are mechanically weak,\(^{10}\) they rarely need to be protected by suspending the limb. Suspension slings are also used to promote joint flexion or avoid a loss of flexion after surgery. This is particularly relevant when dealing with Salter-Harris fractures of the distal portion of the femur in dogs and cats because of the risk of permanent loss of stifle flexion as a result of contracture of the quadriceps femoris muscle.\(^{11}\) Velpeau slings have been recommended for the non-surgical or the postoperative management of scapular fractures but their efficacy is not known.

Bandaging is time consuming, can be costly, and can lead to ischemic injuries.\(^{12}\) All things considered, there is a small incentive for bandaging limbs after fracture repair. The patients where a bandage should be considered are patients with associated tissue trauma (that needs to be protected with a MRJB) or where weight bearing would have a high likelihood of mechanical failure of fixation.

**The need for splinting after fracture stabilization**

Splinting is similar to bandaging but with the placement of rigid, semi-rigid, or hinged support material outside the rolled gauze and inside the self-adhesive tape. Splints have the advantages of MRJB with regard to compression, pain relief, and protection of the incision. Because most splints are rigid, they protect fracture repairs more than MRJB. Splinting is considered when the strength of a fracture repair is deemed too low to sustain protected weight bearing in the postoperative period, for example when small bone fragments are repaired (e.g., repairs of multiple metacarpal/tarsal fractures, repairs of fractures luxations of the talocrural joint). Beyond the protection of fracture repairs, splints are routinely used around the pes or manus to protect tarsal or carpal arthrodeses during the early postoperative period (4 to 6 weeks after surgery). They are also routinely used after the repair of musculoskeletal soft tissues below the elbow or the stifle (e.g., repair of common calcaneal tendon. In the past, the Schroeder-Thomas splint (STS) was used to stabilize radial or tibial fractures. The STS has an outside armature made of a contoured aluminum rod that surrounds the limb in a sagittal plane. Tape connects limb segments proximal and distal to the fracture to that armature. The STS required technical expertise, cautious supervision, and regular care. It is rarely used nowadays. Splints are sometimes used to place a limb in a functional position to facilitate limb use. For example, with a *swimmer puppy* or kitten, limbs can be splinted to achieve a standing position.\(^{13}\) Splinting is also used to provide some stability to fractures that are managed non-surgically.\(^{14}\) However, the scientific literature assessing the safety and efficacy of splints to manage fractures is lacking.

In summary, splints are used in patients with mechanically weak surgical repairs. Even if they can be used to protect the crus or the antebrachium, they are best suited to problem distal to the tarsus or carpus. Little is known about their efficacy and safety.
The need for physiotherapy after fracture stabilization

Physical rehabilitation, also named physical therapy, physiotherapy, and rehabilitation, is the use of manual therapy, electrophysical modalities, therapeutic exercises, and ergonomics to enhance recovery after injury or surgery and in patients with chronic musculoskeletal, neurologic, or degenerative conditions. Physical therapy is often mentioned as a logical consideration in companion animals recovering from the surgical stabilization of fractures.

Seemingly, many patients recover well from fractures and their surgical repairs even in the absence of physical therapy. Some patients, however, face complications that can permanently change the outcome of surgery. The goals of physical therapy, as they relate to postoperative fracture management are to assess patients objectively, to identify patients at high-risk of complications and manage them early and aggressively, to provide pain relief, to decrease edema, to increase limb use (or avoid limb disuse) and mobility and, as part of that goal, to stretch joints (when needed), to increase limb and core strength, to facilitate the postoperative management of patients and decrease complications linked to suboptimal patient care (failure of fixation due to falls or excessive mobility, limb disuse and loss of joint motion, wound complications).

The objective assessment of patients includes an assessment of their mobility, limb use, loss of muscle mass (using a tape measure) and fitness, pain level, and joint motion (using a goniometer). An increasing number of assessment scales are available. Some of these scales are validated.15

High-risk patients are patients at risks of irreversible complications and at risk of (severe or costly) complications that may lead to euthanasia or that may negatively impact their outcome. Increased risk may be linked to the original medical condition (e.g., a distal femoral fracture in a skeletally immature dog or cat places the patient at a high risk of contracture of the quadriceps femoris, a Y humeral condylar fracture places the dog at risk of permanent loss of motion in the elbow joint), the patient (e.g., a particularly young or old dog, a particularly small or large dog, a particularly active or unfit dog, a working dog with the need for high performance), or the owner (e.g., a very independent owner, an owner who is unwilling or unable to participate in the dog’s recovery). Non-ambulatory patients are at increased risk of complications (decubitus ulcers, urinary tract infection, loss of strength and fitness) and are at a high-risk of euthanasia because their management is very labor intensive. Patients with orthopedic lesions in multiple limbs are at a high-risk of complications, particularly failure of fixation.16 Patients with surgical repairs that have less than optimal mechanical properties are high-risk patients. Amputees or neurologically compromised patients are at high risk of complication after fracture repair. Physical rehabilitation, particularly inpatient rehabilitation (by comparison with outpatient rehabilitation, where the patient must be transported back and forth between home and a clinic) can identify these patients early and can offer an environment adapted to the situation.

Physical rehabilitation can provide pain relief when the relief provided by rest and pain medications is deemed insufficient. Pain relief may be provided directly through the use of cold, passive range of motion, massage, transcutaneous electrical nerve stimulation, therapeutic ultrasound, and other methods.
Recognizing and treating limb disuse is one of the most important tasks in the physical rehabilitation of companion animals. Limb disuse is the persistent reluctance to use a limb after injury or surgery or when a chronic condition affects that limb. With disuse, companion animals see a rapid (neurogenic-like) loss of muscle mass, a potential loss of joint motion, and an enhanced pain perception linked to loss amplification of sensory pain receptors (often combined with impaired pain perception / allodynia). Patients in limb disuse also have a loss of bone mass, particularly in distal bones and when patients are skeletally immature at the time of injury. That loss of bone mass can negatively impact bone healing. Additional tissue changes present in limbs with disuse include loss of cartilage thickness and stiffness, loss of joint fluid, loss of ligament and tendon strength. The reversal of these changes can take months or more once limb disuse is managed during physical rehabilitation.

The potential loss of joint motion is a key reason to enroll a dog in a rehabilitation program. The loss of joint motion may result from fibrosis of the joint capsule, adhesions between tissue planes, loss of muscle length, and loss of muscle contractility (a contracture). The most dramatic example of loss of joint motion is the contracture of the quadriceps femoris muscle that may follow a Salter-Harris fracture of the distal femoral physis.\(^{11}\) Other situations lead to loss of joint motion, particularly in joints that articulate tightly (eg, the elbow and tarsus) compared to joints that articulate loosely (eg, the shoulder and hip). Stretching programs must be promptly implemented once a loss of joint motion is documented (using a goniometer) because the recovery of joint motion is more rapid in acute and subacute situations compared to chronic situations. In humans, one can plan to gain 5 to 10° of joint motion per week during a stretching program in acute or subacute situations and 3 to 5° per week in chronic situations. Stretching joints is challenging. It may be done actively through therapeutic exercises or passively using bandages or braces or through manual stretching.\(^{17}\)

Physical rehabilitation can accelerate the recovery of strength and fitness or can minimize the loss of strength after fracture repair. In healthy pets, the recovery rate after fracture repair is generally not a critical issue. That recovery rate becomes more critical when return to function is urgent (eg., in working dogs owned by law enforcement or in high-performance dog) or when the dog has comorbidities interfering with his locomotion (eg, older patient, obese patient, patient with multiple injuries).

While some patients can thrive without a specific rehabilitation program, other patients are at high-risk of complications and they must be cautiously overseen during their recovery. Physical rehabilitation is a valuable tool to identify complication risks, to establish a targeted rehabilitation plan, to monitor the response to therapy, and to make the recovery after surgery more predictable and comfortable for the dog and more convenient for the owner.
References:
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
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 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. Arthrotoomies including removal of endochondral ossification defects or open joint reductions
2. Arthroscopy
3. Many closed fracture repairs
4. TPLOs? or TTA’s?

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* *There is strong evidence that use of antibiotics for days after surgery is not only unnecessary but can actually be detrimental to the patient.*

Now I know there is some conflicting data with TPLO’s that may disagree with that and we will look at the data.

**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, i.e., are you willing to give 96 dogs antimicrobial agents which are not benefitting them to prevent an infection in 2 animals?
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  
Ulrike Matis, Dr. med. vet. PhD, Professor of Surgery, Dipl. ECVS  
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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>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3</td>
<td>1</td>
</tr>
<tr>
<td>3 – 6</td>
<td>2 – 3</td>
</tr>
<tr>
<td>6 – 10</td>
<td>3 – 5</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>5 – 14</td>
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</tbody>
</table>

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 he 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.
AOVET North America

Principles in Small Animal Fracture Management

SUNDAY LECTURE ABSTRACTS

April 10, 2016
Table of Contents

Sunday, April 10, 2016

Open Fractures .................................................................Wosar

Delayed Union and Nonunion .............................................Hayashi

Prevention and Management of Infections of Bone and Implants.............Roe

Technical Errors................................................................Guiot

Radiographic Assessment of Fracture Healing.................................Moens
Open Fractures

Marc Wosar, DVM, MSpVM, DACVS
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
Mountain Animal Specialists Center

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 a 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 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 nonunions
- Assess clinical and radiographic signs of delayed unions and nonunions
- Determine a treatment strategy for delayed unions and nonunions
Delayed Unions and Nonunions
Kei Hayashi, DVM, PhD, Diplomate ACVS
Cornell University

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>Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3 months</td>
<td>2-3 weeks</td>
<td>4 weeks</td>
</tr>
<tr>
<td>3-6 months</td>
<td>4-6 weeks</td>
<td>6-12 weeks</td>
</tr>
<tr>
<td>6-12 months</td>
<td>5-8 weeks</td>
<td>12-16 weeks</td>
</tr>
<tr>
<td>&gt;1 year</td>
<td>7-12 weeks</td>
<td>16-30 weeks</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.

**Postoperative 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.

Preoperative – 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 Intraoperative – Establish robust protocols for clipping, scrubbing and skin sterilization and reward adherence to these processes. Develop a culture during surgery that focuses 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.¹ 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 dead space. 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 dead space 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.² This may reflect the hurried closure process rather than the device itself.

Perioperative 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). Antiibiograms of Staph psuedointermedius 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 dead space
- 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 dead space, 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 dead space 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. Trimethoprim 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 in Fracture Repair

Laurent P. Guiot, DVM, Diplomate ACVS and ECVS
Technical Errors in Fracture Repair
Laurent P. Guiot, DVM, Diplomate ACVS and ECVS

Learner Objectives:

- Identify strategies to reduce the risk of technical errors
- List the 3 major intraoperative steps involved in fracture repair and their potential pitfalls
- Enumerate the measures implemented to identify technical errors and prevent complications associated with them.
Technical errors in fracture repair
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Technical errors include a series of intraoperative mistakes that may or may not lead to the development of intraoperative and/or postoperative complications. These mistakes are surgeon dependent and most often secondary to inobservance of basic operative principles. While numerous difficulties may arise during the repair of a fracture (regardless of its location, configuration and of the implant(s) being used) it is the surgeon’s responsibility to minimize the risk of occurrence through proper training, planning and execution of a surgical procedure.

Preoperative planning is therefore the foundation of fracture repair and one should always remember that “failing to plan is planning to fail the surgical procedure”. Thorough preoperative assessment must then be performed prior to surgery which includes analysis of fracture configuration to optimize implant selection and identification of potential intraoperative pitfalls.

![Preoperative templating of a comminuted diaphyseal femoral fracture using a dedicated software. The image is calibrated using a spherical marker and a size-matched implant is imported over the radiographs. Major bone fragments can be manipulated to bring the joints in alignment and as certain proper implant selection, including location of locking bolts in this case of interlocking nail.](image)

**Figure 1:** Preoperative templating of a comminuted diaphyseal femoral fracture using a dedicated software. The image is calibrated using a spherical marker and a size-matched implant is imported over the radiographs. Major bone fragments can be manipulated to bring the joints in alignment and as certain proper implant selection, including location of locking bolts in this case of interlocking nail.

**Implant selection** is determined during preoperative planning and adapted intraoperatively based upon findings during surgery. Choosing an inappropriately sized implant will negatively affect the
outcome as it may result in implant failure, iatrogenic fractures and delayed to non-unions. Guidelines pertaining to implant selection are available in the AO manual. These are not absolute, however, and the choice of fixation should always integrate patient related information such as signalment, fracture pattern and presence or absence of concurrent orthopedic injuries. Once selected, the implant is surgically applied to the bone creating a bone-implant composite or construct. This is achieved using proper technique through a surgical approach.

Figure 2: Immediate (left) and 2 weeks postoperative (right) radiographs of a femoral fracture in an immature dog repaired using a bone plate and screws. The early failure of the bone-screw interface can be attributed to the use of a stiff implant (larger plate), the close proximity of the proximal screws from the fracture site, and the relative short length of plate used. Immature bones are less resistant to screw pull-out than mature bone owing to their relatively thin cortices. Strategies to limit such complications include the selection of a longer plate (with a longer level of arm at the level of the fracture) and the use of locking screws. Minimizing interference with biology through the use of less invasive approaches such as open but do not touch would enhance healing and minimize the risk of construct failure though cyclic loading.

Surgical approach to the fractured bone is the first phase of implant application. Selection of a surgical approach will be based on fracture location, repair technique and surgeon preference. Technical mistakes pertaining to the approach could seem harmless to the novice and the importance of this crucial step is often underestimated. Inadequate approach to the bone will increase morbidity, prevent adequate visualization of landmarks, reduce accuracy during implantation and potentially result in intraoperative and/or postoperative complications. Minimizing technical mistakes associated with the surgical approach to the bone is therefore essential to success and can be achieve with proper training once a thorough knowledge of loco-regional anatomy is mastered. It should be noticed at this stage that normal anatomy is disrupted following trauma which complicates the identification of anatomical landmarks and increases the risk of errors during the approach. Optimizing exposure is a key to success as it facilitates restoration of alignment and is necessary to permit the use of proper implantation techniques.

Figure 3: Lateral approach to the femur using open reduction and internal fixation (left), open but do not touch (center), and minimally invasive osteosynthesis (right) techniques. Notice the difference in dissection between approaches which translates in various degrees of iatrogenic trauma to a fracture site.

Restoration of alignment is regarded as one of, if not the most important aspect of fracture repair. Improper postoperative alignment results
from intraoperative mistakes and may be severe enough to warrant immediate revision surgery. Surgical errors leading to misalignment are related to inadequate identification of anatomical landmarks or poor implantation technique. Identification of landmarks is enhanced by adequate exposure of the bone and can be facilitated by the observation of an anatomical specimen. It is advisable to always bring a bone specimen in the operating room during a repair. Adequate fixation must be performed to prevent primary loss of reduction during the surgery. This phenomenon is commonly seen with bone plate fixation when conventional screws (non-locking) are used to secure an inappropriately contoured bone plate. In these cases, screw tightening induces a shift between bone segments which leads to an immediate loss of alignment.

**Figure 4:** Rotational malalignment of a tibial fracture treated with a bone plate and rod combination. The dog (left top and bottom) presents a visible limb malalignment in external rotation. Radiographs of the tibia following the initial surgery show normal axial alignment in the frontal (center left) and sagittal plane (center right). However, the calcaneus is severely deviated on the cranio-caudal projection (center right) which demonstrates an external rotation of the distal segment that occurred during fracture fixation. The surgery was revised two months later using a transverse osteotomy to allow de-rotation and an interlocking nail to stabilize the bone.

**Implantation techniques** are specific to a given implant system (i.e. bone plates, interlocking nails, external skeletal fixators …). Within a given system, individual devices may carry additional or different recommendations for application. For example, insertion of a standard screw to secure a bone plate requires drilling through a drill guide at a predetermined diameter followed by taping using a bone tap. Conversely, choosing a self-taping screw eliminates the need for taping, while
selecting a locking screw warrants the use of a different dedicated guide for drilling and a torque
limiter for screw insertion.

General and specific application guidelines provided by the manufacturer should be followed to
optimize construct stability. Improper implantation technique increases the rate of failure at the
bone-implant interface or of the implant itself resulting in construct instability and compromising
outcome. Critical assessment of implant selection and positioning must occur during and after
surgery through direct observation and diagnostic imaging (intraoperative fluoroscopy and
postoperative radiographs). This analysis will allow for identification of technical errors which
will permit implementation of ancillary treatments as needed, including revision surgery and/or
making recommendations for postoperative management.

**Figure 5:** Immediate postoperative radiographs of a comminuted tibial fracture treated with a plate-rod
combination. The intramedullary rod used to re-align the fragments was inserted in a suboptimal direction with a
cauda orientation. This induced a severe tipping of the proximal segment that resulted in a significant increase
in tibial plateau angle. In addition, the third screw is anchored too close to the fracture site which could lead
to premature construct failure. The increase in TPA augments the cranial cruciate ligament strain which
could translate in premature failure of the ligament. Revision surgery should be immediately considered.

**Postoperative management** is also essential following surgical management of a fracture and
errors in postoperative care can be as detrimental as intraoperative mistakes. Recommendations
for postoperative care must address wound management, bandaging, activity restriction,
medications and recheck scheduling. In particular, bandaging can play a major role in the
development of complications. The choice of applying a specific bandage over an extended period
of time is based on the necessity to address soft tissue related issues, to prevent weight bearing
activity or to provide additional mechanical strength to the repair.

**Figure 6:** External fixators require adequate postoperative care throughout the recovery period.
Proper bandages and continuous monitoring (left) are necessary to minimize the risk of pin track
infection (right).
Radiographic Assessment of Fracture Healing

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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
Radiographic Evaluation of Fracture Healing
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Postoperative 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

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